THIRD EDITION

OPERATIONS MANAGEMENT

THEORY AND PRACTICE

B. MAHADEVAN

Introducing MyLab | South Asia **Operations Management**
See inside cover for details

Supplier
Procurement
Manufacture
Product
Supply Chain
Inventory
Distribution
Logistics
Retail
Customer

ALWAYS LEARNING

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OPERATIONS MANAGEMENT

third edition

THEORY AND PRACTICE

B. Mahadevan

Indian Institute of Management Bangalore

PEARSON

Delhi • Chennai

BRIEF CONTENTS

CONTENTS

To
my parents, Balu and Saroja,
my wife Sujatha and
my daughter Dhrithi

PREFACE

OBJECTIVES

Operations Management: Theory and Practice is the successful culmination of evolved ideas and clarity of thought arising out of teaching the subject at the Indian Institute of Management Bangalore for nearly 22 years. This book is the outcome of continuous testing of alternative ideas, concepts and pedagogical designs with MBA students, working executives from diverse industries, and research scholars.

Although there are several books available on the subject written by international authors, students find it difficult to relate to the examples used in them. The basic concept of this book is to bridge this critical gap by preserving all the salient features one usually finds in international textbooks, and at the same time, to enrich the book with contextually relevant examples. Throughout my teaching career, I have discovered that contextual references can go a long way in helping the students relate to the concepts discussed. Furthermore, such references can fuel their imagination and improve their understanding of concepts. Therefore, the examples and the Ideas at Work boxes in this book draw the students' attention to the issues faced by Indian organizations while applying the concepts discussed in the book. They also provide insights on the variations adopted by such firms in the practical application of these concepts. Since several firms and their product–service offerings are referenced throughout this book, I have provided an index of companies at the end of the book.

Throughout the book, I have made an effort to provide a pleasant experience of going through seemingly tough models and concepts in operations management. I hope the readers will enjoy reading the book, and I look forward to receiving comments and suggestions from the students and teachers using this book at bmahadevan207@gmail.com.

NEW TO THE THIRD EDITION

I am thankful to the instructors and students for providing several useful suggestions for potential improvements in the second edition. These have largely influenced the work on this edition. While retaining the most appreciated features of the earlier editions—Ideas at Work boxes, solved quantitative examples, and illustrations and examples from the Indian context— I have updated the third edition to include a more current and holistic coverage of operations management.

Here are the highlights of the changes in the third edition:

- ***Chapter reorganization:*** The chapters have been reorganized so that students can easily position the relevance of the topics discussed and understand the critical linkages between various topics discussed in other chapters in a better way.

- ***Changes in chapter titles:*** While incorporating the updates and changes in the chapter content, I have taken a more balanced perspective of topics by including more service sector applications and examples. This has necessitated, for example, to change the title of Chapter 15 to "Operations Planning".
- ***New chapter:*** Sustainability is increasingly becoming important for businesses. Several of the current students will be required to play a key role in managing businesses that are also sustainable in their operations. In order to equip the students with the necessary understanding of the related issues, a new chapter—Chapter 3 titled "Sustainability in Operations"— has been introduced in this edition.
- ***Updated material:*** Several topics such as the design of manufacturing processes, lean management and six sigma have been revised to make them more comprehensive. Moreover, many of the Ideas at Work boxes and the data provided in the tables have been updated to reflect recent events. The description of the new attempts by businesses to addresses sustainability and project management pertaining to Terminal 3 of Indira Gandhi International Airport, New Delhi, are some examples in this category.
- ***Additions to the end-of-chapter exercises:*** **Mini Projects** and **Net-wise Exercises** have been updated in this edition to provide a wide range of application-oriented problems to students. Moreover, additional problem sets have been included in several chapters. These additions bring the students closer to the real-life applications of various concepts and help them relate to these concepts better.
- ***Video Insights:*** This is a new feature introduced in this edition. In an era of media convergence and availability of useful information on the Internet, the students need to benefit from these and expand their understanding and scope of application of the concepts discussed in the book. To facilitate this process, over 15 videos have been identified and their URLs have been provided so that students can pursue them. These videos cover the actual working of a variety of manufacturing and service firms and expert opinions and interviews on certain aspects of operations.
- ***Formula Review:*** In chapters where several formulae have been introduced, a new feature has been added at the end of such chapters. This provides a quick summary of all important formulae covered in that chapter.

ORGANIZATION

Operations Management: Theory and Practice (3e) comprises 19 chapters, which have been divided into four sections.

Part I: *Conceptualizing Sustainable Operations* consists of four chapters that introduce how to understand the operations function, the role of strategy in creating successful operations in firms, the need for making it sustainable and the manner by which such firms eventually become a physical reality to conduct their operations in the real life.

Part II: *Operations and the Value Chain* deals with the important issue of supply chain management in three chapters. The topics covered in these chapters include supply chain management, facilities, location and sourcing and supply management.

Part III: *Designing Operations* consists of six chapters that deal with various elements of the design of an operations system. This includes process and capacity analysis, design of manufacturing processes, design of service systems, product development and total quality management.

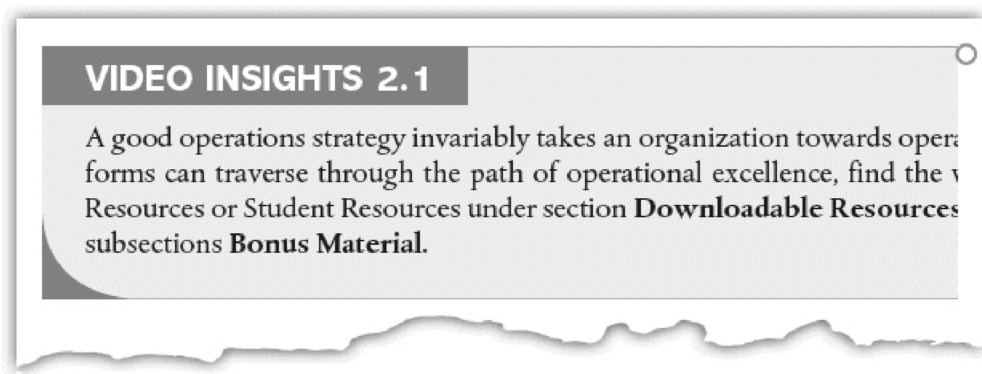
Part IV: *Planning and Control of Operations* consists of six chapters in which alternative approaches for the planning and control of operations are discussed.

PEDAGOGICAL FEATURES

To enable students to understand the concepts discussed in the chapters, the following pedagogical features have been incorporated into each chapter:

Video Insights

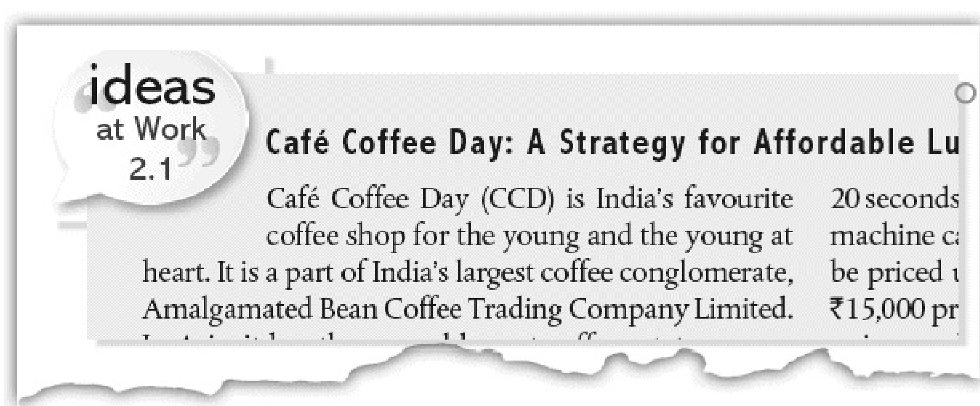
These are provided in each chapter to help students understand the concepts better. Document containing the URLs can be downloaded from the resource website.


VIDEO INSIGHTS 2.1

A good operations strategy invariably takes an organization towards opera
forms can traverse through the path of operational excellence, find the v
Resources or Student Resources under section **Downloadable Resources**
subsections **Bonus Material**.

Ideas at Work boxes

This novel feature in each chapter directly relates chapter concepts to real-world practices in the Indian scenario and enables students to develop an application-oriented approach.


ideas at Work 2.1

Café Coffee Day: A Strategy for Affordable Lu

Café Coffee Day (CCD) is India's favourite coffee shop for the young and the young at heart. It is a part of India's largest coffee conglomerate, Amalgamated Bean Coffee Trading Company Limited.

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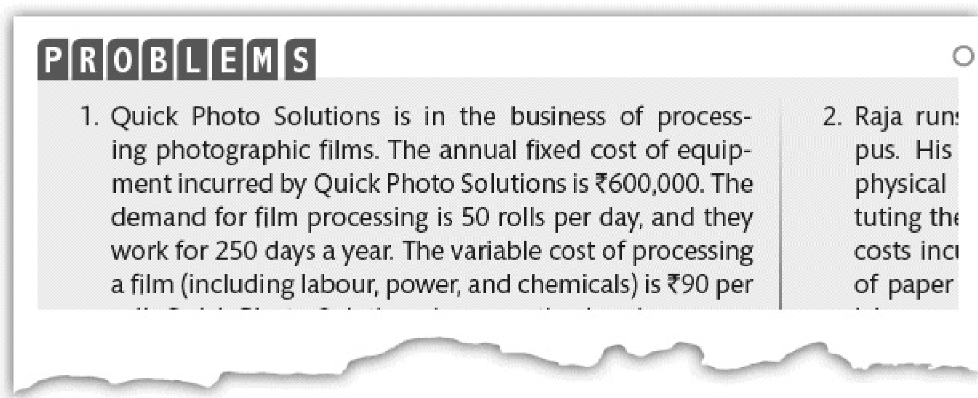
Problems

The quantitative problems at the end of each chapter enable students to deepen their understanding of the concepts and models of Operations Management.


PROBLEMS

1. Quick Photo Solutions is in the business of processing photographic films. The annual fixed cost of equipment incurred by Quick Photo Solutions is ₹600,000. The demand for film processing is 50 rolls per day, and they work for 250 days a year. The variable cost of processing a film (including labour, power, and chemicals) is ₹90 per

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Mini Projects

To help instructors guide students through an applied learning process, the chapters provide Mini Projects. These ideas enable students to broaden their understanding of the subject through extended work.


MINI PROJECTS

1. Select two close competitors in any sector of industry and study their annual reports for the last three years.
   (a) Compute relevant measures of supply chain performance for both of them for these three years and report your significant observations from the study.
   (b) Do you see any significant change in the

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(b) Wha
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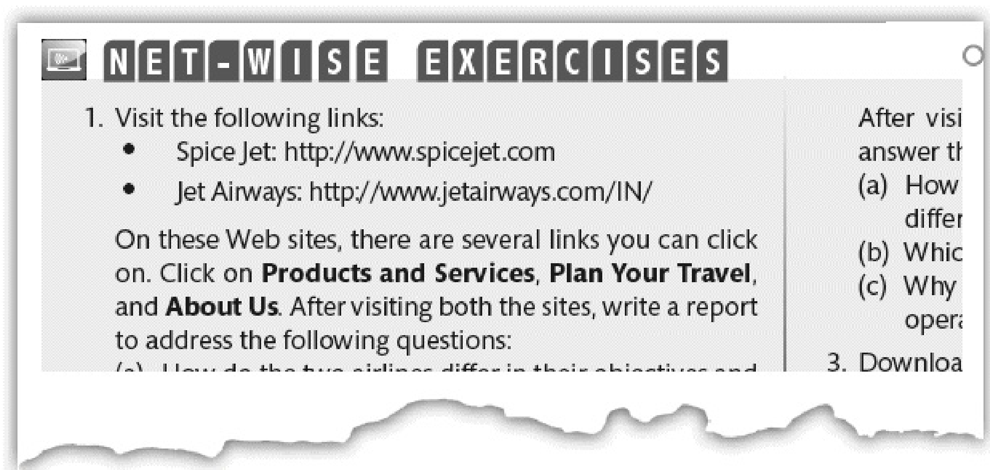
Net-wise Exercises

Through Net-wise Exercises, students are exposed to online data so that they can access a wealth of information on various additional topics related to the chapter and also apply the chapter concepts to this data.



NET-WISE EXERCISES

1. Visit the following links:
   - Spice Jet: http://www.spicejet.com
   - Jet Airways: http://www.jetairways.com/IN/

   On these Web sites, there are several links you can click on. Click on **Products and Services**, **Plan Your Travel**, and **About Us**. After visiting both the sites, write a report to address the following questions:

After visi
answer th
(a) How
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(b) Whic
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opera
3. Downloa

Cases

End-of-chapter case studies provide insights into the operations management practices of organizations in the service sector as well as the manufacturing sector.

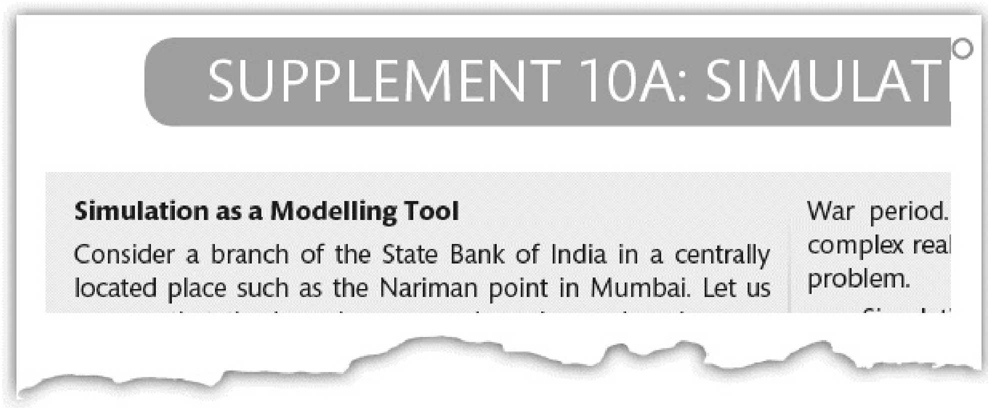
CASE: GINGER HOTEL

Roots Corporation Limited is a fully owned subsidiary of the Indian Hotels Company Limited (IHCL), which is a part of the Tata Group. With more than 90 properties, IHCL is India's largest hotel chain. It has been in the hospitality sector for

over a centu
of hotels und
was launchec
Ginger hotels

Supplements

End-of-chapter supplements help students understand complex topics such as simulation and linear programming.


SUPPLEMENT 10A: SIMULAT

Simulation as a Modelling Tool

Consider a branch of the State Bank of India in a centrally located place such as the Nariman point in Mumbai. Let us

War period. complex real problem.

TEACHING AND LEARNING PACKAGE

A variety of resources has been provided with this book to help students understand the concepts better and to aid instructors in teaching the subject. These include:

- ***Videos Insights:*** 15 video URLs have been identified and provided for the students to connect theories taught in the classroom with real-life examples. This pedagogical feature brings together videos giving insight into prevalent industrial practices, manufacturing procedures and interviews for conceptual clarity.
- ***Instructors' Manual:*** Instructors have access to special material prepared for them, including an instructors' manual with suggested cases for use, alternative course outlines and other relevant information.
- ***MS Excel-based Solutions:*** All the exercises in the book are available in the form of Excel files. The files have additional scope for "what if" scenarios in some problems, enabling instructors to create as many variations of the problem as required.
- ***PowerPoint Slides:*** All chapters have a corresponding PowerPoint file highlighting the key concepts discussed in that chapter.
- ***Multiple-choice questions:*** The multiple-choice questions on the companion Website are designed to test students' comprehension of key topics.

Both Instructor and student resources are available on the book's companion Website, www.pearsoned.co.in/bmahadevan

ACKNOWLEDGEMENTS

The role played by students, executives, research scholars and my colleagues at IIM Bangalore in shaping my thinking is invaluable and beyond verbal quantification. Over the years, they have constantly challenged my thinking and provided me with new perspectives on the subject. Many industry participants and MBA students at IIM Bangalore have worked with me on several live operations management problems during the past ten years. These problems invariably culminated in some written project reports. I have drawn many examples from these reports while discussing several concepts in the book. I am thankful to all of them for their contributions.

I am thankful to several Indian companies that have permitted me to use some of their material in the book.

I greatly appreciate the assistance provided by Neeraj Bhalla, Associate Editor—Acquisitions (B&E), Purushothaman, Production Editor— Higher Education, and his team at Pearson Education for their professional approach and meticulousness that have significantly contributed to improve the quality of this edition, and I am thankful to these people for their dedication and support in this project.

As always, my wife Sujatha and my daughter Dhrithi provided me with moral support throughout the development of this project.

B. Mahadevan

ABOUT THE AUTHOR

B. Mahadevan is a professor of operations management at the Indian Institute of Management Bangalore, where he has been teaching since 1992. He was also the Dean (Administration) of the institute and a member of the Governing Board of IIM Bangalore for four years. He has more than 23 years of wide-ranging experience in teaching, research, consulting and academic administration at IIM Bangalore and other reputed institutions such as IIT Delhi and XLRI, Jamshedpur. Earlier, he was the Chief Editor of *IIMB Management Review*, the premier Indian journal for management educators, consultants and practitioners. He was also the EADS–SMI Chair Professor for sourcing and supply management at IIM Bangalore.

Professor Mahadevan received his M.Tech. and Ph.D. from the Industrial Engineering and Management Division of IIT Madras. He holds a bachelor's degree in engineering (production engineering) from the College of Engineering, Guindy, Chennai.

He was a visiting scholar at the Amos Tuck School of Business Administration, Dartmouth College, New Hampshire, during 1999– 2000. He was also a retainer consultant to Deloitte Consulting LLP, USA, in 2001–2002. He is also on the board of trustees of some NGOs providing valuable community and social services.

Professor Mahadevan is a member of the editorial board of the *Production and Operations Management Journal* and the *International Journal of Business Excellence*. He served in the editorial board of *Six Sigma and Competitive Advantage*. Besides being on the advisory boards of several business schools and management journals in India, he has published several of his research findings in leading international journals such as *California Management Review*, *European Journal of Operational Research*, *Interfaces*, *Production and Operations Management*

Journal, *International Journal of Production Research*, *International Journal of Technology Management*, *Asian Journal of Operations Management*, *International Journal of Yoga*, *Vikalpa*, *South Asian Journal of Management and IIMB Management Review*. He is a lifetime member of the Society of Operations Management and a member of the Production and Operations Management Society.

Professor Mahadevan has been recognized for his excellence in teaching both at IIM Bangalore and outside. He has been consistently rated among the top five professors in IIM Bangalore's Teaching and Executive Education Programmes. He was also conferred the ICFAI Best Teacher Award by the Association of Indian Management Schools in 2005. He was one among the 40 nominees, who were nominated globally, for the Economic Intelligence Unit's (EIU) Business Professor of the Year Award, 2012.

Apart from *Operations Management: Theory and Practice*, Professor Mahadevan is also the author of *The New Manufacturing Architecture* and has developed software that addresses issues in restructuring manufacturing systems for competitive advantage. His research interests include supply chain management issues in e-markets and e-auction.

Professor Mahadevan's other interests include researching the possibility of using ancient Indian wisdom to address contemporary concerns. He is active in inculcating these ideas among his students and the youth through various forums and public lectures. He was also a member of the Central Sanskrit Board, an advisory body to the Ministry of HRD, Department of Education on all Sanskrit policy issues in the country.

Part 1

Conceptualizing Sustainable Operations

CHAPTER 1

Operations Management: Trends and Issues

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What do you understand by the term operations management?
- What is the status of the manufacturing and service industries in India?
- What are the emerging opportunities and challenges for operations management?
- Can the principles of operations management be applied to both manufacturing and service organizations?
- What is the role of operations in an organization?
- What are the key components of an operations management system? What is the nature of the interaction among them?

The success of Narayana Health (NH) is mainly due to the proper implementation of operations management in its day-to-day activities. The growth of NH to 14 multi-speciality hospitals is mainly because of its planning, passion, and compassion; this is what operations management is all about. Managing a workforce of 12,000 is mainly attributed mainly to strategic thinking and implementation. The success rate is made possible by employing cost reduction in several methods. The main vision of the NH group is not to lose a single patient in terms of want of money and conducting the surgeries in a cost-effective manner.

Source: Franck Boston. Shutterstock

ideas at Work 1.1

Narayana Health (NH): A Journey That Began with Wining the Heart Of India

Indians are three times prone to heart diseases than Europeans. By 2013, while there is a need for 2.5 million heart surgeries per year in India, we are doing only 90,000. Moreover, India produces 80 cardiologists a year compared to 800 in the US. There is a huge shortage of doctors and paramedical staff in the country. To complicate the matter even more, 70% doctors are in urban areas, whereas 70% people live in rural areas. This appears to be a serious problem of lack of adequate health-care for the citizens. However, a closer look at the story of Narayana Health (NH) suggests that mass healthcare cover is not about money but about planning, passion, and compassion. Operations Management can work at its best to address such problems.

NH journey first started with a 300-bed hospital started by Dr. Devi Shetty in the outskirts of Banga-lore city in 2001 that began providing heart surgeries to patients at significantly low costs. Currently, the group has 14 hospitals in multiple locations with multiple specialties that offer a total of 5,700 beds. Over the next 18 months, there are plans to add new hospitals in Siliguri, Bhubaneswar, Mysore, Mumbai, and Delhi in addition to Cayman Islands and Malaysia, which will add another 2,500 beds capacity to the NH network. There are plans to expand this to about 30,000 beds by 2020. On account of this, the work force is likely to grow from the current strength of 12,000 to nearly 40,000. Managing such a massive expansion requires sound strategic thinking, creation of new facilities in a cost-effective manner, and operating them on a day-to-day basis with better planning. All these issues belong to the domain of Operations Management.

Many of the operational aspects of the NH network are governed by the vision that nobody should go back from the hospital for want of money. A heart surgery package at NH could be anywhere between ₹75,000 and ₹150,000 compared to a typical cost of ₹300,000 in other hospitals. Achieving such dramatic cost reduction calls for employing several methods. These include input cost reduction, benefiting from process innovations and scale economies, and bringing innovative ideas in design of facilities and resource deployment. Further, productivity improvements would be very crucial and an ongoing activity in such a system. In NH, we find several examples illustrat ing these.

Due to volumes and supplier development efforts, NH is able to buy a pair of glove at ₹4.50 as against ₹9.50 by directly sourcing it from Malaysia. Many of the expensive equipment such as MRI scan machine are installed by vendors on a pay-per-use model rather than an outright purchase. This brings down the cost of an MRI scan and also increases its utilization. Hospitals are located on the outskirts of the cities to bring down the capital costs. The Mysore cardiac hospital was built using pre-fabricated materials and has no air-conditioning, except in operation theatres, thereby bringing down the cost of the facility dramatically low.

Another strategy to bring down the cost is to increase the volume of patient flow. To achieve this, NH has diversified into multi-specialties (such as Eye care, Orthopaedics, Neuroscience, and so on). Furthermore, NH recruits the best doctors and pays them as per the best industry standards. However, they are convinced to work a little extra. For the doctors at NH, 10 years ago, the plan was to do five surgeries a day with a 150-bed capacity, which itself was felt high. However, currently with 5,700 beds, they perform 30 surgeries a day. As a result, nearly 10–12% of all cardiac surgeries performed in India is done in NH network.

Narayana Health is an example of a service system. Like NH, every other service organizations as well as manufacturing organizations face similar set of issues, although in varying degrees. As illustrated in the case of NH, these issues can be addressed by applying several tools and techniques, collectively known as Operations Management.

Source: Based on Babu, V. (2012), “Pulse on the future”, *Business World*, March 5, 2012, pp 40–45; Chaki, D. (2013), “Straight from the heart”, *Business India*, Sep. 30–Oct. 13, 2013, pp 61–63.

1.1 INTRODUCTION TO OPERATIONS MANAGEMENT

Manufacturing, service, and agriculture are the major economic activities in any country. In India, manufacturing and services together constitute nearly 75 per cent of the gross domestic product (GDP). In recent years, growth in the GDP has been primarily due to the growth in these sectors of the economy. Moreover, the share of the service sector in the GDP has grown steadily from about 40 per cent to over 51 per cent between 1996 and 2006. In view of their contribution to the country’s GDP, management of manufacturing and service operations are important economic activities. Significant improvements in productivity and cost savings can be achieved through operations management—a discipline that focuses on activities that relate to the planning and control of operations in manufacturing and service organizations. Efficient operations management can also have a positive impact on the overall health of the economy.

A manufacturing firm essentially engages in converting a variety of inputs into products that are useful for individuals and organizations. For example, a manufacturer of machine tools employs several production workers, buys raw material and components from various suppliers, and manufactures machine tools in a factory using an extensive array of manufacturing facilities. In this case, the factory encompasses a large number of interrelated conversion processes for the transformation of raw material into the final product, that is, the machine tool.

A service organization, on the other hand, responds to the requirements of customers and satisfies their needs through a service delivery process. Service organizations leave an impression in the minds of their customers through their service delivery. Typical examples of such organizations include management consultancies, automobile garages, hotels, hospitals and banks. A service organization may not always make use of material inputs and may not always produce products that are used by the customer. For instance, a law firm providing legal consultancy to its clients may not provide material inputs to the system or produce material output. Instead, the input and output are informational and experiential in nature. However, in the case of a service system like an automobile garage, a restaurant or a health care system, there are material inputs and material outputs (in the form of products consumed by the customers, as in the case of a restaurant). Despite this difference, service systems also have a conversion process that utilizes resources and delivers useful outputs from the system.

An *operations system* is defined as one in which several activities are performed to transform a set of inputs into a useful output using a transformation process. These inputs and outputs can be tangible, in the form of raw materials and physical products, or intangible, in the form of information and experiences. Viewed in this manner, manufacturing and service systems could be broadly classified as operations systems. **Operations management** is a systematic approach to addressing issues in the transformation process that converts inputs into useful, revenue-generating outputs. Four aspects of this definition merit closer attention:

> **Operations management** is a systematic approach to addressing issues in the transformation process that converts inputs into useful, revenue-generating outputs.

- *Operations management is a systematic approach.* It involves understanding the nature of issues and problems to be studied; establishing measures of performance; collecting relevant data; using scientific tools, techniques, and solution methodologies for analysis; and developing effective as well as efficient solutions to the problem at hand. Therefore, for successful operations management, the focus should be on developing a set of tools and techniques to analyse the problems faced within an operations system.
- *Operations management involves addressing various issues that an organization faces.* These issues vary markedly in terms of the time frame, the nature of the problem, and the commitment of the required resources. Simple problems

include deciding how to re-route jobs when a machine breaks down on a shop floor, or how to handle a surge in demand in a service system. On the other hand, decisions such as where to locate the plant, what capacity to build in the system, and what types of products and services to offer to the customers require greater commitment of resources and time. Operations management provides alternative methodologies to address such wide-ranging issues in an organization.

- *Transformation processes are central to operations systems.* The transformation process ensures that inputs are converted into useful outputs. Therefore, the focus of operations management is to address the design, planning, and operational control of the transformation process.
- *The goal of operations management is to ensure that the organization is able to keep costs to a minimum and obtain revenue in excess of costs through careful planning and control of operations.* An appropriate performance evaluation system is required for this. Therefore, operations management also involves the development of performance evaluation systems and methods through which the operating system can make improvements to meet targeted performance measures.

Since manufacturing and service organizations form the operations system, it helps to understand the prevalent trends and the status of manufacturing and service organizations in India before we dwell on the various elements of operations management.

1.2 MANUFACTURING AND SERVICE SECTOR TRENDS IN INDIA

The index of industrial production (IIP) is a measure of the growth in the manufacturing sector. The Centre for Monitoring Indian Economy (CMIE) collects data on several macroeconomic indicators, including the IIP. Table 1.1 shows some of the salient aspects of the manufacturing and service sectors of the Indian economy. It is evident from Table 1.1 that the corporate sector has been going through tough times. There has not been much growth in sales revenue. However, there has been a steady increase in operating expenses and compensation to the employees. This has resulted in a situation where the profit after tax (PAT) has been progressively and significantly shrinking in the last three years. The service sector companies have been experiencing this more significantly than the manufacturing sector companies as evident from the table. On the whole, this points to the importance of deploying sound operations management practices in both manufacturing and service sectors of the Indian economy.

Over the years, there has been an increase in raw-material consumption. This perhaps indicates that manufacturing organizations are increasingly buying components and semi-processed items from suppliers. Furthermore, there has been a gradual increase in the cost of material and labour, which are primary inputs in the manufacturing system. Such an increase in the input cost is likely to put greater pressure on firms to cut down waste and improve productivity to remain competitive in the market. Therefore, the focus areas of operations management are likely to be in the areas of better supplier management, elimination of waste from the system, and improvement in overall productivity. Several sectors of the industry have been focusing on some of these initiatives.

TABLE 1.1 Salient Aspects of the Corporate Sector of the Indian Economy

Index of Industrial Production	2009-10	2010-11	2011-12	2012-13
Manufacturing	4.84	8.95	3.00	1.29
Capital goods	0.99	14.75	–3.97	–6.04
Consumer goods	7.65	8.57	4.37	2.43
Intermediate goods	6.03	7.39	–0.62	1.60
Corporate sector performance				
Manufacturing sector				
Sales	5.0	20.7	19.3	9.3
Operating expenses	4.8	22.3	19.6	10.1
Raw materials expenses	6.9	25.1	21.5	8.3
Compensation to employees	10.9	15.0	9.1	12.7
Profit After Tax (PAT)	43.1	15.4	18.4	–4.6
No. of companies	8751	8320	5690	3978
Non-financial services sector				
Sales	8.3	15.7	13.6	2.7
Operating expenses	6.1	17.7	15.3	1.3
Compensation to employees	5.3	15.0	14.3	14.1
Profit After Tax (PAT)	15.3	–28.0	–54.5	–7.7
No. of companies	6137	6125	4328	3065

All numbers in the table represent growth % over the previous year.

Data compiled from Economic Outlook of Centre for Monitoring Indian Economy (CMIE) using their time series data available at http://economicoutlook.cmie.com

Globally, India is emerging as an important manufacturing base and is competing closely with China in attracting several multinational companies to set up their manufacturing plants. Several studies point to emerging opportunities for Indian manufacturing to grow and attain a global presence. India has a unique advantage in the form of abundant low-cost labour and technical manpower. The Global Manufacturing Competitiveness Index 2013 released by Deloitte rated India at number four, next to China, Germany, and the US among 38 countries. It predicted India to reach the second position in the next 5 years. The report suggested that India's rich talent pool of scientists, researchers, and engineers as well as its large, well-educated English-speaking workforce and democratic regime would make it an attractive destination for manufacturers. Global manufacturing executives increasingly view India as a place where they can design, develop, and manufacture innovative products for sale in local as well as in global markets. Therefore, Indian manufacturing firms can, on the one hand, exploit the low-cost advantage as an entry strategy to capture global markets and, on the other develop, unique capabilities to position as an active participant in the global value chain.

The examples discussed here underscore the need for use of operations management to remain competitive in business and tap the emerging opportunities in the global arena. Effective operations management also requires a greater understanding of the various activities pursued under its banner and the critical linkages between operations and other aspects of business.

1.3 SERVICES AS A PART OF OPERATIONS MANAGEMENT

The service sector encompasses a wide spectrum of activities in every country. The growth of the service sector in India during 2002 to 2007 has been very significant. Table 1.2 provides some details on the share of some sectors of services in the overall GDP. The central government began taxing three services in 1994–95. This has grown steadily, and as of 2012–13, the number of services taxed has gone up to 119. During this period, both the number of assessees and the service tax revenue has been growing very rapidly. According to the Central Board of Excise and Customs (CBEC), between 1994–95 and 2012–13 the tax revenue has grown from ₹4.1 billion to ₹1.325 trillion.[1] These figures indicate the growing importance of services in the Indian economy and the need to apply management practices to plan and control operations in the service sector.

Although services and manufacturing are classified as separate sectors in a macroeconomic sense, from the perspective of operations management, this separation is artificial. In operations management, a "pure product" and a "pure service" are just two ends of the spectrum, and not separate entities. In reality, a vast majority of operations share a continuum of services and products. Therefore, most of the principles, tools and techniques of operations management apply to both these sectors. This product–service continuum is illustrated in Figure 1.1.

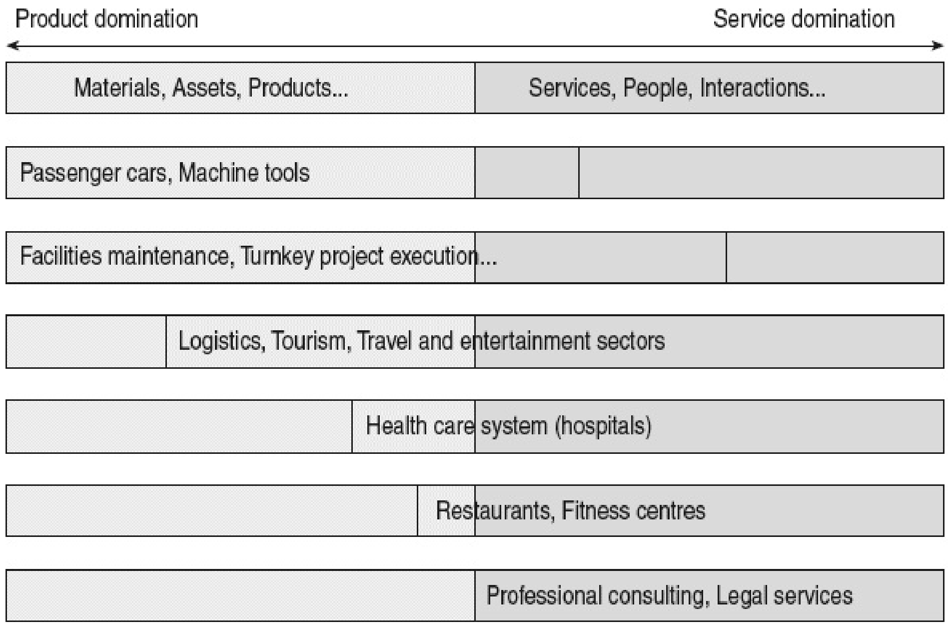
TABLE 1.2 Service Sectors in India: Share of GDP in Percentage

	2008-09	2009-10	2010-11	2011-12	2012-13#
Service sector growth rates in GDP					
Trade, hotels, transport, and communications	16.9	16.5	17.2	18.0	25.1
Transport, storage, and communications	7.8	7.7	7.3	7.1	
Financial services, insurance, real estate, and business services	15.9	15.8	16.0	16.6	17.2
Community, social, and personal Services	13.3	14.5	14.0	14.0	14.3
Construction	8.5	8.2	8.2	8.2	8.2
Total (including construction)	62.4	62.7	62.6	63.9	64.8

Advanced Estimate

* Compiled from Chapter 10 on Services Sector in Economic Survey 2012–13, government of India, Ministry of Finance, Economic Division. For more details see http://indiabudget.nic.in

FIGURE 1.1 The service–product continuum



Services such as management consulting, health spas, and education have dominant service attributes. They form one end of the spectrum. Similarly, manufacturing and supply of machine tools, gadgets, and consumables have a dominant product attribute, and they form the other end of the spectrum. However, several businesses share both service and product attributes. Take the case of automobiles. There is a product attribute in it since it involves the physical structure of the passenger car. On the other hand, there is also the experiential component of using the car, which forms a significant part of the product. This is the service component. Similarly, in the case of a restaurant, the food items share both product and service attributes. There are certain important differences between services and manufacturing. Let us take a brief look at each of these differences.

Intangibility

Fundamentally, services differ from manufacturing with respect to tangibility. Because services are experiences rather than objects, they cannot be touched, tasted or felt as in the case of objects. At the most, the recipients of services can form an opinion (based on some personal assessment) about the quality of the service offered. This has important implications for defining and assessing the quality of the service.

> Fundamentally, services differ from manufacturing with respect to tangibility, heterogeneity, simultaneity, and perishability.

On the other hand, in a product-oriented operation, the product is defined by certain attributes and the customer faces less ambiguity with respect to the product, its attributes, and its performance. This is because the customer can touch and feel the product and make his/her own assessment of the product.

Heterogeneity

The second differentiating aspect of services is the high degree of heterogeneity associated with them. Since the experiential component is dominant in a service, it is likely that no two services are exactly alike. The differences are attributed to the differences in the service receivers (customers), the service providers, and other parameters of the service delivery system. Therefore, a dentist attending to two consecutive patients having identical ailments may provide more or less the same type of service. Nevertheless, the two patients may have different perceptions of the quality of the service and may have different satisfaction levels. Moreover, the time spent by the dentist in both the cases could vary greatly. High heterogeneity results in high variability in the operations system performance and the need to factor them into the planning and control of operations.

> High heterogeneity results in high variability in the operations system performance.

Simultaneous Production and Consumption

More often, services occur in the presence of the customer, who may also be involved at the time the service is produced for his/her consumption. In the example of the dentist and the patient, the doctor and the patient are in the system together to produce and consume the service. This holds for education, entertainment, travel, tourism, and hotel services as well. In the case of manufacturing, however, most goods are produced at some point in time and distributed to the customer later. This difference has implications for the design, planning, and control of service operations, as the degree of customer contact in a service delivery system is likely to be high.

> VIDEO INSIGHTS 1.1
>
> Operations management in service organizations have a different set of issues to address. In order to develop an understanding of the peculiar issues pertaining to operations management in service organizations, a peep into service systems will be a valuable exercise. Hospitality and Healthcare sectors of services face unique challenges arising out of people-intensive service delivery, where the customer involvement is also high. To understand the issues in these sectors, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Perishability

Services are perishable. This implies that they cannot be inventoried. Thirty minutes of a doctor’s consulting expertise today cannot be stored for future use, reused, or returned in a future period. Similarly, the treatment for an acute headache likely to be faced by a patient sometime in the future cannot be stored in advance and reused at that time. The possibility of inventorying the supply and using it at a later time is very common in a manufacturing system. The implication for operations is that service systems require methods that work without inventories.

Services cannot be inventoried.

The characteristics of tangibility, heterogeneity, simultaneity, and perishability apply to "pure services," which are more experiential in nature. Furthermore, businesses with dominant service characteristics will have these features dominating over the other product-related features. For example, in the case of a fast-food joint, there is both the service aspect and the product aspect. A customer having a plate of *idli* with *sambar* experiences all the four attributes discussed here when viewed from the service angle. However, there is also a product angle to the restaurant. For instance, viewing *idli* as a product may enable the restaurant owner to inventory it for future use (later in the day).

ideas at Work 1.2

Operations Management in Service Systems

Intangibility, heterogeneity, perishability, and simultaneous production and consumption are the factors that differentiate service systems from manufacturing systems. Despite these differences, many of the operations management tools that were initially developed for manufacturing organizations are applicable to services as well. A study on the Ahmedabad Regional Passport Office (ARPO) illustrates this fact.

In March 2001, the regional passport officer of the ARPO was concerned about the long lead time taken for processing passport applications and issuing passports. The estimated lead time was 145 days at that time, so there was always a long queue of applicants waiting at the ARPO, either to know the status of the application or to submit the application form. To improve the response time, the existing process needed to be studied and redesigned. The situation called for the application of the principles of operations management to a service setting.

A detailed study of the process was undertaken to investigate the reasons for the long lead time. Excessive delays and long lead times often point to operations management issues pertaining to capacity, process, procedures, and use of technology and people. Process mapping, estimating the time for each step in the process, and assessment of capacity imbalances are important steps in studying issues related to long lead times in any operations system. In the case of the ARPO, this data was collected. Although the ARPO had a sanctioned staff of 103, the staff strength was 57 in January 2002. It augmented the capacity by employing 40 casual workers. It received about 235,000 applications in a year. Detailed studies were initiated to understand the various processes involved in issuing passports. See Figure 1.2 for an illustration of the process followed for passport application and approval.

FIGURE 1.2 Process-flow diagram for application processing

Detailed discussions with the officers revealed several opportunities for improving the existing situation. The activities at the ARPO were labour-intensive, and the organizational rules and procedures were highly centralized. Further, the discussions revealed that there was scope for automation of some of the activities. In the present scenario, it took a lot of time to access information on the application status, and Web-based services could reduce this time. The uneven load on police stations and the need to modify and simplify certain rules were some other issues that merited attention. Independent of the study, some administrative and procedural changes were already underway at the ARPO. Attention to all the issues that were highlighted during the study through better capacity management could help reduce the lead time in processing passports.

The data collected during the study was subjected to detailed analysis, and alternative methods were identified for the design and operational control of the operations at the ARPO. These include the use of waiting line models to explore alternative ways of redesigning the service delivery system; process redesigning to eliminate waste; improvements in productivity and the discovery of hidden capacity in the system; the identification of a new system for tracking operational performance, benchmarking and improvement; and the use of workload analysis and capacity planning methodologies. We shall discuss these aspects of operations management in the forthcoming chapters.

Source: Adapted from N. Ravichandran and D. Bahuguna, “Rule Bound Government Agency to Customer Centric Service Facility: Can Indian Passport Offices Make The Leap?” *IIMB Management Review* 18, no. 1 (2006): 59–66.

Despite these differences between products and services, from an operations management perspective, there are similarities between these two categories. Table 1.3 lists some of the salient differences and similarities between a manufacturing and a service system. The differences, as we have already discussed, are mainly due to the four distinguishing features of services. The similarities, on the other hand, are due to the basic need to manage operations. Design of operations requires decisions on capacities, products, and services to be offered. Operational planning and control requires that suppliers are managed, operations properly planned and scheduled, and demand matched with supply. These issues are common to both manufacturing and services, though the tools and techniques used to handle these issues may be specific to manufacturing and services.

TABLE 1.3 A Comparison of Manufacturing and Service Organizations

Manufacturing Organizations	Service Organizations

Differences	
Physical, durable product	Intangible, perishable product
Output can be inventoried	Output cannot be inventoried
Low customer contact	High customer contact
Long response time	Short response time
Regional, national, international markets	Local markets
Large facilities	Small facilities
Capital intensive	Labour intensive
Quality easily measured	Quality not easily measured
Similarities	
Is concerned about quality, productivity and timely response to its customers	
Must make choices about capacity, location, layout	
Has suppliers to deal with	
Has to plan operations, schedules and resources	
Must balance capacity with demand by a careful choice of resources	
Has to make an estimate of demand	

1.4 OPERATIONS AS A KEY FUNCTIONAL AREA

Before we understand the various sub-functions in operations in detail, it would help to appreciate the role of operations in an organization and its relationship with other functional areas of business. Irrespective of the activities and the type of business it is involved in, every organization has a few important activities. These include operations, marketing, finance, and human resources management. *Operations management*, as we have already seen, deals with the management of the conversion process in an organization. The *marketing* function is responsible for understanding the requirements of customers, creating a demand for the products and services produced, and satisfying customer requirements by delivering the right products and services to customers at the right time. Both operational and marketing activities require estimates of financial needs, tapping the market for funds, and management of working capital. These activities broadly constitute the *finance* function. Every organization employs a number of people who have varied skills, backgrounds and work requirements. Managing the workforce and addressing a host of issues related to them is another important requirement in an organization. The *human resources management* function deals with such issues. These four areas form the basic functions of any organization, as depicted in Figure 1.3.

As shown in the figure, the four functions have mutual interactions among them. The decisions made in each of these functional areas could form an important input in another functional area. For example, organizations typically begin their yearly plan with the marketing function making an estimate of the next year’s sales. This input forms the basis for production planning in the operations area of business. Depending on the production plans, procurement planning is done and all these factors lead to a certain estimate of the fund requirements. This forms an important input for the finance function. At the time these plans are executed, the interactions between these functions are even greater. The human resource management function influences the productive capacity of labour available in real time. The actual production of goods and services influences the marketing activities to be undertaken and the quantity and timing of available funds from sales. Such interactions are common in most organizations.

In every manufacturing or service organization, there are several sub-functions within the core operations function. Figure 1.4 provides a broader view of the nature of activities pursued within the core operations function and its linkages with other functions, both within and outside the organization. As shown in the figure, the operations function in an organization has five layers: (i) the customer layer, (ii) the core operations layer, (iii) the operations support layer, (iv) the innovation layer, and (v) the supplier layer. The *customer layer* consists of the end customer and various others in the distribution chain, including retailers and dealers. Within an organization, there are three layers. The *core operations layer* represents the manufacturing set-up in the case of a manufacturing organization. This may consist of fabrication, machining, assembly and final inspection. In the case of a service organization, the service delivery system consisting of the physical facilities and personnel forms the core operations layer. In every organization, there are other activities that directly interact with the core operations layer and provide a variety of support services. These form the *operations support layer*. This typically includes areas such as marketing, quality, design, planning, costing, information technology, purchase and materials, stores and maintenance. The third layer internal to an organization is the *innovation layer*. Every organization needs to devise strategies to remain competitive in the market. The strategy formulation process drives the research and development activities in an organization and enables the organization to bring new products and services to its customers.

FIGURE 1.3 The basic functions of an organization

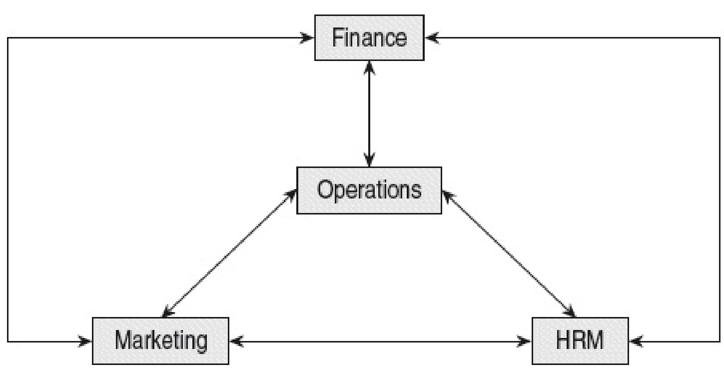
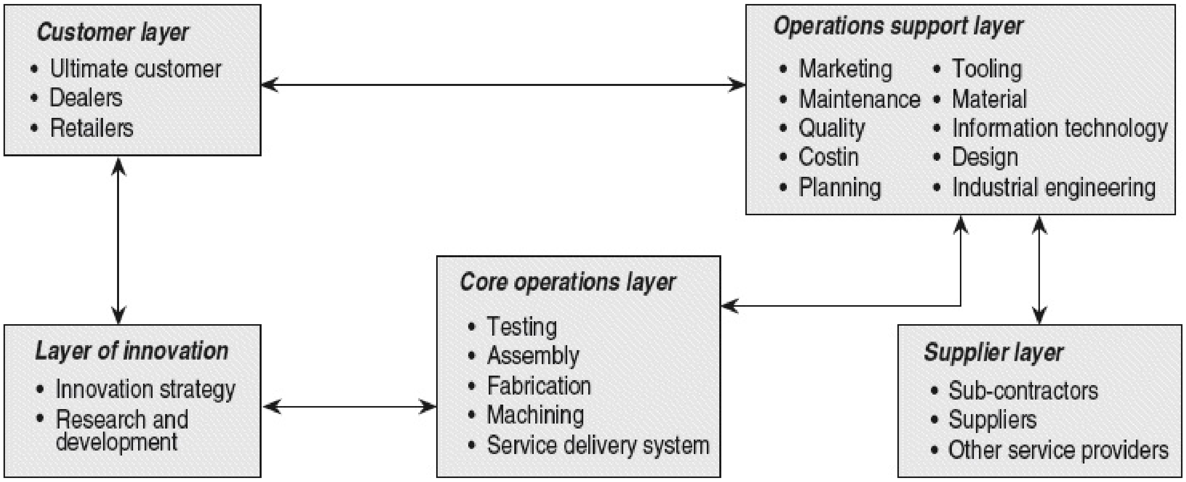


FIGURE 1.4 Operations function and its linkages in an organization



Source: B. Mahadevan, *The New Manufacturing Architecture* (New Delhi: Tata McGraw Hill, 1999).

The last layer, that is, the *supplier layer*, is external to the organization. Consisting of a network of suppliers, sub-contractors and other specialized service providers, this layer collectively represents the inbound logistics of the organization.

The customer layer interacts with the marketing function, and the inputs from the marketing function are crucial for planning operations. The supplier layer interacts with the materials or procurement function of an organization. The procurement function, in turn, interacts with the core operations layer and ensures timely availability of the various materials required. The customer layer also provides critical inputs to the layer of innovation, which forms the basis for the strategy formulation process. Based on the strategies made, several changes are made to the core operations layer. Therefore, there is a critical linkage between the core operations layer and the innovation layer.

1.5 OPERATIONS MANAGEMENT: A SYSTEMS PERSPECTIVE

A systems perspective facilitates a comprehensive understanding of the various aspects of operations management. A systems perspective essentially involves identifying the input, the output, and the processing and feedback mechanisms in a system. Figure 1.5 presents a systems perspective of the operations management function.

> The basic inputs in an operating system are labour, material, and capital.

The basic inputs in an operating system are labour, material and capital. The availability of skilled labour is an essential requirement as it is not possible to operate the system satisfactorily and deliver good-quality goods and services without adequate supply. The second input in operations is material. All manufacturing organizations process raw materials and convert them into useful products. Materials are required in several service systems as well. A healthcare system such as a multi-specialty hospital requires medical consumables such as cotton, disposable syringes, and other equipment. Similarly, a hotel requires a variety of raw material for preparation of food. Therefore, material forms a critical input in operations. The third important input in operations is capital. Capital is required to buy resources such as plants and machinery, to pay labour, and for investing in materials that are being processed into finished goods.

FIGURE 1.5 Operations management: a systems perspective

Processing includes the various activities that an operating system undertakes to convert the raw material into useful products for customers. The conversion process adds value to the product and enables the organization to sell it in the market. In the case of service organizations, the conversion process involves committing the various resources at its disposal to deliver useful services to the customer. Irrespective of whether it is a manufacturing or a service organization, there are a set of activities to be performed in the conversion process. These activities are presented in the processing section of Figure 1.5.

> **Processing** includes the various activities that an operating system undertakes to convert the raw material into useful products for the customers.

Product and process designs are an integral part of the conversion process. Every operations system must make important decisions with respect to the type of products and services to be offered. Furthermore, once the right mix of products and services are identified, appropriate processes for manufacturing and delivering them to the customers need to be identified. This involves deciding on the type of technology to use, the type of machines to be used in the conversion process, and the exact method of creating the products and services. These steps are known as product and process design. For example, when the low-cost airline Spice Jet started its operations, it had to make these choices. It chose to fly to only three locations connecting western India to Delhi. It had to decide on the type of aircraft to use, the in-flight services to offer, and various other aspects, such as ticketing and reservation, airport logistics, and passenger interfaces at the airport and outside. In manufacturing, a similar exercise can be visualized for Hyundai, when it started to manufacture passenger cars in India in 1998.

VIDEO INSIGHTS 1.2

The best way to understand the need for operations management and the issues to be addressed in a manufacturing system is to make a factory visit. A factory visit gives us a bird’s eye view of various aspects of managing the operations. The Honda factory in the USA and Mahindra’s XUV 500 factory in India provide a good introduction to the concepts of operations management in manufacturing organizations. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Once the product and process designs are finalized, an operations system must focus on ensuring that the demand for products and services is met. At this stage, the organization may also require operations planning to ensure the availability of adequate material and capacity to meet the targeted production and service delivery. This is known as operations planning. The operations system also requires methods for real-time control of operations as there may be several deviations from the plan. For example, there might be a breakdown of machinery or rejection of a lot of material supplied by a vendor. Alternatively, some customer might change his/her order quantity or cancel the order altogether. The operations control activity takes care of these changing requirements in an operations system. In the airline example, the issues relate to the pricing of tickets, capacity planning, and the handling of tickets cancellations and schedule delays. A planning system will help the airline in route planning, rerouting aircraft, and short-term capacity management.

Another important activity in the conversion process pertains to ensuring adequate supply of materials for the operations system. This requires that the suppliers of various materials are identified and relationships established with them. With such an arrangement, it will be possible to place orders for material with the suppliers and receive them within the stipulated time. This activity is labelled as purchasing and inventory control in Figure 1.5. From an operations management perspective, the processing part of the system primarily focuses on identifying the nature of resources required, planning for material and capacity, and ensuring that changes in real time are addressed.

A planning system will help the airline in route planning, rerouting aircraft, and short-term capacity management.

A fast-food restaurant may provide various types of food for breakfast, as per its process and product design. In several manufacturing organizations, services are also offered in the form of after-sales support and warranty.

An important aspect of operations management is estimating demand. This is done through *forecasting*.

The output of an operations system consists of goods and services. An organization that manufactures passenger cars will provide many variants of the passenger car. On the other hand, a fast-food restaurant may provide various types of food for breakfast, as per its process and product design. In several manufacturing organizations, services are also offered in the form of after-sales support and warranty. In addition to these tangible outputs, it is inevitable that an operations system will leave certain impressions and value judgments in the minds of its customers and stakeholders. For instance, a manufacturer of copper products such as Hindustan Copper will not only supply copper products to its customers, but also create an impression in the mind of the customer. For instance, its customers may feel that though the quality of the product is good, it is costly in comparison with its competition. People living in the vicinity of its factory may form opinions about the company on matters related to environmental pollution. The labour practices adopted by the company are likely to influence its prospective employees.

In recent times, organizations have begun to understand their role as a responsible entity in society. Pollution of the atmosphere creates greater problems leading to global warming. Industries such as leather processing and petrochemicals tend to generate large amounts of effluents. Sustainability is another area of major concern. In a country like India, businesses and society compete for limited natural resources such as water. In the state of Kerala, the local society protested against Coca-Cola for drawing water from the locality for their bottling plant. In such situations, the government and judiciary bodies such as the Supreme Court play an active role and intervene to ensure that these issues are resolved. To avoid disrupting the balance in society, an operations system must take such factors into consideration while configuring its input–processing–output elements.

It is useful to understand how the operations system considers these factors and reacts to them. In any system, the feedback loop serves the purpose of identifying the deviation paths and highlighting the areas that need immediate correction. In an operations system, there are three feedback loops available for making corrective measures. These include quality management, maintenance management, and process improvement. These operations management activities provide checkpoints to identify the areas requiring improvement and ensure that corrective measures are indeed taken.

The demand for the goods and services offered by an organization cannot be entirely controlled by the organization. At best, an organization can influence the demand to an extent. From a systems perspective, the demand is an exogenous variable. However, planning for production, capacity and material clearly depend on the demand that the operations system is likely to face in the upcoming periods. Therefore, an important aspect of operations management is to estimate demand. This is done through what is known as *forecasting*.

1.6 OPERATIONS MANAGEMENT FUNCTIONS

From the description of the various aspects of operations management in the systems perspective, one can distil some of the important functions of operations management. These functions are carried out irrespective of whether the organization is in manufacturing or services. Table 1.4 lists these functions.

The important functions can be understood by: (a) categorizing them under design issues and control issues, as shown in Table 1.4; and (b) classifying them as long-term issues and short-term issues, based on the planning horizon.

Design Versus Operational Control Issues

An examination of the left-hand column in Table 1.4 shows that the operations management decisions listed in that column pertain to the design of an operations system. **Design issues** relate to the configuration of the operations system and provide an overall framework under which the operations system will function. The operations management functions pertaining to design include designing products, services and processes, setting up a quality assurance system, deciding on the layout and location of facilities, and capacity planning. Design issues in operations management establish the overall constraints under which the operations system functions. A few examples will help clarify this characteristic feature of design issues in operations management.

> **Design issues** in operations management establish the overall constraints under which the operations system functions.

TABLE 1.4 Operations Management Functions

Design Issues	Operational Control Issues
Product and service design	Forecasting
Process design	Operations planning and control
Quality management	Supply chain management
Location and layout of facilities	Maintenance management
Capacity planning	Continuous improvement of operations

For example, once the capacity of the resources to be used in the system is decided, it sets limits for the actual use of the system in operation. If Maruti Suzuki India Limited installed an engine plant that has the capacity to produce 200,000 engines annually, then, in actual operation, it can produce no more than 200,000 engines. Similarly, if a multi-specialty hospital is located in Pune with a 200-bed facility, it is understood that it will largely serve residents in the vicinity of Pune up to a capacity of 200 in-patients at any time. Setting policy guidelines and procedural details for various aspects of the operations system is also a design activity. A typical example is the setting up of a quality management system that establishes rules and policies with respect to what is acceptable and what is not.

Operations management decisions listed in the right-hand column of Table 1.4 share a different characteristic. They all address the vital issue of planning and operations control. Once the design choices are exercised, operations management amounts to putting the available resources to best use and handling various issues as and when they arise. The available capacity could be better utilized through production planning and by scheduling operations so that idle time is minimized. Furthermore, required capacity and material could be estimated and made available through purchasing and scheduling procedures. All these constitute operational control decisions in operations management.

Every issue addressed in design is inevitably addressed again in operational control. However, the context differs in the two cases. Capacity planning as a design issue lends itself to a different type of analysis compared to capacity planning in operational control. In the case of the latter, the objective is to match the requirement to the available capacity, whereas in the case of the former, the objective is to find out how much capacity is required for meeting targeted business plans. Moreover, design issues often turn out to be strategic in nature, while operational control issues are tactical in nature. Strategic decisions frequently involve large capital outlay and are made with critical inputs from an operations strategy process. Such decisions are made by the top management to improve the competitiveness of the organization. Operational control issues, on the other hand, are tactical, repetitive and routine in nature. Lower-level operations managers often make such decisions.

> Every issue addressed in design is inevitably addressed again in operational control.

Long-term Versus Short-term Issues

Another useful approach to understanding the various operations management functions is to view them from the planning horizon perspective. Certain operations decisions are made once every five to ten years. For example, the decision to locate a manufacturing or service delivery facility is made as and when a new facility is to be introduced. Similarly, product line decisions and capacity augmentation decisions are made once every three to five years. Typically, a majority of design decisions are made with a planning horizon of five to ten years. Such decisions usually require a long lead time, multiple levels of decision-making and huge capital outlay. Therefore, they tend to be made at less frequent intervals.

Some other decisions are made in fixed cycles of one year. Every organization makes a business plan coinciding with its financial year, wherein specific targets for sales are established. The annual business planning exercise leads to aggregate operations planning. Once the aggregate operations planning is done, master scheduling and material and capacity requirements planning are done for the next quarter or three months. These are medium-term decisions. Finally, several operations management decisions are made for a short run of a week or less. These decisions include detailed scheduling of operations, quality management and control, and reacting to disruptions and changes in plans.

1.7 CHALLENGES IN OPERATIONS MANAGEMENT

Challenges in operations management arise mostly from developments that create a need for new, and, at times, more efficient system of operations management. The economic reforms in the 1990s opened up the indian markets to overseas players, which posed new challenges for domestic companies. With time, there have been more changes in the form of rising customer expectations, technological developments, and growing awareness about environmental issues. Each of these developments needs to be addressed with appropriate changes in the strategy, design and implementation of operations management practices.

Competitive Pressure due to Economic Reforms

It is more than 20 years since the economic liberalization and globalization policies of the Government of India came into force. During these years, the Indian corporate sector has learnt what exactly the melting pot of global competition means. Due to integration of the Indian economy with the global economy, the Indian companies are required to benchmark the manufacturing sector against the best in the world to enhance their competitiveness. Companies that are able to meet the stiff competition are able to discover the unprecedented opportunity for growth as they discover new markets and customers in other parts of the world. Competitive pressure manifests in terms of three major challenges:

Falling prices

There has been a continuous fall in prices of branded, engineered consumer products as well as industrial products. For example, the on road price of a Hyundai Santro GLS model in 2000 was ₹440,000/- and the price of a Santro Xing GLS model in April 2014 was about ₹480,000/-. Over the last 15 years, the annual growth rate in price of several white goods such as refrigerators, washing machines, and ovens have been far less than inflation rate. Similarly, industrial buyers constantly enforce annual cost reduction targets for their suppliers. Therefore, learning to profitably operate in an era of falling prices is a challenge.

Shrinking delivery quote

Several years back it was not uncommon to book a vehicle (such as a car or a scooter) and wait for taking the delivery. The car manufacturer may not be able to satisfy the customer in terms of the colour choice. However, due to economic reforms, these issues have been pushed to the background. Today, responding to the requirements of the market, rather quickly, is very important. Otherwise, the customers will switch to other suppliers who are willing to respond to them fast. Several service firms such as insurance providers and banks are expected to provide a high level of responsiveness. Manufacturing companies are also constantly facing the challenge of quickly reacting to their customer needs. For example, textile manufacturers are expected to cut their lead time from order placement to final delivery down to 2 months. Otherwise, large retailers such as Wal-Mart, Gap, and Tesco are not interested in placing orders on them. Therefore, developing new methods of shrinking lead time is another challenge for the companies.

Build-to-order requirements

Customers increasingly demand several variations of products and services. They also demand flexibility to change their requirements until the point of service and product delivery. Systems that allow them to customize, configure, and visualize their own version of products and services are more in demand than a standard off-the-shelf version with a few pre-determined variations. In order to respond to these emerging requirements, a firm need to develop build-to-order capabilities.

Growing Customer Expectations

Look at the number of tariff plans and options offered by mobile service providers such as Airtel and Vodafone these days. They provide multiple postpaid and prepaid options that appear to satisfy every customer category in the market. This is a good indication of the growing customer expectations and the ability of organizations to respond to them. Such developments have been greatly facilitated by the economic liberalization process that we discussed earlier. A decade ago, customers would not have made any fuss about the services provided by the Department of Post and Telegraphs, simply because they had no other choice. The situation was similar in most sectors, whether a customer wanted to travel by air, get a phone connection, or buy a car. Today, however, they have a variety of choices in of these situations. Many courier services can substitute India Post. Several private airlines and telecom companies offer multiple versions of services. Many different models of cars, starting from basic models such as the Maruti 800 and the Omni to high-end cars such as the Toyota Camry are available today.

Exposure to such developments increases customer awareness, enabling them to demand better-quality products and services. They prefer more variety, greater levels of customization, and the ability to have it in discrete quantities and without waiting too much for the product or service they want. This means that manufacturing organizations and service providers constantly need to invest in understanding changing customer tastes and provide goods and services by aligning various aspects of the operations. Organizations need to develop the capability to bring out newer product and service versions that are not only better but also cost-effective. This introduces new challenges for operations management.

Technological Developments

In the last few tears, technological developments have changed the way businesses in many sectors operate. Take, for example, the banking sector in our country. With the advent of automated teller machines (ATMs) and the Internet, the face of banking is undergoing a sea change. Customers need not visit a bank branch to draw cash or to check their account balance. These transactions can be carried out at an ATM. Drafts and cheques can be replaced with electronic payment gateways and fund transfer mechanisms. Similar facilities are now available in other sectors. For example, consider the process involved in buying a train ticket. By visiting a Web site like http://www.irctc.co.in, a customer can accomplish all the required tasks pertaining to ticket booking and cancellation at leisure.

The changes that manufacturing organizations are going through are no less than service organizations. In this age of electronic markets, a manufacturing organization can procure goods and services by organizing a reverse auction on the Internet. In a matter of 3 to 4 hours, the best price for a component and the supplier willing to provide the component at a desired quality can be located. Similarly, a team of design personnel from across different geographical locations can participate in new-product development using technological tools.

From these examples, we can appreciate that today's businesses are constantly challenged by the rapid technological advancements. These advancements tend to have a dramatic impact on the competitiveness of businesses. They force structural changes in a sector of the industry and trigger several changes in the operational practices of firms.

Environmental Issues

Growing industrialization at one level indicates the economic progress of a nation. However, at another level, it introduces new concerns and challenges in operations. In the recent past, there has been growing concern regarding the impact of business activities on the environment. These include concerns regarding the depletion of natural resources and the waste generated from production systems and end-of-life products. Increasingly, firms are under pressure to take responsibility of restoring, sustaining, and expanding the planet's ecosystem instead of merely exploiting it.

When the Government of India announced a scheme for special economic zones (SEZs), it generated controversies and social concerns. In several such cases, local communities were reluctant to part with fertile land, which was then used for industrial purposes. This has implications for the location of manufacturing and service facilities.

Consider the case of passenger cars. In a country like India, 12 out of 1000 people have a passenger car. In the United States, this figure is 512 per 1000 people. While this could be an indicator for the passenger-car industry to set its growth projections, it also indicates the challenges arising out of availability of petrol and diesel and increased emissions. Unless the issue of emissions is addressed and alternative fuels and non-conventional technologies are invented, the sector will not grow to meet its potential. Design of products and operational practices must take these environmental concerns into consideration.

Growing urbanization creates societal problems arising out of scarcity of available resources and generation of solid wastes. With high population density in cities, the consumption of energy and water in countries like India is on the rise. Such a situation requires better practices and newer methods of addressing these requirements using better operational practices. These days, due to the increased use of electronic gadgets, the amount of e-waste being generated is also on the increase. Similarly, the use of plastics and bio-non-degradable items also pose challenges to businesses and society.

Businesses need to refine their operations management practices to be able to address these requirements. Operations management practices must address environmental concerns in order to ensure a sustainable world.

1.8 CURRENT PRIORITIES FOR OPERATIONS MANAGEMENT

Each of the challenges identified in the previous discussion clearly points to new priorities for operations management. Economic reforms and liberalization have established the importance of the customer/market. Organizations need to relate the operations system to the customer/market. Otherwise, they may find it difficult to survive in the long run. As customer aspirations grow, organizations must find ways and means of dealing with the proliferation of variety. Operations management practices need to be developed for this purpose. One way in which organizations can meet growing customer aspirations is by getting into a continuous learning mode. In the future, addressing emerging environmental concerns through better operations practices will become a necessity. Some such priorities for present-day organizations are discussed in some detail here:

- *Relate the operations system to customer/market requirements*. Choices in manufacturing and services cannot be made on the basis of internal conveniences, as was the practice in the pre-reforms era. All the choices made in an organization demand that the customer is central to the design, whether it concerns performance measures, manufacturing and service-delivery system design, supplier management, or product development. If the customer has difficulty using a product or service, there should be methods for understanding the difficulty and rectifying the mistakes. This calls for better quality management practices in every organization.
- *Acquire capabilities to tolerate product/service proliferation*. Customers are likely to demand more choices and value-offerings from manufacturing and service organizations. In order to remain competitive, every organization needs to understand customer requirements and incorporate them in new product development initiatives. New procedures and systems should link the customer layer to other layers of an organization (see Figure 1.4). The development of new products and models often becomes necessary for organizations. However, large product/service variations often result in a spectrum of offerings ranging from "low-volume, high-variety" to "high-volume, low-variety." Operations management practices need to address these requirements and enable managers to handle the complexities arising out of variety.
- *Develop systems and procedures that promote learning*. Continuous improvements in factors affecting competition, such as quality, delivery, cost, and responsiveness, are very important for every organization. These improvements do not take place in isolation or by mere accident. Instead, improvements happen out of continuous learning on the part of the employees in an organization. A good operations management practice in an organization will help the organization set up a continuous improvement methodology. New systems and procedures that help employees to learn need to be put in place.
- *Develop green manufacturing practices*. Green manufacturing practices are operational practices that ensure that products are manufactured in a sustainable manner by conserving scarce natural resources and minimizing pollution and other negative impacts on society and nature.

Environmental imbalances are of great concern as they threaten the society and its sustainability. Non-governmental organizations (NGOs) and interest groups such as Greenpeace, international bodies such as the World Trade Organization (WTO), and government and regulatory bodies impose stringent regulations on organizations to reduce the adverse effects of manufacturing activities on the environment. Policy makers have brought in new legislations that put regulatory pressures on businesses as a means to address environmental concerns. Notable among these are the EU directives on compulsory product-take-back at the end of life of a product, The Netherlands National Environmental Plan, and the package recycling and product take-back laws in Germany.[2] In Germany, the Commercial and Industrial Waste Avoidance and Management Act holds producers responsible for end-of-life disposition, recovery, and reuse of their products.[3] Therefore, it is inevitable for every organization to develop green manufacturing practices.

In an era where human beings are facing serious environmental concerns like global warming and depletion of natural resources, organizations should reduce the total environmental burden by moving beyond mere "greening" and take ownership of the environmental impacts associated with the total life cycle of the product. This essentially calls for fundamental changes in the underlying product and process design, taking into account all possible effects a product might have throughout its life on the environment, both within the firm and beyond its boundaries. The use of clean technologies is another important requirement for maintaining a balanced environment.

ideas at Work 1.3

India – an emerging global Manufacturing Base

Mounting global competitive pressures have forced multi-national companies (MNCs) to look for the most competitive way of manufacturing and delivering products and services. Being one of the BRIC (Brazil, Russia, India, and China) countries, India seems to be an attractive location for the MNCs to invest into the future. Siemens, for instance, found that during the recent global recession, Asia in general and both India and China in particular have escaped from the recession by showing steady growth. Siemens AG (German parent company) CEO believes that Siemens Ltd. (Indian subsidiary) will play a key role not only as a manufacturing base but also by generating own innovations and local supply chains.

The growing importance of India as a manufacturing base stems from three main factors. First is the peculiarity of the Indian market that is extremely cost sensitive. Therefore, there is an in-built need to develop products that are priced low without compromising on quality and meeting optimum specifications of the customers. In Siemens Ltd., this was addressed by developing SMART products (S – Simple to use; M – Maintenance friendly; A – Affordable; R – Reliable, and T – Timely-to-Market). For example, Siemens Ltd. delivered the world’s first 1200 kV sulphur hexafluoride (SF6) circuit breaker to Power Grid Corporation of India Ltd., which requires less than half the space and fewer lines to transmit the same power. It also has the capacity to transmit 8000 MW electricity from distant generating stations. Similarly, Siemens Ltd. launched SWT-2.3-113 direct drive wind turbine targeted at low to moderate wind markets.

The second factor that drives India as an emerging manufacturing base is to utilize these capabilities and deliver cost-effective products and services to global markets. Using the capabilities in manufacturing, engineering, and redesigning tools in India, Siemens AG has been able to cut costs by 30–50%. On account of these, the attractiveness of India increases. For instance, Siemens AG in its annual internal evaluation ranked Siemens Ltd. the second best regional company in 2010–11, ahead of the US, China, and many others.

This encourages the MNCs to explore more opportunities in India. In the case of Siemens AG, it has responded to these developments by investing significantly in India in recent times. Siemens AG has invested 1 billion euros in Siemens Ltd. in 2011. In January 2012, it opened up two new factories in India in addition to the existing 20.

India is at the central point of the global growth strategy of several firms. This is because of a vibrant domestic market and the potential to serve as a manufacturing base for the global market. It may, therefore, not be surprising to see India emerge as a global manufacturing base as the Siemens example seems to point to us.

Source: Bana, S. (2012), "Ahead of the Curve", *Business India*, April 15, 2012, pp 46–54.

SUMMARY

- *Operations management* is a systematic approach to addressing issues in the transformation process that converts inputs into useful, revenue-building outputs.
- Globally, India is emerging as an important manufacturing base and is closely competing with China in attracting several multinational companies to set up their manufacturing plants in India. Several recent studies point to emerging opportunities for Indian manufacturing to grow and attain a global presence.
- From an operations management perspective, a "pure product" and a "pure service" are just two ends of a spectrum. In reality, a vast majority of operations share the continuum of products and services.
- Despite several important differences between products and services, from an operations management perspective, there are several similarities between the two settings.
- Every organization has five layers that make up its value chain. The physical arrangement of these five layers depicts the structural aspects of an operations system.
- The decision context in operations management can be broadly classified as *design issues* and *operations control issues*. Moreover, there are *long-term* and *short-term decisions* involved in operations management.
- Some of the challenges faced by operations firms include the need to address increased competition due to economic liberalization and globalization, growing aspirations of customers, rapid technological advances, and emerging environmental concerns.

REVIEW QUESTIONS

1. What is an operations system? give some examples of operations systems.
2. What do you understand by the term "operations management"?
3. What are the major operations management issues that manufacturing organizations face in India?
4. How would you define a service system? give some examples to support your definition.
5. How important is it to apply formal management principles to service operations?
6. "There is nothing like a service system or a manufacturing system. In reality, there is a continuum between these two extremes." Comment on this statement.
7. "Services are very different from manufacturing. Therefore, it is not appropriate to use the same set of principles for managing operations in manufacturing and service organizations." Do you agree with this statement? give reasons in support of your argument.
8. What do you understand by the term *systems perspective*? Use the example of operations management to explain.
9. What is the role of operations in an organization? What are the other functions in an organization? Are these functions independent of one another? give some examples to support your argument.
10. What are the various functions of operations and how are they linked to other parts of an organization?
11. Distinguish between the following terms:

    a. Service attributes and product attributes
    b. Manufacturing organizations and service organizations
    c. Design functions and operational control functions in operations
    d. Long-term functions and short-term functions in operations

12. Identify three emerging environmental concerns and their impact on operations management. What changes do you envisage in operations management to address these concerns?

NET-WISE EXERCISES

1. Visit the following Web sites to understand the current trends and the growth in India’s manufacturing sector:

   - http://indiabudget.nic.in/budget2013–2014/es2012–13/echap-09.pdf
   - http://nmcc.nic.in/default.aspx (examine the contents under various heads)
   - http://nmcc.nic.in/pdf/strategy_paper_0306.pdf (go through the report on a strategy for the manufacturing sector)

   Now, answer the following questions:

   a. What is your understanding of the status of the manufacturing sector in the country?
   b. What are the key steps that the National Manufacturing Competitiveness Program proposes to improve the competitiveness of manufac-turing?

2. Visit http://www.servicetax.gov.in/ to know more about the growth of service tax in India. Look up http://fieo.org/view_section.php?id=0,23&lang=0 to know more about the status of the Indian service sector and its export potential. Furthermore, there are several important links listed in this Web site. Look them up and prepare a report on the status of the service sector and its export potential by answering the following questions:

   a. Comment on the growth of the Indian services sector and its exports during the last ten years.
   b. Is India a dominant player in global trade for services? Does it export more services? What types of services are exported from India?

3. In the future, all manufacturing and service organizations would be required to adhere to sustainable practices. Therefore, every operations manager must develop a good understanding of the issues and challenges that they are likely to face and possible actions that they can take to address these concerns. Visit the following URLs and study in detail how environmental issues are being addressed by organizations:

   - http://www.ecocycle.org/
   - wwww8.hp.com/us/en/hp-information/global-citizenship/reporting.html

   Prepare a report to answer the following questions:

   a. What are the implications of the mandatory requirement of “product take-back"? How will it affect the operations management practices of manufacturing organizations? Can you identify two areas on which product take-back will have significant impact and show how they will be affected?
   b. How does Hewlett-Packard address environmental concerns? Identify three interesting aspects of their policy and show how an operations manager could implement these policies in his/her organization.

SUGGESTED READINGS

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CHAPTER 2

Operations Strategy

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- Why do firms engage in strategy-formulation exercises from time to time?
- How are strategies formulated? What is the linkage between corporate strategy and operations strategy?
- What is the role of performance measures in an organization?
- What are the various options available to organizations to compete in the market?
- What is world-class manufacturing?
- What are the emerging trends in technology and business? Will these trends have an impact on the operations strategy process in organizations?

In order to achieve operational excellence, Indigo airlines have deployed check-in staffs as baggage handlers. These practices help in clearing the peak hour demand and saving time and cost for the company. The company’s strategy is to increase the responsibilities of the staff and thrive as a successful operator in the aviation sector.

Source: https://book.goindigo.in/

ideas at Work 2.1

Café Coffee Day: A Strategy for Affordable Luxury

Café Coffee Day (CCD) is India's favourite coffee shop for the young and the young at heart. It is a part of India's largest coffee conglomerate, Amalgamated Bean Coffee Trading Company Limited. In Asia, it has the second largest coffee estate ownership, which endows it with abundant source of coffee. In addition, there are 11,000 small growers from whom CCD sources coffee beans. These choices with respect to the supply chain for coffee beans enable them to provide single origin coffee to the connoisseur.

In some sense, CCD has brought in the concept of cafés to India. The first CCD outlet opened in 1996 on Brigade Road in Bangalore continues to be one of the most happening places in the city. Since then, CCD has grown into the largest organized retail cafe chain in the country. CCD outlets are also present in Vienna, Austria, and the Czech Republic. There are about 1700 outlets in India, and there are plans to increase it to over 2000 outlets in India and 200 in overseas by December 2014.

The concept, strategic intent, service delivery design, and various other choices made at CCD makes it unique. A typical CCD outlet is a smart, simple space where the customers could sit down, talk, and listen to conversations, hold short meetings, or even have a lot of good fun, all over steaming cups of coffee. A typical customer is about 25 years old and never visits the CCD outlet alone. In a CCD outlet, the coffee is served efficiently; the outlet is clean and the setting relaxed yet peppy. What distinguishes CCD from the other competitors such as Barista, Au Bon Pain, and Costa Coffee is the pricing strategy, which the MNCs struggle to get after a few iterations. CCD offers a single-serve coffee machine that can dispense a cup of tea in about 20 seconds. They have also developed a 5 Kg, 30 cm tall machine called Coffee Day Wakeup, which is likely to be priced under ₹5,000 compared to Italy's Lavazza's ₹15,000 product. The service delivery design of CCD is unique and is based on the strategic intent of providing an affordable luxury to the chosen customer segment. There are four formats available. These include **Café Coffee Day, The Lounge, The Square, and XPRESS Outlets.** There are over 1500 Cafés spread across 200 cities in India where over 300,000 customers step in on a daily basis. The Lounge offers a wide range of food and beverages, targeting a more mature and affluent group of customers. The Square is a premium range of cafés catering to the connoisseur and widely travelled. The Lounge and the Square outlets are designed in such a manner that it can be used for a serious business conference or for a relaxed meeting. Facilities available include a free wi-fi, a presentation screen, single-origin coffee, and exquisite cuisine.

The XPRESS Outlets offer quick coffee to the moving population and are located in the city's key spots. Each of these outlets is designed to suit the targeted customer segment. The XPRESS Outlets occupy just 60 square foot of space, whereas The Square and the Lounge are much bigger.

The strategy of CCD is to be the best Café chain by offering a world-class coffee experience at affordable prices. A closer look at various aspects of CCD suggests the importance of developing a corporate strategy and aligning various aspects of operations to the overall strategy. We shall see some of these aspects in detail in this chapter.

Source: http://www.cafecoffeeday.com; "Tomorrow's Goliaths: Café Coffee Day", *Business Today*, December 2, 2011, pp. 80–84.

Organizations constantly endeavour to maximize their value-creation opportunities and benefit from the same. The profit-making potential of an organization is directly related to the competitive advantage that it enjoys in the market over its competitors. Therefore, it is very important for every organization to seek an answer to the question: "What should the organization do to create competitive advantage for itself and sustain it for a longer time?" The strategy-making process addresses this critical question and provides some vital information that helps the organization to create competitive advantage. A strategic planning exercise enables an organization to respond to market needs in the most effective manner by aligning the various resources and activities in the organization to deliver products and services that are likely to succeed in the marketplace. At the end of this exercise, the organization will typically be able to spell out its strategic intents and develop an overall corporate strategy. Through the strategy-making process, the organization equips itself with the required systems and procedures. A good strategy often brings in rewards for the organization in the form of profits, a higher market share, and a dominant position in its sector in several aspects of business.

> **Operations strategy** is the process of making key operations decisions that are consistent with the overall strategic objectives of the organization.

Every organization, whether in services or manufacturing, has a strategic intent. The strategic intent could be to provide goods and services at a low cost, or to provide a highly customized product or service. For example, the strategic intent of a law cost air line is to provide affordable air travel. The strategic intent influences the overall corporate strategy of an organization, which, in turn, shapes its operations strategy. **Operations strategy** is the process of making key decisions regarding the operations function of an organization on the basis of inputs from its overall corporate strategy. In this manner, it links the overall strategic intents and the corporate strategy to specific aspects of the operations system. Strategic decisions include, for example, the extent of capacity to be built into the system, the type of process and technology to be used, the nature of products and services to be offered, and the type of supply chain to be configured. In the process of making these decisions, it is important to identify key measures of operational excellence. In this chapter, we shall look at all these aspects of operations strategy in detail. Before we discuss the strategy-formulation process, it would help to understand the context and relevance of operations strategy in any organization.

2.1 THE RELEVANCE OF OPERATIONS STRATEGY

An analysis of the competitive scenario in our country in the last ten years reveals that it is now imperative for organizations to have a sound operations strategy. Due to globalization of the economy, Indian manufacturing and service firms have had to face competition from other parts of the world. Indian organizations are now required to have a global outlook as opposed to the traditional domestic outlook. They can no longer afford to ignore the need for customer orientation and cost cutting, which have become crucial to the survival of an organization in these competitive times. In the post-liberalization era, Indian firms are exposed to greater levels of competition than ever before. Korean and Chinese goods flood the markets these days, and this has profoundly influenced various sectors, ranging from industrial goods to consumer non-durables. When markets get overcrowded with players, excess capacity builds into the system and organizations face pricing and other pressures. In general, when the number of players increases and a particular sector has excess capacity, competing organizations promise quick delivery and greater options in products and services at a lower cost in order to win customer orders. Indian organizations in several sectors are currently facing such a situation. On account of this, a number of Indian firms have faced a significant fall in prices, a dramatic reduction in delivery quotes, and the proliferation of variety. Organizations need to devise methods to remain competitive in the market under these conditions.

> A strategic planning exercise enables an organization to respond to the needs of the market in the most effective manner by:
>
> i. identifying products and services that are likely to succeed in the marketplace, and
> ii. aligning the resources and activities in the organization to deliver these products and services.

Even when the annual inflation during the last ten years has averaged at about 5–6 per cent, several component manufacturing firms have been asked to reduce the price of the components that they supply on an annual basis. Triveni Engineering, a manufacturer of turbines, faced a 40 per cent reduction in the price of turbines in the “less than 3.5 million watts” category during the period 2000–04. ABB India reported that the price of a 33-kV circuit breaker dropped from ₹275,000 in 1990 to ₹180,000 in 1999. In such a scenario, better cost management practices are required in manufacturing and service organizations to handle the threat of competition.

> *Pricing pressures, lead-time reduction*, and the proliferation of variety are some of the key challenges faced by Indian organizations.

In addition to cost pressures, organizations have faced competitive threats in the lead time for supply of goods. Lakshmi Machine Works (LMW) is a Coimbatore-based manufacturer of machinery for the textile industry. Until 1997, it had been able to obtain customer orders and supply machinery after a period of 48 to 60 months. In several cases, customers were willing to pay in advance and wait for such a long time. However, with the entry of several Korean and European manufacturers, the lead time for supply of machinery was pushed down to 10 months. Therefore, LMW had to respond to this challenge in the market not only to remain in business but also to be profitable.[1] Similar examples of a demand for lead time reduction exist in several other sectors of the industry. While it was customary to book a passenger car and wait for a few months for delivery, today, a manufacturer of passenger cars cannot afford to make customers wait that long. The development of superior capabilities to cut down lead time is an important requirement today.

The third area of concern is the proliferation of variety. In response to mounting competition, there has been a proliferation of variety in several sectors of the industry. These sectors include white goods, electronic appliances, and industrial goods. Nowadays, it is interesting to note that even simple commodities such as wheat flour and salt, which were never considered to be branded items, have more than a dozen varieties to choose from. Clearly, organizations need to develop a high capability for managing variety.

Returning to the example of passenger cars, the industry was delicenced in 1993. Until that point, customers had a very limited choice of features, colours, shapes, and sizes. All this changed with the liberalization of the sector. Today, passenger-car manufacturers are forced to offer a wide range of choices to customers.

One can draw several key inferences from the developments in the area of operations management in the last decade. Some of these are as follows:

- Competitive dynamics will change on account of socio-economic changes and the policy changes of the government. The expectations of customers will also change along with these.
- Organizations need a structured approach to scan the market and distil the changing needs at the marketplace. They also need a mechanism to chalk out a plan for responding to these changes in the most effective way.
- With the changes in the marketplace, the competitive priorities for an organization must also change. Organizations need to tune their operations to match with the competitive priorities.
- The above-mentioned processes are expected to repeat several times in the future, and organizations must be in a position to respond to changes whenever the need arises.

As per our definition of corporate and operations strategy, all these functions are achieved through a strategy-formulation exercise. Therefore, it is important for organizations to develop the capability to devise strategies for operations and to revisit the strategy-formulation exercise as and when there is need for it. We shall now turn our attention towards the strategy-formulation process.

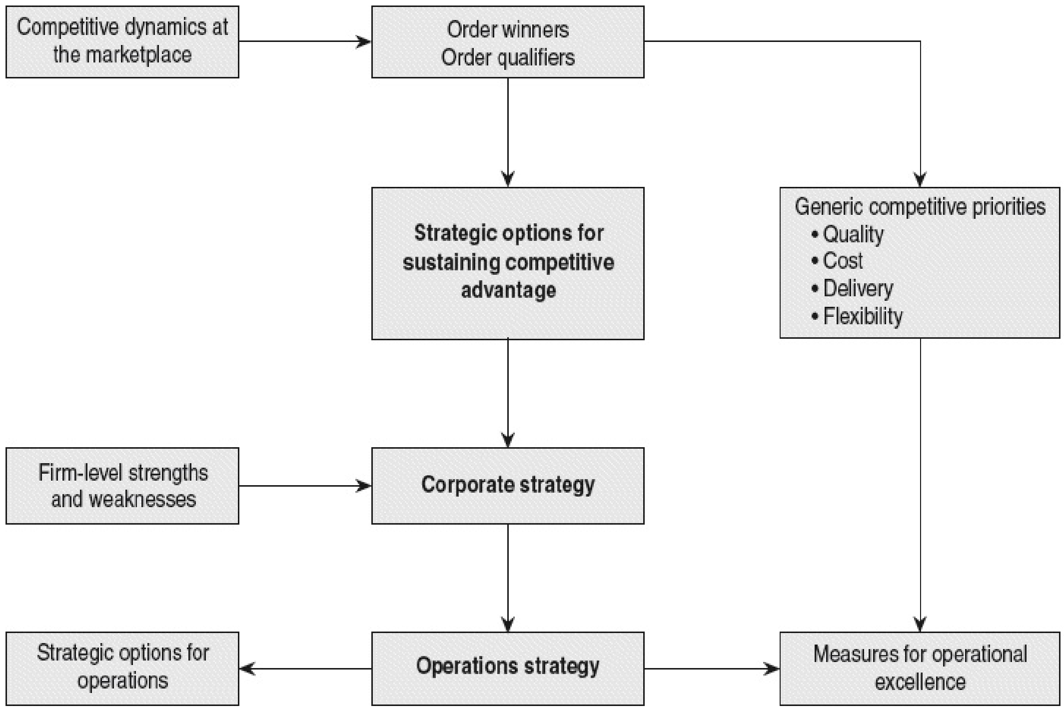
2.2 THE STRATEGY-FORMULATION PROCESS

The process of formulating an appropriate operations strategy involves a sequential and structured set of activities. Figure 2.1 depicts the various steps in the process. These can be grouped into three broad steps. The first step is to identify the strategic options for sustaining competitive advantage. Once these options have been identified, the overall corporate strategy can be devised on the basis of firm-level strengths and weaknesses. The corporate strategy provides the basis for arriving at the appropriate operations strategy for the organization.

As shown in the figure, the strategy-formulation process can also be understood in terms of a series of detailed steps, which include:

1. understanding the competitive dynamics at the marketplace,
2. identifying order-winning and order-qualifying attributes,
3. deciding on strategic options for sustaining competitive advantage,
4. matching the strategic options with the resources, constraints, values, and objectives of the organization to arrive at the overall corporate strategy,
5. developing the operations strategy on the basis of the corporate strategy, and;
6. using the operations strategy to select appropriate options for configuring an operations system and establishing relevant measures for operational excellence.

FIGURE 2.1 The strategy-formulation process



Step 1: Understand the Competitive Market Dynamics

Any strategy-making exercise begins with scanning the marketplace and understanding its dynamics. Market dynamics direct the organization toward the issues it should consider while formulating its operations strategy. It provides useful information on competitors, the nature of offerings that they make to the customer, customer expectations, missing links between expectations and current offerings, and the intensity of competition. An analysis of this information will enable an organization to identify which aspects of its products and services can provide it a unique positioning and a competitive advantage over its competitors. Tata Motors' positioning of the Nano in the ₹100,000 range is an illustration of how organizations use such information to arrive at their operations strategy. A similar example in the services sector is the positioning of Café Coffee Day. Their outlets are positioned as cafes that provide "affordable" luxury, and seek to satisfy the needs of a demographic segment that comprises young employees and college-goers.

In the previous section, we discussed the liberalization process and saw how the current level of expectations has changed in several industry sectors. Under normal circumstances, customers may have several expectations besides price, such as performance, quality, ease of use, delivery commitments, technological superiority of products, and critical post-sales support. Customer expectations keep changing with time. Technological improvements and evolution of markets and infrastructure may cause a shift in customer expectations about a product or a service. The demographic profile of the customer base may also shift over the years. Moreover, customers may be exposed to newer choices either by a smart competitor or due to the entry of foreign firms into the market. Therefore, it is important for organizations to prioritize their alternatives and understand what is likely to have a greater impact in the market. Customer expectations and the competitive priorities that an organization needs to pursue could be better understood using the notion of order-winning and order-qualifying attributes.

Step 2: Identify Order-qualifying and Order-winning Attributes

Order-qualifying attributes are the set of attributes that customers expect in the product or service they consider for purchase. The absence of any of these attributes will result in the customer removing the product or service from his or her list of items under consideration. The mere presence of these attributes, however, does not guarantee that the customer will buy the product. It only indicates the minimum or threshold level of requirements for considering the product.

> **Order-qualifying attributes** are the attributes that customers expect in the product or service they consider for buying.

There are other attributes that have the potential to sufficiently motivate the customer to buy the product. Such attributes are known as **order-winning attributes**. The perception of the customer is that the presence of these attributes indicates to him or her that the product/service under consideration surpasses the basic requirements and, therefore, has the potential to provide better value for money. The presence of order-winning attributes in a product/service helps the customer differentiate it from the competitors' offerings. It also favourably influences the customers' buying decision with respect to the product/service. The more the number of such attributes that a customer perceives in a product/service, the greater is the chance that the customer may buy the product/service.

> **Order-winning attributes** are attributes that have the potential to sufficiently motivate the customer to buy the product.

What constitutes order-winning and order-qualifying attributes might change from time to time. During the early and mid-1980s, superior quality was an order-winning attribute for several multinational organizations. Therefore, they invested much of their strategic planning and implementation efforts towards developing quality-management systems. However, in the 1990s, quality became an order-qualifying attribute as customers began to expect high levels of quality in products/services. Moreover, several competitors were able to match customer expectations with respect to quality. The next order-winning attribute was high delivery reliability. Organizations developed just-in-time practices to addresses the issue of delivery. Other order-winning attributes that have evolved over time include efficient consumer response, speed, variety, and convenience.

Step 3: Identify Strategic Options for Sustaining Competitive Advantage

After an analysis of the competitive dynamics, an organization will be in a position to identify the order-winning and order-qualifying attributes for the products/services that it offers. At the end of the exercise, the order-winning and order-qualifying attributes provide the organization with a set of options for sustaining competitive advantage. Competition analysis may indicate that the organization will do better by providing high-quality goods, or that a wider variety of options will bring success. It could also indicate convenience in usage in some cases. Such an exercise often points to more than one possible attribute for order winning. These attributes also help an organization develop appropriate operational measures of excellence.

Step 4: Devise the Overall Corporate Strategy

Organizations may not be in a position to make use of all the strategic options available to them. This is because they face constraints in operating with the resources available to them. For instance, the top management may have certain preferences and views on how desirable the options are from an internal perspective. Moreover, the organization’s culture and values may not permit it to exploit the available options fully. Therefore, the next critical step is to match the strategic options available for sustaining the competitive advantage with the available resources and constraints and to develop an appropriate strategic plan that fulfils the organization’s objectives, taking into consideration its strengths and weaknesses. The outcome of this exercise is the *overall corporate strategy*.

Step 5: Arrive at the Operations Strategy

Once the corporate strategy is arrived at, it serves as the basis for the operations strategy. For instance, if the overall strategy of an organization is to provide low-cost goods, then the choices made in operations will be consistent with this overall strategy. For example, large capacities will be built to exploit scale economies. Procurement and supply-chain functions will develop appropriate methods for locating low-cost, high-quality suppliers and devise systems for continuous cost reduction of input material. Planning and control will emphasize on continuous cost improvement, productivity maximization, and cost control and management. Product portfolio decisions will de-emphasize variety and instead design systems with fewer variations. The organization will benefit from large-volume. Process design will reflect choices such as continuous flow, mass production system and self service so that operations can be delivered at lower fixed costs. Simultaneously, appropriate control systems and performance measures for operational excellence will be developed so that these are consistent with the strategy of cost minimization.

The outcome of the operations strategy formulation process is Step 6, the development of measures for operational excellence and the selection of specific options for configuring the operations system, as illustrated in Figure 2.1. In order to configure an effective operations system, knowledge of the alternatives available for operations systems and measures of excellence is imperative. Some of these alternatives are described in the following sections.

2.3 MEASURES FOR OPERATIONAL EXCELLENCE

The operations-strategy exercise is inextricably linked to developing measures for operational excellence. Such measures serve several purposes in the operations-strategy process. **Operational-excellence measures** provide the critical linkage between order-winning and order-qualifying attributes identified through the strategic planning exercise and the choices made in the operations. Developing a set of measures pertaining to each attribute helps organizations to evaluate how well the operations system is responding to the requirements of the marketplace. Based on this evaluation, necessary changes can be made to the operations system to align the activities with the strategic goals, should there be a mismatch or underperformance of the operations system.

Operational-excellence measures provide the critical linkage between order-winning and order-qualifying attributes identified through the strategic planning exercise and the choices made in the operations.

VIDEO INSIGHTS 2.1

A good operations strategy invariably takes an organization towards operational excellence. To know more about how forms can traverse through the path of operational excellence, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

In order to understand the important role of operational-excellence measures in the strategic planning process, let us look at an example of some operational measures. Table 2.1 provides an interesting comparison between Japan's Toyota and the United States' General Motors (GM), and brings out the superiority of Toyota's production system over GM's production system. Toyota's production of vehicles during 1987 was half of the production of GM. For a factor of two in the production volume, we notice that there was a factor of nearly 23 in the number of employees in GM compared to Toyota, and a factor of nearly 18 in the number of people in purchasing. It is also evident that while GM did most of the detailed engineering in-house, Toyota outsourced 70 per cent of the engineering activity to its suppliers. GM took nearly double the time (in hours) taken by Toyota to design and deliver a new car to the customer. Clearly, such differences in operational measures are indicative of the varied overall strategic goals these two firms were pursuing at that time.[2]

TABLE 2.1 Comparison of Operations on the Basis of Some Operational Measures

Performance Parameters (1987)	Toyota Japan	General Motors, U.S.
Production of vehicles (million)	4	8
Number of employees	37,000	850,000
Parts on which detailed engineering is done (%)	30	81
Number of employees in purchasing	337	6000

Number of suppliers for upholstery	1*	25**
Design to customer delivery time (million hours)	1.7	3
Design to customer delivery time (months)	46	60

Notes: *Single supplier; **25 Suppliers were supplying components to the seat-building department.

Source: J. P. Womack, D. T. Jones, and D. Roos, The Machine That Changed the World (New York: Rawson Associates, 1990).

ideas at Work 2.2

Measures for Operational excellence: the Case of Indigo Airlines

Airlines sector is going through several challenges ranging from huge capital costs, low utilization, rising fuel costs, and customer dissatisfaction on account of delays. As a result, all the major Indian airline companies are struggling to make profits. While other airlines are struggling, Indigo seems to the thriving. In airlines sector, measures for timeliness, cost, and resource productivity are important. A closer look at some of the performance measures that Indigo utilizes may partly provide some answers to this puzzle.

In Indigo, check-in staff also doubles as a baggage handler, thereby improving the responsiveness for the arriving customers at the check-in counters. Such operational practices are very important to handle peak hour demand. For example, 2800 passengers check into about 16 flights leaving Delhi before 8 am every day. Another measure pertains to baggage clearance. By the time the passengers deplane and reach the baggage carousels, the first consignment of bags must have already arrived. The number of baggage handlers deployed is a function of this measure of performance. In the case of Indigo, four handlers stack bags in hold to save space and time. The number of employees per aircraft is a measure of operational productivity. Indigo has 96 employees per aircraft compared to 250 of Air India. Huge capital cost of the airplane requires measures to ensure better utilization. In the case of Indigo, the ground crew takes about 20 minutes to prepare the aircraft for the next flight. This ensures that Indigo planes fly about 12 hours a day.

Source: V. Mehra, “Soaring above the rest”, *Business Today*, June 24, 2012, pp. 84–92.

The example we just discussed points to some interesting aspects of performance measures. First, it shows that performance measures serve a very useful purpose in benchmarking with the competitors. Second, the operational measures pertain to specific aspects of operations management. For example, measures such as return to normal quality after new-model introduction and average development time reflect the flexibility and delivery aspects of an organization. Measures such as number of suggestions (for improvement) pertain to quality. Clearly, there is a generic set of options that an organization would pursue as its competitive priority. For every such option, several operational measures could be used to assess the performance of the operations and to ensure that they are consistent with the organization's strategic objectives.

Four generic options are generally found to be useful in any operations-strategy exercise. These include **quality, cost, delivery**, and **flexibility**. In a strategic planning exercise, organizations identify one or more of these as their competitive priorities. If, for instance, the strategic exercise of an organization indicates the need to provide faster and more reliable delivery of products and services to customers, the operational measures of excellence must be able to capture the performance of the operations system with respect to reliability and speed of response. Therefore, measures of excellence should be appropriate and case specific, pertaining to lead time, schedule adherence, and on-time delivery. Table 2.2 presents a sample list of operational measures. These measures are not exhaustive or prescriptive. The list merely indicates some possible suggestions, as found in practice. In reality, organizations come up with their own set of measures consistent with their strategic goals.

> Four generic options are generally found to be useful for any operations-strategy exercise: quality, cost, delivery, and flexibility.

Five sets of measures are given in Table 2.2. The first four—quality, cost, delivery, and flexibility—pertain to measures for assessing each generic option. All these measures are operational in nature and often do not translate into financial numbers found in annual reports. On the contrary, these measures capture the performance of an operations system in each of these categories. For example, the value of import substitution and target-cost reduction exercises directly measure the operational aspects of cost reduction.

While the first four measures directly pertain to the four generic categories of competitive priorities for any organization, the last set consists of measures that indirectly affect any of the four measures. These measures are used by several organizations in improving their competitive advantage. They draw attention towards areas requiring improvement, which would have otherwise been ignored. Take, for example, the measure of indirect labour to direct labour ratio. As the ratio increases, it points to more indirect workers in the organization. More indirect workers may often point to high levels of supervision and more effort in managerial planning and operational control. Such an increase in activity invariably increases the lead time of several processes. Further, it also adds to the overall cost. The number of certified deliveries indicates how many vendors have been certified While the first four measures directly pertain to the four generic categories of competitive priorities for any organization, the last set consists of measures that indirectly affect any of the four measures. These measures are used by several organizations in improving their competitive advantage. They draw attention towards areas requiring improvement, which would have otherwise been ignored. Take, for example, the measure of indirect labour to direct labour ratio. As the ratio increases, it points to more indirect workers in the organization. More indirect workers may often point to high levels of supervision and more effort in managerial planning and operational control. Such an increase in activity invariably increases the lead time of several processes. Further, it also adds to the overall cost. The number of certified deliveries indicates how many vendors have been certified to supply without inward goods inspection procedures. As this number increases, the procurement costs will come down and the quality will also improve, because the suppliers would have passed through stringent quality requirements before qualifying.

TABLE 2.2 A Sample List of Operational Measures

Direct Measures	
Quality	**Cost**
First-pass yield	Average days of inventory (number of inventory turns)
Quality costs	Manufacturing cost as percentage of sales
Defects per million opportunities	Procurement costs, total cost of ownership
Number of suggestions per employee	Value of import substitution, cost reduction
Process capability indices	Target cost reduction efforts
Delivery	**Flexibility**
Lead time for order fulfillment and service delivery	Number of models introduced
Procurement and manufacturing lead time	New-product development time
On-time delivery for supplies	Breadth and depth of the product and service offerings
Schedule adherence	Process flexibility
Indirect Measures	
Indirect-labour to direct-labour ratio	Number of suggestions per employee
Ratio of lead time to work content	Non-value-added content in processes
Process-rate to sales-rate ratio	Number of certified deliveries
Average training time per employee	Delivery quote for customized products and services

2.4 OPTIONS FOR STRATEGIC DECISIONS IN OPERATIONS

Translating the corporate strategy into the operations strategy essentially involves making choices in the design and operational control of the operations system. The choices are made in such a fashion that the options are consistent with the overall strategic objectives of the organization. Figure 2.2 depicts the options available for strategic decisions in operations management. The product portfolio addresses the core issues of the type of products to offer through the operating system as well as the breadth of each offering. Similarly, technology, capacity, supply chain, and process options enable an organization to make appropriate choices in the respective domains.

Product Portfolio

One of the strategic choices that an organization can make is with respect to its product portfolio. By **product portfolio**, we mean decisions regarding the products that the organization wants to produce, the number of variations in each product line, and the extent of customization that it can offer to its customers. In reality, organizations operating in the same sector and offering similar products/services differ widely with respect to the range of choices in their offerings to customers. This is a reflection of their overall strategic objective. A few examples will help us understand this concept better.

FIGURE 2.2 Options for strategic decisions in operations

Let us consider air travel from Bangalore to Delhi. IndiGo and Jet Airways offer similar services for passengers, but differ vastly in terms of the services offered. Jet Airways is a full-service airline that provides business- and economy-class travel facilities. In addition, it offers free air miles accrued through a frequent-flier scheme. IndiGo, on the other hand, offers just economy-class tickets. There are wide differences in the in-flight services offered by the two airlines. While Jet Airways begins a journey by serving a glass of soft drink to its customers and follows it with appetizers, a meal, coffee, tea, and mineral water (in unlimited quantities), in the case of IndiGo, nothing is available free of cost. A limited choice of snacks and meals is available against payment. At the outset, it may appear as though Jet Airways' offer is more attractive. However, a closer analysis will show that the two airlines pursue different strategic objectives and, therefore, have different competitive priorities and customer segments to cater to. IndiGo's priority is one of low operational costs while that of Jet Airways is of high-quality service.

A similar example of how the product portfolio varies with the overall strategic objective can be seen in the varied range of restaurants in metropolitan cities such as Mumbai. Restaurants ranging from small self-service eating joints to multi-cuisine restaurants with a host of well-trained waiters and huge dining spaces span the entire range of product/service port-folio options. These options are related to the overall strategic intent of each organization.

Several such examples exist in the manufacturing industry as well. Consider Dell and Lenovo, two well-known computer manufacturers. The overall strategic objective of Dell appears to be one of providing highly differentiated products, whereas Lenovo appears to emphasize robust and reliable computing power. Therefore, the product portfolio choices for these two manufacturers are different.

> **The product portfolio** of an organization refers to decisions on what products the organization wants to produce, the number of variations in each product line, and the extent of customization it can offer to its customers.

These examples demonstrate the role of a product portfolio in fulfilling the desired strategic objectives of an organization. If the overall strategic objective is to provide a highly differentiated set of products and services to the customer, it is possible to achieve this by offering product/service customization. On the other hand, if the overall objective is one of cost leadership, then the product portfolio tends to be narrow.

For an organization desiring to provide a wide product portfolio to its customers, flexibility will be the most important competitive priority. Several aspects of operations management will be configured to meet this objective. Operational control systems and performance measures will be chosen in such a manner that they emphasize flexibility over other criteria such as cost and delivery. The organization should develop an efficient and responsive new- product development process that can respond to the changing requirements at the marketplace with newer versions of the product.

Process Design

Appropriate choice of processes is another option through which an organization can translate its strategic objectives to operations. *Process design* refers to the overall configuration of the operations system in such a way that the various activities are consistent with the process choice. Viewed alternatively, process choices influence the nature of material and information flow in an organization. At a broad level, three types of flow happen on account of process choices: *continuous streamlined flow, intermittent or batch flow, and jumbled flow*. The choice of process technology will be consistent with that of the product portfolio decisions that an organization makes.

> Process choices lead to three types of flows: continuous streamlined flow, intermittent or batch flow, and jumbled flow.

Consider a volume manufacturer such as Hero MotorCorp. Ltd. (HML) and a variety manufacturer such as Bharat Heavy Electricals Limited (BHEL). The process choices of these two manufacturers are vastly different and are in line with their overall objectives. The overall objective of HML can be stated as providing a variety of high-performance motorbikes at reasonable prices. BHEL’s overall objective is to fulfil complex and huge turnkey engineering contracts in the power sector on time. A manufacturer emphasizing high production volumes, fewer varieties, and low cost (HML in our example) will make process choices that are appropriate for this requirement. In operations management, a mass or a batch production system is appropriate for such manufacturers. In the case of BHEL, on the other hand, the process choice will be influenced by the need to have a wide variety and a large production volume of a single or a few units. Project shops and functional layouts are some appropriate processes for BHEL. Similar examples could be found in services as well. A banking service for a high networth individual (Such as SBI Kohinoor Barjara Branch) will have a process design which is different from the regular branches of State Bank of India[3].

An organization working towards the objective of providing a wide range of products to its customers will have to make a process choice that is more of the batch/intermittent flow type. The production planning and control systems, scheduling, and the procurement practices will all be influenced by the flow system an organization chooses to adopt. Some of these issues are discussed in greater detail in Chapter 4.

Supply Chain

A manufacturer of goods relies on other business organizations for raw materials and components required in the manufacturing process. It also depends on other business entities to supply its finished goods to the end customers through a market. The **supply chain** is the network of entities supplying components, raw materials, and a host of services to the organization as well as those distributing the finished goods and services to customers through alternative channels. Organizations need to make appropriate supply-chain choices consistent with their strategic objectives.

> The **supply chain** is the network of entities supplying components, raw materials, and a host of services to an organization as well as those distributing the finished goods and services of the organization to its customers through alternative channels.

Recent studies have shown that fundamentally two types of supply chains can be configured—an efficient supply chain and a responsive supply chain. As the name suggests, an *efficient supply chain* is designed with the main objective of pursuing efficiency goals with respect to supply-chain operations. Essentially, this translates into cost optimization and maximum utilization of the resources employed in supply-chain operations. In the case of a *responsive supply chain*, the key objective is to develop a capability to respond fast to market requirements. To design an appropriate supply chain, it is imperative to have a good understanding of the product profile for which the supply chain is configured. The product profile is the result of the product–portfolio decisions made as part of the operations strategy.

Let us consider the design of a supply chain for the distribution of Annapurna atta (flour) and salt. Salt and flour are functional products. Functional products are characterized by stable demand patterns, little or no change in consumption patterns, and a reasonable level of predictability of demand. Moreover, customers are not likely to pay a significantly higher price because of some special aspect in the distribution of the product or the service. There are no fashion and fad elements in these products, based on which a price premium could be extracted from customers. Under these conditions, cost minimization and efficiency goals will be the strategic requirement, and the supply chain should be configured accordingly.

The strategic requirements for some products are in sharp contrast to those for functional products. For instance, consider products such as Tanishq watches and jewellery offered by Titan. These products are trendy, expensive, and sensitive to fashion fads. There is also a need for creating greater variety and more designs to satisfy diverse tastes and preferences. As the demand for such goods is difficult to predict, the organization has very little lead time to react to changing patterns and customer preferences in the market. This category of products is known as *innovative products*. The supply chain for such products should be designed with the basic objective of providing a high level of responsiveness. The two examples discussed here demonstrate the need for configuring the outbound supply chain (dealers, distributors, retailers, etc.), in the case of *consumer goods,* in tandem with the choice of the product portfolio and the overall strategic objectives of the firm.

In the case of industrial goods, too, the design of supply chains should be consistent with the strategic objectives of the organization. This is true for the design of inbound supply chains (raw material and component suppliers) as well. We shall now look at two more examples to understand the design of supply chains in the case of industrial goods. The first is the requirement of raw materials such as steel plates and rods for the manufacture of components by a manufacturer of gearboxes for automobiles. In this case, the product falls neatly into the description of a functional product. Therefore, the organization needs to configure its supply chain for the raw materials on the basis of efficiency. Let us consider another product—a digital control system for remotely monitoring various parameters and thereby controlling the operations of a steel-making machine. Due to several new developments in electronics and processor speed and capabilities, the product is likely to be subjected to frequent changes in design and enhancements. It should have a supply chain that is able to bring in new enhancements in the control system as and when they happen in the market and help in making product upgrades more frequently. In this case, the organization is handling an innovative product and should be able to configure a responsive supply chain for the control system.

Efficient supply chains are designed with the central objective of overall supply-chain cost minimization and better asset utilization. Organizations need to incorporate several features in their supply chain to achieve this objective. The design of a responsive supply chain, on the other hand, begins with the basic premise that uncertainty in demand and large forecast errors are often the reality. Therefore, the supply chain requires certain strategies to address these issues. Further, developing systems to improve responsiveness is another objective of the design. Our intention here is to merely show how the design of the supply chain will be influenced by the overall strategic objectives of the organization. In Chapter 5, we shall return to the question of supply-chain design and provide some more details on the different methods organizations adopt to design efficient and responsive supply chains.

An efficient supply chain is designed with the main objective of overall supply-chain cost minimization and better asset utilization.

Technology

Technological advancements in recent years have offered new opportunities for creating competitive advantage. Recall how Asian Paints first utilized technological advancements for mixing basic pigments to distribute paints in a large variety of colours and a large assortment of sizes. Organizations making a strategic choice to operate in the mid-volume, mid-variety products and services could utilize new technology such as flexible manufacturing systems and computer-integrated manufacturing to improve productivity and to respond faster to the market. Technology can provide unique advantages to organizations in providing better products and services to customers. Prominent among these are the following:

- *Increased resource utilization*: Computer-based operation of systems has enabled high resource utilization in systems.
- *Scheduling flexibility*: Technology often enhances flexibility in scheduling various customer orders as it enables organizations to react to changes swiftly. Therefore, organizations can use technology to provide better customer service.
- *Ease of changes*: Changes in design and process plans can be easily accommodated through the use of technology. Further, complex operations can be handled without much difficulty and the desired quality levels can be achieved.
- *Ease of expansion*: Technology also provides volume flexibility to the organization and makes it much easier to expand in response to a growing market.
- *Reduced lead time*: Advanced technological features make it possible to cut down lead time.
- *Lower in-process inventory*: Several of the benefits discussed here directly translate to lower work-in-process inventory and reduced cost.

VIDEO INSIGHTS 2.2

To be competitive in manufacturing, firms need to imbibe good manufacturing practices, implement robust quality systems, and invest in new technology solutions for manufacturing and quality control. Auma India’s Bangalore facility demonstrates the use of some of these elements to build competitiveness. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

It is evident that by using new technology options for processes, organizations can react faster to customer needs, manage a wide portfolio of product offerings, and yet maintain high levels of productivity. Therefore, process technology is considered to be a potential enabler of operations strategy in organizations. In some cases, the use of radically new technologies results in high depreciation and operating costs. However, if the strategic intent is to provide high levels of responsiveness to customers, it may be possible to recover these costs by passing them on to the customer by way of a premium for the additional value provided in comparison to the competition.

Capacity

Capacity refers to the maximum number of units of goods that can be produced per unit of time in a manufacturing system. In a service system, it refers to the maximum number of service offerings that can be made per of unit time. For example, when a two-wheeler manufacturer reports that it has an installed capacity of 20,000 vehicles per day, it merely indicates the maximum number of two-wheelers it can produce in a day. Similarly, if an inter-city bus operator says that its capacity is 500 passengers per day, it points to the limit of its service. Capacity decisions in operations have an important strategic dimension as they directly and significantly influence the cost of goods and services offered in three ways. First, there is an accrued cost advantage due to economies of scale. Economy of scale is an economic principle that illustrates the relationship between the cost of the goods produced by a system and the appropriate levels of capacity built into the system. According to this principle, as a firm grows and production units increase, it will have a better chance to decrease its costs. A firm can thus benefit from lower total costs by operating at a predetermined level.

> In a manufacturing system, **capacity** is the maximum number of units of goods that can be produced per unit of time. In a service system, the term capacity refers to the maximum number of service offerings that can be made per unit of time.

The second aspect of cost advantage comes from cost accounting principles pertaining to marginal costs and contribution. The cost of goods and services produced is a function of the fixed and variable costs of the operating system. Every organization has three major types of investments in fixed costs. They are: (1) asset costs arising out of investment in machinery and buildings; (2) manpower costs of the supervisory and managerial workforce; and (3) facilities maintenance costs to sustain several support facilities. By increasing the productive capacity (and consequently the sales), it is possible to spread these fixed costs over a larger base of activities and thereby achieve lower costs and greater contribution.

The third benefit arising from large capacity investments is that it provides additional cost advantages in procuring other factors of production. Large capacity implies a large production base and large amounts of procurement of key raw materials and other resources. Large volume provides bargaining power in the market. Furthermore, the firm will be in a position to influence key trends in the industry and to channelize the development efforts of its suppliers and collaborators to its overall benefit in the long run. Let us consider an example to understand how this is possible. Reliance Industries Limited is one of the largest petrochemical manufacturers in the world. Many of the finished products of Reliance, such as petrol and LPG, are stored in tanks and transported through tankers to various distribution points. A large number of tankers is required at the Jamnagar facility and the Hazira facility near Surat. Typically, the daily requirements are in the range of 3000 trucks. The large scale of operation enables Reliance to negotiate better rates for trucking services.

2.5 BREAK-EVEN ANALYSIS

Break-even analysis is a related concept that links capacity to costs. It explains the significance of having greater productive capacity to lower costs and maximize profits or contribution. Let us use the following notations to understand the concept of break-even:

F = Fixed costs of production
v = Variable cost of production of one unit
p = Selling price of one unit of the product
c = Contribution of one unit of product towards fixed costs
S = Sales volume (in terms of number of units)
BEP_{Sales} = Sales volume required to achieve break even

It is obvious that as every individual unit sells at a price p and has incurred a variable cost of v, the difference between the two is the excess over the variable cost that could cover the fixed costs. This quantity is known as the *contribution margin* (c), and can be represented by the following equation:

$$c = p - v$$

The **break-even point** is the point at which the contribution margin is able to cover the total fixed costs. Therefore, at the break-even point, the organization will have a no-profit, no-loss situation, but would have covered all the fixed costs invested in the system.*Break-even sales* refers to the number of units to be sold at the break-even point. The break-even point and break-even sales can be expressed as follows:

$$BEP_{Sales} = \frac{F}{c}$$

The **break-even point** is the point at which the contribution margin is able to cover the total fixed costs.

It is clear from the discussion on break-even analysis that as an organization's cumulative production exceeds the break-even point, it will provide significant cost benefits to the organization as after that, the fixed costs need not be covered any more. Larger capacity utilization will invariably provide cost advantages to the organization.

EXAMPLE 2.1

A company manufactures ball-point pens that it is able to sell at ₹15 per piece. The variable cost of the pen is ₹10 per unit. If the company has made a total investment in fixed costs to the tune of ₹30,000, what is the break-even sales for the pen? Graphically represent the cost structure and the break-even point.

Solution

F = Fixed costs of production = ₹30,000
v = Variable cost of production of one unit of the pen = ₹10
p = Selling price of one unit of the pen = ₹15

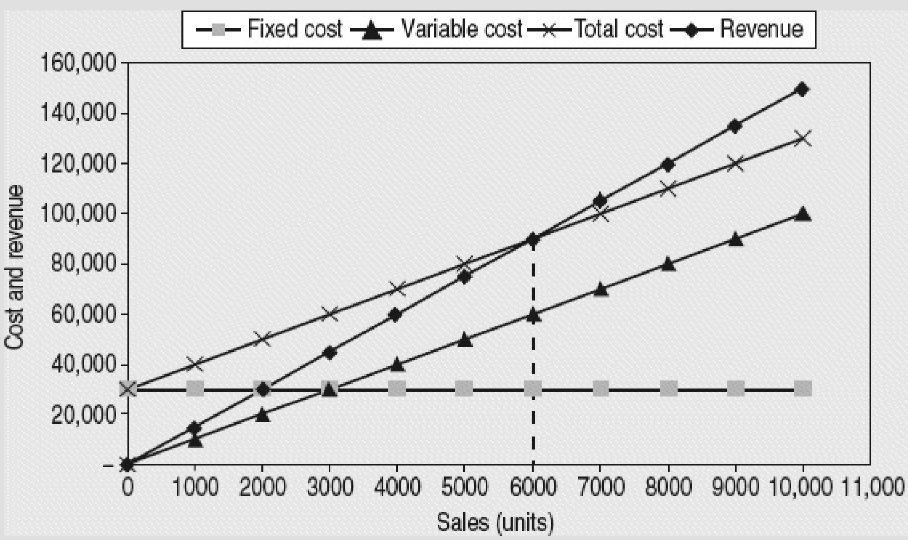
Therefore, contribution of one unit of the pen towards the fixed costs (c) can be calculated as follows:

$$c = p - v = ₹15 - ₹10 - ₹5$$

$$BEP_{Sales} = \frac{F}{c} = \frac{30,000}{5} = 6000 \text{ units}$$

As seen in Figure 2.3, the point of intersection of the total cost and the revenue curve is the break-even point, and the corresponding sales are the break-even sales.

FIGURE 2.3 Graphical representation of the break-even point



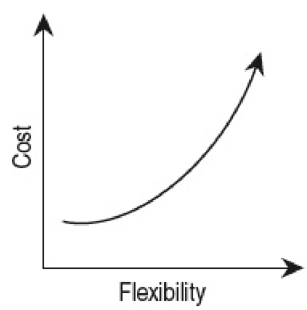
2.6 THE COST VERSUS FLEXIBILITY TRADE-OFF IN OPERATIONS STRATEGY

From our discussions on the various options available for operations strategy, it is evident that the cost and *flexibility* dimensions compete with each other. Flexibility would mean more options in product variety and process design, which may not allow the organization to exploit the benefits of volume. Therefore, capacity costs may have to be spread over smaller volumes of several varieties. Further, the organization may need a responsive supply chain. Forecasting errors could be high, resulting in non-moving inventory and wastages. All these choices tend to increase the cost of the products. In contrast, providing less flexibility would mean fewer product varieties. Organizations pursuing such an objective will be able to pursue cost-reduction goals very well through the various strategic options available for configuring their operations. Fewer varieties of products will enable the organization to build large capacities, have a streamlined flow process, and configure an efficient supply chain.

> *Flexibility* and cost are competing dimensions in operations strategy.

Figure 2.4 shows the relationship between flexibility and cost dimensions in operations strategy. As shown in the figure as flexibility increases, the cost is also likely to increase. There are two options left to an organization to handle situations arising out of increased flexibility. One is to pass on the costs to the customers as a premium. Generally, as flexibility increases, the perceived value of the product also increases and customers do not complain about paying a premium for flexibility. The other option is to develop procedures in the operating system to overcome such trade-off obstacles in comparison with those of their competitors. World-class manufacturing concepts enable organizations to pursue this option.

FIGURE 2.4 Flexibility versus cost: competing dimensions



2.7 WORLD-CLASS MANUFACTURING PRACTICES

Management practices in manufacturing have undergone significant evolution during the course of the twentieth century. The culmination of these is the guiding principles of excellence in manufacturing, known as *world-class manufacturing (WCM)*.[4] We have already seen in the previous sections how quality, cost, delivery, and flexibility are important components of the operational excellence of any organization. There is one crucial difference between world-class manufacturing organizations and others. The latter category of organizations constantly faces *trade-off obstacles* in meeting the desired levels in the competitive priorities. For example, a firm may perform very well in quality parameters but not so well when it comes to the other three parameters. For such firms, providing high-quality goods and services would mean increased cost due to tighter and closer quality control and management and perhaps an increase in the lead time, thereby resulting in poor performance in delivery. In some other cases, organizations might have overcome the cost-versus-quality trade-offs, but not the other two, that is, flexibility and delivery.

> A world-class manufacturing organization excels in all the four generic competitive priorities— quality, cost, delivery, and flexibility—by overcoming all tradeoff obstacles.

World-class manufacturing organizations, in contrast, will be able to perform very well in all the four parameters at the same time and meet the desired goals in each of these. Overcoming trade-off obstacles requires substantial investment in systems and procedures that enable organizations to build this capability. Such investments are made in almost all functions of operations management and considerable time is required to stabilize the system.

Toyota's Journey as a World-class Manufacturer

A look at the evolution of the Toyota production system (TPS) provides a good understanding of how organizations transform into world-class manufacturers. The earliest investments in the TPS were mostly in the area of quality. A vast body of knowledge, tools and techniques, and special procedures were developed to effectively address the quality–cost trade-off. These can be collectively called the philosophy of total *quality management (TQM)*.

The second area of concern was delivery reliability. Therefore, the required investment was made to address this aspect and appropriate tools and techniques were developed for this purpose. These included lead-time and lot-size reduction methods, new planning and scheduling methodologies using what is known as a "pull-based" system, systematic methods for waste elimination from the system, alternative methods for sourcing and supply management, and dramatic improvements in resource availability by making the required changes in the maintenance systems. These tools and techniques can be broadly grouped under the *just-in-time (JIT) philosophy*.

The third area of concern was that of achieving flexibility without jeopardizing quality and cost. While some of the principles of JIT, such as lot-size reduction, had already enhanced the capability to handle variety, some more tools were developed. Notable among these was the *mixed-model line assembly*, a scheduling method in which every unit manufactured (or assembled) can be different from the previous one. The other area where new tools were developed was the area of new-product development. Active and direct involvement of suppliers in the product-development process was encouraged. All these systems, tools, and procedures were developed and perfected over a span of more than 20 years. Moreover, these new methodologies emphasized the crucial role of employees at all levels and the leadership and involvement of top management. Thus, several areas of operations management were addressed to overcome the trade-off obstacles.

Principles of World-class Manufacturing

World-class manufacturing, share some common principles that can be collectively referred to as the principles of WCM:

- Just-in-time (JIT) systems

- Total quality management (TQM)
- Total productive management (TPM)
- Employee involvement
- Simplicity

Here, we shall discuss these principles briefly. These concepts are dealt with in detail in other chapters.[5]

Just-in-time (JIT) systems

In simple terms, the core philosophy of **JIT systems** is to provide an organizational framework that continuously reveals opportunities for the elimination of non-value-added activities. If, due to poor design of the factory layout, components travel a few kilometres before being converted into saleable products, customers may not be interested in paying for the excess transportation. Therefore, in the long run, organizations need to eliminate such wasteful activities in order to be world class. Similarly, in the case of a service system such as a housing-loan approval system, the existing procedure may call for unnecessary and redundant information from the customer and many internal departments. Such a system will result in delays in processing; the introduction of errors in processing, data integration, and reconciliation efforts; and a host of other problems that waste precious managerial effort and time. It is obvious that by eliminating such unwanted activities, a substantial reduction in time can be achieved. Moreover, it will also result in the efficient use of resources, leading to lower costs. Due to its emphasis on waste elimination and its relentless pursuit of the same, JIT is also known as a *zero-inventory system*.

> The core philosophy of **JIT systems** is to provide an organizational framework to continuously reveal opportunities for the elimination of non-value-added activities.

Total quality management (TQM)

An organizational framework to expose wasteful activities alone is not sufficient. It should be complemented by an equally effective organizational framework for continuously eliminating them. Therefore, world-class manufacturing organizations equip themselves with this feature through the use of **total quality management (TQM) philosophy**. The TQM philosophy helps to achieve this purpose by organizing the entire workforce into small improvement groups and creating a mindset for continuous improvement. As the JIT system in an organization exposes new areas for waste elimination, the TQM system uses the improvement methodologies to either eliminate the problems altogether or to minimize them. An organization following TQM principles will be in a position to overcome the quality-versus-cost trade-off.

> **Total quality management (TQM) philosophy** helps an organization in organizing the entire workforce into small improvement groups and in creating a mindset for continuous improvement.

Total productive maintenance (TPM)

The third distinguishing feature of world-class manufacturing is the use of TPM. Contrary to the traditional belief that maintenance has to be done only by “qualified” maintenance crews, world-class manufacturing companies have realized that transferring some of the routine maintenance tasks to the workers themselves offers numerous benefits. This gives the direct workers a sense of ownership of the process they work on, and they become aware of the problems associated with improper usage or misuse of their facilities. It helps an organization maintain equipment so regularly and so thoroughly that it hardly ever breaks down or malfunctions during a production run. Prolonged use of TPM methodology in the organization ensures a high degree of predictability of resource availability as breakdowns are almost eliminated. TPM therefore helps organizations to overcome the trade-off associated with delivery.

Employee involvement

In order to put the three systems discussed so far in place, it is necessary to break away from the rigid classification of labour that is characteristic of traditional manufacturers. In organizations that use JIT, TQM, and TPM, production workers may perform some maintenance tasks. Alternatively, another group of employees may work on some improvement projects. The group may have to be allowed to perform their own quality checks, and a certain degree of autonomy may have to be granted for the scheduling and planning of their production tasks. All these changes may appear to be unconventional for a traditional manufacturing system. Functional managers and production supervisors may have a feeling of losing control. Personnel managers may not like these new arrangements as they may have to negotiate with the workers’ union to change some of the work practices. It may pose problems for the cost accountant because he/she may not know how to allocate the labour cost between the direct and the indirect components that a worker performs in the new set-up. Alternatively, the cost accountant may wonder how to define direct labour. Despite these hiccups, the experience of world-class manufacturing organizations suggests that the net effect of such changes is a substantial gain for the organization. These new changes in working patterns are defined as *employee involvement*.

Simplicity

The last feature that is peculiar to WCM organizations is the simplicity with which they function. The best examples of simplicity can be seen in the Toyota production system. The introduction of JIT, TQM, TPM, the *kanban* system, fail-proofing systems (such as *poka yoke* and *andon* lights), and employee involvement have all contributed to the ideal of simplicity. As business grows, and as more varieties of products are introduced into the system, the complexity of the manufacturing, management, and control systems do not increase in proportionate terms. This helps WCM organizations to overcome trade-off obstacles. Moreover, this feature also indicates how well systems and planning methodologies have been established that are robust enough to aid the increase in the scale and complexity of activities in an organization. In ordinary organizations, systems, and methodologies are not tuned to scaling up operations in the future. Therefore, increasing variety, for example, may result in a hike in cost due to the increased complexity of managing operations.

A simple demonstration of the various benefits of simplicity can be seen in the use of *kanban* cards, a method of production scheduling typical to JIT systems. *Kanban* cards are used in several world-class manufacturing organizations. In very simple terms, the use of *kanban* resembles a supermarket operation. In a supermarket, as a customer takes away his/her item of choice from the display shelf, the line staff will merely replenish the stock to desired levels at periodic times. As the line staff replenishes the stock, the inventory of stock at the stores diminishes. The supplier of the item periodically monitors the stocklevel at the stores and responds to the depleting stock with his/her routine of replenishment. Proceeding in this manner, a simple event of sale of finished goods to a customer may trigger a chain reaction in the system and induce all the upstream components of the supply chain to react to the change.

Instead of using a complex planning process and paperwork to communicate orders across various people in the system, an alternative system like *kanban* (which is highly visible and instantaneous in response) can be used. In the former method of planning and control, a centralized planning department computes the requirement at various stages in the system and subsequently communicates the decisions arrived at through the planning process to all affected entities. In the case of *kanban*, on the other hand, this is left to the affected parties themselves. The entire system operates using a decentralized planning framework, whereby it is able to respond to changes more effectively.

Challenges in WCM

Transforming into a world-class manufacturing organization has not been easy for most organizations even though the principles of WCM are very simple and intuitively appealing. Several reasons could be attributed to this. The most significant among them is the fact that organizations have a mindset inertia that generally resists changes. Only during periods of crisis that threaten the very survival of the organization are changes accepted without much resistance. Besides crisis situations, the only other factor that can galvanize change is the active role of top management in spear-heading the change process. The second reason is the quantum of effort required to establish the required systems and planning methodologies in a world-class manufacturing organization. Transformation into a truly world-class manufacturing organization may call for sustained efforts over 8–10 years.[6] Often, organizations lack such levels of stamina and therefore lose the tempo midway. If these two issues are addressed properly, transformation will definitely be possible.

2.8 EMERGING CONTEXT FOR OPERATIONS STRATEGY

In recent years, several developments that affect operations management practices have taken place in the marketplace. We shall now take a look at how some of these developments have influenced operations and what are their implications for operations strategy.

Globalization of the Indian Economy

One of the on-going developments that could potentially affect operations management practices in the country is the globalization of the Indian economy. Beginning in 1991, the Government of India brought new reforms, enabling easy import of foreign goods to India. Due to the reduction in import tariffs, the landed cost of several imported goods became less than that of the same product produced by Indian manufacturers. For example, during 1993, the price of hot-rolled coils was as low as USD 300 per tonne. With a customs duty of 45 per cent and a surcharge of 11 per cent, its landed cost was lower than the domestic rate by a few thousand rupees. The setting up of new facilities by MNCs and build-up of excess capacity are the other important aspects of globalization. The excess supply resulting from these developments will drive prices down. A *Business Today* report on the white goods industry attributed falling prices to these reasons. The report pointed out how the cost of a 5-kg automatic washing machine fell from ₹8000 in 2003 to ₹6000 in 2005. Similarly, a 1.5-ton air conditioner that was available for ₹25,000 around 2001 was priced at just ₹15,000 in 2005.[7]

In addition to cost pressures from overseas players, Indian manufacturing organizations have had to face large-scale dumping of goods as, in a liberalized economy, it is difficult to stop this practice effectively. When the vitrified-tile price in India was at ₹120 per square feet, Chinese suppliers offered it at ₹30 per square feet. This brought enormous pressure on Indian suppliers and prices began to fall significantly.[8] Therefore, the new market scenario sets new priorities for operations management as the manufacturing organizations need to face the new challenges.

> Advantages enjoyed by Indian manufacturing firms:
>
> - Ability to provide goods and services at a fraction of the cost at which they are available in developed countries
> - large installed base of manpower with technical knowledge, manufacturing know-how, and experience in manufacturing management

Despite these new challenges, Indian manufacturing firms have greater chances for market expansion on account of the liberalized economy because of two important factors. The first is the overall attractiveness of Indian organizations due to cost factor advantages. Indian manufacturing firms can provide goods and services at a fraction of the cost at which they are currently available in the developed countries. This is because of the relatively low cost of labour. The second advantage for India is the large installed base of manpower with technical knowledge, manufacturing know-how, and experience in manufacturing management. Therefore, Indian firms need to understand these issues and incorporate them in their operations strategy. Cost reduction opportunities and other strategic options need to be pursued to compete on the basis of operations. To compete in global markets, Indian organizations need to develop the following capabilities:

- Identify a segment and create global scale.
- Develop and hone process skills and create operational excellence.
- Move from mere manufacturing of components to design and development through greater investment in research and development.

The Outsourcing Wave

Globally, firms are looking towards India for their software development and maintenance needs. Based on the successful experience of outsourcing software jobs to India, firms in developed countries are increasingly shifting a variety of other jobs here. This is what we refer to as the outsourcing wave. India’s share in worldwide service exports was 0.6% in 1990, 1% in 2000, and 3.3% during 2011. Between 2007–08 and 2011–12, the annual growth rate in export of computer software and services including ITES was 18.27% in rupee terms. The key motivation for a firm to outsource some of its processes stems from three factors: cost, capacity, and core competency. A vast majority of examples from the BPO industry point to significant cost benefits accruing to the outsourcing firm on account of factor cost differentials. By investing in specialized processes and processing only specific requirements, the outsourcing service provider is able to deliver the same service at a much lower cost.

> **Business process outsourcing (BPO)** is an arrangement by which some of the non-core business processes of an organization are carried out by a third party on behalf of the organization.

The second reason for outsourcing is the benefit of quick expansion of capacity without actually investing one’s own funds. Third is that the organizations are increasingly showing a preference towards investing their funds, management time, and other resources in the core aspects of the business. This is primarily due to the fact that value addition is mainly dependant on the core competency of a business. Since the primary consideration for a BPO is cost, operations strategy for a BPO firm must emphasize cost leadership. Otherwise, the BPO activities may be shifted to a competitor. Another critical performance measure is quality. Since an organization often outsources the entire range of operations in a business process to a third party, they need to develop stringent quality norms. Therefore, such organizations need strategic plans to ensure adherence to strict quality norms. In several other cases, in addition to the cost and quality requirements, stringent delivery requirements may also have to be met as the outsourced processes may be in the intermediate stages of the value-creation process.

> The key motivation for a firm to outsource some of its processes stems from three factors: cost, capacity, and core competency.

Collaborative Commerce through the Internet

The use of the Internet in commerce and trade is a very recent development. It has become possible for remote trading partners to share real-time data through network connectivity, client-service architecture, and other IT-based resources. For example, a supplier of bearings for Lucas–TVS, Chennai, may be located in a far-off place. However, using IT-based resources, the supplier can deal with Lucas–TVS on a real-time basis. Many companies, such as Lucas– TVS, are using this aspect of e-commerce to develop several collaborative mechanisms for mutual benefit. Kanban signals can now be sent through the Web. Tenders, requests for quotations (RFQs), and requests for proposals (RFPs) can all be submitted through the Web. Trading partners can exchange vital production planning and other technical information for mutual benefit. A large number of government departments also use electronic market mechanisms for tendering. By 2005, about ₹150 trillion worth of orders were tendered online. Due to this new method, the number of days to complete the tender process came down from 90–135 days to a mere 30 days.[9] This practice of using the Internet or electronic markets to enable trading partners to transact efficiently can be defined as collaborative commerce.

> **Collaborative commerce** refers to the use of the Internet or electronic markets to enable trading partners to transact efficiently.

Collaborative commerce opens up new areas in operations management. Many of the traditional methods of operations management can be either replaced or supplemented by new procedures using the electronic method. Many organizations have already begun to make use of collaborative commerce in two areas. The first relates to procurement and supply management practices. Traditionally, firms take considerable time in identifying appropriate sources of supply, shortlisting a few suppliers, having long negotiations, and finally arriving at a mutual agreement upon price. After the price and other terms are agreed upon, paperwork and procedural formalities are required to generate the purchase order and to send it to the selected supplier. These steps require considerable time, effort, and cost. This entire process can be made more efficient using electronic markets and electronically conducted auctions. We shall discuss these trends in detail in Chapter 7. In the next 10 years, one can expect significant changes in the procurement practices of several organizations.

The second emerging area of collaborative commerce is in design and new product development. Today, it is possible for several entities across geographically distributed locations with varying time zones to work together in a new product development project. Much of new product development involves the development of new ideas, designs, and templates before trial production is taken up. Until this stage, information exchange is the most important aspect. Since information can be instantaneously transmitted across a pair of connected computers through the Internet, it is possible to exchange this information in real time and benefit from the expertise of a larger group. Furthermore, collaborative commerce also enables organizations to benefit from a huge reduction in development time.

Another interesting development in new-product development is real-time access to the latest component designs that a manufacturer intends to use in its product and the ability to benefit from the latest enhancements in the components and subsystems. The manufacturer can access the virtual world of the component manufacturer, choose alternative designs, fit them into its virtual model, evaluate the desirability of using one model over another, and finally decide on an appropriate component. Such an approach to design is likely to result in huge reductions in cost and time for the organization.

The recent trends in government policies and technological innovations indicate several promising developments in the practice of operations management. It is imperative for present-day organizations to be aware of these developments and to take them into consideration while designing their operations strategy.

SUMMARY

- A *strategic planning exercise* enables an organization to respond to market needs in the most effective manner by aligning its resources and activities to deliver products and services that are likely to succeed in the market.
- *Operations strategy* is the process of making appropriate decisions in the operations function on the basis of inputs from the corporate strategy.
- A strategy-formulation exercise enables an organization to identify *order winners* and *order qualifiers*. These attributes change from time to time.
- Four generic performance measures are generally found to be useful in any operations-strategy exercise—*quality, cost, delivery*, and *flexibility*.
- Translating corporate strategy to operations strategy requires making appropriate choices with respect to *product portfolio, processes, technology, capacity*, and the *supply chain*.
- World-class manufacturing organizations feature five basic elements of operational excellence. These include *just-in-time (JIT) manufacturing, total quality management (TQM), total productive maintenance (TPM), employee involvement*, and *simplicity*.
- The dismantling of trade barriers demands that Indian manufacturing and service organizations equip themselves with the required operations-management practices to tap global trading opportunities.
- Current trends such as business process outsourcing (BPO) and collaborative commerce through the Internet point to new requirements in operations management.

REVIEW QUESTIONS

1. What does the term *operations strategy* mean? How is it different from *corporate strategy*?
2. Why do firms engage in operations-strategy exercises? How often do they perform such exercises?
3. What are order-winning and order-qualifying attributes? Give three examples of each in the service and manufacturing industries.
4. How do firms identify order-winning and order-qualifying attributes?
5. Briefly describe the strategy-formulation process.
6. What is the use of measures for operational excellence? Explain with the help of a few measures.
7. What is the linkage between product choices and process choices in an organization?
8. An organization is currently manufacturing basic cooking utensils for household use. Although it has been in operation for the last ten years, of late there has been a margin squeeze due to a fall in its sales volume. The organization is trying to decide if it should provide a wider range of product choices to its customers in order to improve its margins. What are your suggestions to the organization for resolving this confusion? Would your answer have been different if they were manufacturers of high-end premium cookware?
9. What does world-class manufacturing mean? What are the characteristic features of a world-class manufacturing organization?
10. Why do some firms such as Arvind Mills invest in huge capacity in their operations? Will they benefit from this?
11. How can an organization configure its supply chain using an operations-strategy process?
12. What is the role of technology in operations strategy?
13. What do you understand by the term *flexibility–cost trade-off* in operations strategy?
14. How does a world-class manufacturing organization differ from other organizations?

15. How do economic liberalization and globalization measures influence operations management practices? Give some specific examples to argue your case.
16. What are the main factors promoting business process outsourcing?
17. How can the Internet affect the practice of operations management? Does it have any implications for operations strategy?

PROBLEMS

1. Quick Photo Solutions is in the business of processing photographic films. The annual fixed cost of equipment incurred by Quick Photo Solutions is ₹600,000. The demand for film processing is 50 rolls per day, and they work for 250 days a year. The variable cost of processing a film (including labour, power, and chemicals) is ₹90 per roll. Quick Photo Solutions is presently charging a processing fee of ₹150 per roll.

   a. Compute the break-even point for Quick Photo Solutions.
   b. Is Quick Photo Solutions making any profit in the operations?
   c. Beginning next year, Quick Photo Solutions expects the processing cost to go up to ₹100 per roll on account of increase in the cost of power and chemicals. What will be the break-even point under the revised cost structure? Will the firm make any profit? By how much should the daily demand increase so that it can continue to have the same break-even period that it had prior to the price increase?

2. Raja runs a reprographic service in a university campus. His investments in photocopying machines and physical infrastructure in terms of office space, constituting the fixed costs, amount to ₹250,000. The variable costs incurred by Raja are as follows: cost of one sheet of paper = 5 paise; cost of power = 12 paise per page; labour cost per page = 23 paise. Raja charges 60 paise per page for photocopying.

   a. What is the break-even volume for Raja?
   b. The expected daily demand for the service is estimated to be between 125 pages and 500 pages. How long will it take for Raja to break even at the extreme ends of the daily demand?
   c. If Raja brings down the rate to 55 paise per page, he is confident that he will reach the highest daily demand shown in his estimate. Will he then be able to reach break even faster?
   d. Raja is willing to invest another ₹50,000 on some improvements in his unit. This will bring down the labour cost to 18 paise per page. How long will he take to break even if he invests in the improvements?

3. A manufacturer of condiments has to decide between Machines A, B, and C, three alternative machines available for final packaging. While the initial fixed costs are high for Machines B and Ccompared to Machine A, their operating costs are lower. The relevant cost data for each of the machines is given in Table 2.3.

TABLE 2.3 Cost data of Machine A, Machine B, and Machine C

	Machine A	Machine B	Machine C
Fixed cost	₹20,000	₹40,000	₹80,000
Variable cost	₹5 per unit	₹4 per unit	₹3 per unit

The manufacturer is not sure which machine he should choose. What should he do? (Hint: Identify the volume of production at which use of these machines is justifiable)

NET-WISE EXERCISES

1. Visit the following links:

- Spice Jet: http://www.spicejet.com
- Jet Airways: http://www.jetairways.com/IN/

On these Web sites, there are several links you can click on. Click on **Products and Services**, **Plan Your Travel**, and **About Us**. After visiting both the sites, write a report to address the following questions:

a. How do the two airlines differ in their objectives and strategies?
b. Why and how are the in-flight services different from each other?
c. What effect has Spice Jet had on the airline sector and on other airlines?

2. BMW is one of the leading car manufacturers in the luxury car segment. It is known for its premium standards and quality. Visit the **Company**, **Research & Development**, and **Production** links on the company Web site, www.bmwgroup.com/e/o_owww.bmwgroup.com/forschung_entwicklung/forschung_entwicklung_2011.html. There are several sub-links under these heads. Click on them to understand various aspects of BMW's operations.

   Maruti manufactures India's largest-selling car. Visit Maruti's Web page, http://www.marutisuzuki.com/, and click on **About Us** and **Our Cars**.

   After visiting both the Web sites, prepare a report to answer the following questions:

   a. How are the strategies of the two companies different?
   b. Which customer segment do they cater to?
   c. Why does BMW have different brands while Maruti operates under one brand?

3. Download the report on Dupont's approach to Operational Excellence available at the following URL:

   http://www2.dupont.com/Consulting_Services/pt_BR/assets/downloads/OP%20E_White%20Paper_FINAL_12%2014%2005.p

   After going through the report, prepare a write-up by answering the following questions:

   a. Why should organizations address the issue of operational excellence? What benefits can they get out of this exercise?
   b. What are the salient features of Dupont's approach to operational excellence?
   c. What is the significance of operational risk management? How is it addressed?

CASE:GIGNER HOTEL

Roots Corporation Limited is a fully owned subsidiary of the Indian Hotels Company Limited (IHCL), which is a part of the Tata Group. With more than 90 properties, IHCL is India's largest hotel chain. It has been in the hospitality sector for over a century. Roots Corporation Limited operates a group of hotels under the brand name Ginger Hotels. The first hotel was launched in Whitefield, Bangalore, in June 2004. Today, Ginger hotels are located in 27 cities in India.

At a glance, a Ginger hotel will appear to be very similar to any other hotel. A Ginger hotel offers all the facilities that a normal hotel would offer. These include check-in facilities; rooms with a TV, fridge, and a tea/coffee maker; room services such as laundry; restaurants; digital safes; Wi-Fi connections; meeting rooms, a business centre, gymnasium, car rental service, doctor on call, and currency exchange. However, the similarity ends at this level.

A Ginger hotel distinguishes itself in several ways in the manner these services are offered. Unlike other hotels, Ginger hotels offer a limited à la carte menu in the restaurant at a nominal price. In case a guest does not like what is being offered, it is possible to call up nearby restaurants, place an order, and collect the food from the Give n' Take Counter in the hotel. The rooms are compact and well maintained, and are available at a price that is much lower than the price charged by other hotels for a similar service.

"Please help yourselves" is a line that can be seen on most of the brochures and booklets in a Ginger hotel, and it aptly reflects its most distinguishing feature It is not uncommon for guests to use the self-service check-in kiosk, identify their room, and carry their luggage to the room. As soon as a guest enters a Ginger hotel, he/she will come across several operations with a self-service facility. Some elements of self-service are described here:

- *Self-Service Check-in*: Upon arrival, guests can check into the hotel without any assistance from the reception counter. This is possible because Ginger hotels have self-check-in kiosks.

- *Give n' Take™ Counter*: Ginger hotels have a "Give n' Take" counter that the guest can use to deliver used clothes for laundry in the morning and to collect washed clothes after 7.30 p.m. the same day.
- *Smart Get Set*: There is an ironing room in every floor in Ginger hotels. Guests can use the room for pressing their clothes. Further, there are water dispensers on each floor, from which guests can fill their bottles.
- *Smart Knick Knacks*: Ginger has installed vending machines for hot and cold beverages and packed snacks. These vending machines can be accessed round the clock, irrespective of whether the restaurant is working or not.
- *Smart Mart*: There are vending machines that supply other things such as toiletries, combs, toothpaste, hygiene products, and mosquito repellants.

The company summarizes "the Ginger experience" as one providing intelligent, well-thought-out facilities and services at great value and with no frills attached.

QUESTIONS FOR DISCUSSION

1. How will you describe the overall strategy of Ginger Hotels in the hotel industry?
2. Is their operations strategy consistent with the overall strategy? What are the operational elements of Ginger Hotels that provide this strategic dimension to the operations?
3. Can you identify the strategic and operational benefits that Ginger Hotels is likely to derive from the operations strategy and operation system design that it has chosen?

Source: www.gingerhotels.com

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CHAPTER 3

Sustainability in Operations

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- *Why is sustainability important for business? What is the notion of sustainability?*
- *What are the basic tenets of sustainable operations management?*
- *What do you mean by reverse logistics? What role does it play in creating sustainable operations?*
- *What are the salient aspects of remanufacturing? How can one set inventory control policies in remanufacturing?*
- *What challenges organizations are likely to face in creating sustainable operations?*

For a business firm to prosper or continue to develop its potential, sustainability in its action is important. Sustainability operation in a business includes economic, environmental, and social sustainability. Economic sustainability enables a business organization to deliver products and services that result in profit. Environmental sustainability enables an organization to deliver the products and services without compromising or affecting the ecological balance. Social sustainability enables a firm to make a healthy and better way for the current and future generations to live.

Source: Tungphoto. Shutterstock

Ideas at Work 3.1

First Energy: A Sustainable Technology to Address Cooking Needs

Most of the cooking needs in rural areas in India are met with fossil fuels, mainly firewood. This method of cooking is unsustainable as it may lead to major deforestation. As the availability dwindles, it may become expensive. Petro-chemical-based solutions such as kerosene are also a non-renewable source and pollute nature. Moreover, these solutions are not healthy. Addressing this requirement using principle of sustainability may require complete rethinking. It needs innovation in the very technology of cooking, source of fuel, equipment design, and manufacturing. First Energy, a Pune-based firm, is an illustration of the various aspects of creating sustainable operations.

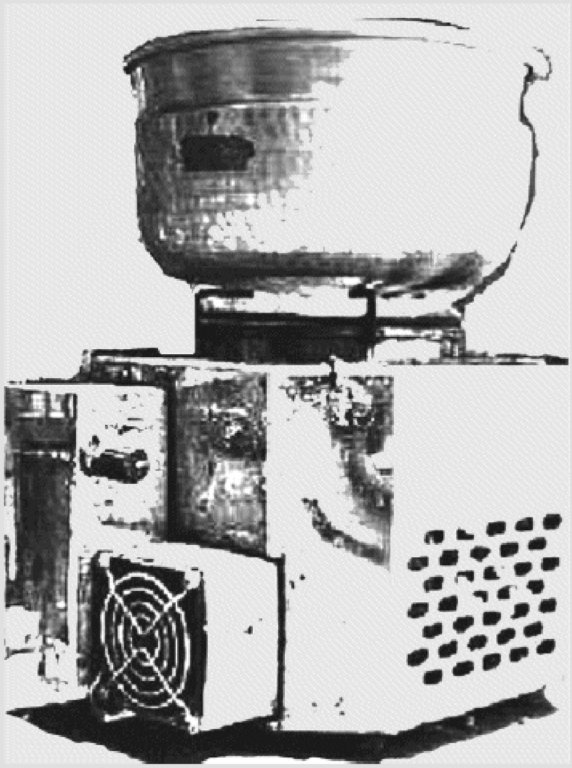
First Energy provides cooking solutions that are based on biomass. The fuel pellets are made from peanut shells, bagasse, and other agricultural wastes. In order to introduce this new technology, design of a stove is critical. First Energy designed a new stove jointly with Indian Institute of Science, Bangalore, and branded as Oorja. The technology used for cooking is based on gasification, a process of controlled combustion producing a gas that can be used as fuel. The stove has a perforated chamber with a fan. The unit is powered by a rechargeable battery. The fuel burns at high temperatures with relatively low smoke emission. With the result, the fuel is much cleaner than firewood.

The Oorja stoves were first launched in 2007. Oorja is an alternative to wood, kerosene, and even LPG. In the commercial food service kitchen, Oorja could replace conventional cooking fuels such as LPG and diesel. Oorja offers an integrated solution: a combination of a uniquely designed ‘micro-gasification’ device or stove and a biomass-based pellet fuel. When used together, the Oorja solution delivers efficiency and value that are higher than conventional cooking devices that use LPG and diesel.

The cost of the stove is about ₹1500 and the fuel pellets ₹12–₹14 per kilogram. In order to cook a meal for a family of five, about 600 g of the fuel may be required. The sustainable solution can save customers 30–50% on total fuel operating costs depending upon the pattern of usage. First Energy has more than 1000 dealers who reach about half a million households in Karnataka, Madhya Pradesh, and Maharashtra. Alternative product designs for commercial operations have been done and the commercial version of the stove burns about 6–18 kg of fuel to cook for 50–300 people.

The experience of First Energy points not only to the immense potential for designing sustainable products and solutions but also the importance of such initiatives to conserve natural resources. As in the case of Oorja, in the future, such solutions may also be cost effective. However, it calls for a vision, a newer approach to product and process design, and new investments. We shall see these aspects of sustainability in this chapter.

Source: Based on Sharma, E.K. (2011), Fuel’s Gold, *Business Today* October 16, 2011, pp. 100–102 and information available in www.firstenergy.in



Business organizations are affected by certain events from time to time. Some of the events introduce cyclical changes leading to shrinkage and growth of sectors of the economy. However, certain other events introduce more fundamental changes in the way business is conducted. A recent example is the advent of information and communication technology (ICT) and Internet-based electronic market mechanisms. This has altered the business landscape completely and brought about newer methods of creating competitiveness. One such factor that is probably to affect business at a very fundamental level is the notion of sustainability. In the next 15 years, only such firms that have understood this well will be able to operate successfully.

> Over the recent past, there has been growing concern on the impact of business on environment. These arise on account of depletion of natural resources, waste generated from production and service systems and at the end-of-life of products.

Over the recent past, there has been growing concern on the impact of business on environment. These arise on account of depletion of natural resources, waste generated from production and service systems, and at the end-of-life of products. Increasingly, firms are under pressure to take responsibility for restoring, sustaining, and expanding the planet's ecosystem instead of merely exploiting them. In this chapter, we shall see various facets of sustainability and their relevance to the manner in which firms organize their operations.

3.1 SUSTAINABILITY: A KEY BUSINESS REQUIREMENT

In our quest to lead a comfortable life, mankind continuously engages in innovation and new product and technology development. On the other hand, business organizations are constantly engaged in increasing their profitability and market shares. In this process, one of the main agendas that organizations seem to be pursuing is to create a consumption-oriented society. Innovation initiatives coupled with marketing and advertising activities in an organization focuses on fuelling the imaginations of the customers and fulfilling their new found wants. On the other hand, design and new product development activities are focusing on making existing product lines obsolete and bringing new generations of products and services. As consumption increases, production and distribution activities also increase, creating fresh business opportunities. This approach to business has resulted in certain outcomes:

1. In this approach to business growth and profitability, we seem to have forgotten for the moment that resources required for sustaining the current levels of consumption may be fast depleting.
2. The increased level of industrial activity generates enormous amounts of toxic industrial wastes that threaten to harm the atmosphere.
3. The increased level of consumption leads to greater levels of disposal of solid wastes. Modern societies (especially in big cities) are finding it increasingly difficult to handle the wastes.
4. Increased consumption of natural resources also lead to more atmospheric pollution that it may soon threaten our health.

There are enough indications of these trajectories in our development path. Studies indicate that the US has 5% of the world's population but consumes 30% of the world's resources and creates 30% of the world's waste. On an average, an American consumes 17 times more than Mexican counterpart and 100 times more than Ethiopian. If everybody consumed at the US rate, then we would need 3–5 planets to sustain our current levels of consumption. On account of these, in the past three decades alone, one-third of the planet's natural resources base has been consumed. Moreover, the CO_2 emissions have grown on an average by 2% per year, leading to a 40% increase in emissions during 1990–2007. One illustrative example is the case of bottled water. In 2004, nearly 28 billion plastic bottles were produced. Nearly 85% of them landed in the garbage. Furthermore, in order to manufacture these bottles, 17 million barrels of oil was used and about 2.5 million tonnes of CO_2 emitted from the manufacturing system. Depletion of the ozone layer in the atmosphere, faster melting of the polar icebergs, and frequent devastations caused by the nature are some of the larger pointers to the need to address the issue of sustainability.

Governments across the world have recognized the importance of sustainability. In the last 10 years, we saw a multifaceted approach to tackle the problem of environmental protection and sustenance. Policy makers have brought in new legislations that put regulatory pressures on businesses as a means to tackle the problem. With increase in economic and social costs of disposal, increasing protests from environmental protection groups against dumping wastes in third world countries and reducing spaces for landfill, legislations have also evolved from the earlier forms of pollution-level control to the recent forms such as 'compulsory take-back of products at the end-of-life'. Notable among them are the EU directives on compulsory product take-back at the end-of-life, The Netherlands National Environmental Plan and the package recycling and product take-back laws in Germany.

> The legislations based on ‘extended producer responsibility’ require business organizations to take responsibility for the reverse supply chain. This has introduced more complexities in operations management.

This required the business organizations to take responsibility for the reverse supply chain (used, thrown away products by the customers reaching back the manufacturing facility). These legislations are based on ‘extended producer responsibility’—a policy tool to minimize environmental waste generated from businesses. This has introduced more complexities in operations management (OM) for the firms. This also increases the cost of the operations. Scare resources will increase the cost of various inputs for the business organizations. Increasing difficulties in handling disposals will increase the supply chain costs for an organization. Therefore, the economic viability of organizations may be threatened if the issue of sustainability is not factored into organizations.

3.2 NOTION OF SUSTAINABILITY

A widely adopted definition of sustainability is that used by the World Commission on Environment and Development (WCED) (1987): ‘Development that meets the needs of the present without compromising the ability of future generations to meet their needs’. From a business perspective, the operational definition of sustainability will encompass three dimensions: social, environmental, and economic.

> A widely adopted definition of sustainability is ‘Development that meets the needs of the present without compromising the ability of future generations to meet their needs’.

Economic sustainability refers to the ability of business organizations to deliver products and services that fetches revenues in excess of the cost. At the plant level, it is operationalized as production or manufacturing costs. OM practices are at the core of economic sustainability. Since organizations use a variety of resources and engage in design, production, distribution, recycling, and recovery of used products and services, they will need to fine tune their practices to address this. Productivity enhancing initiatives, choice of design, material, and technology that can reduce the cost are aspects of economic sustainability.

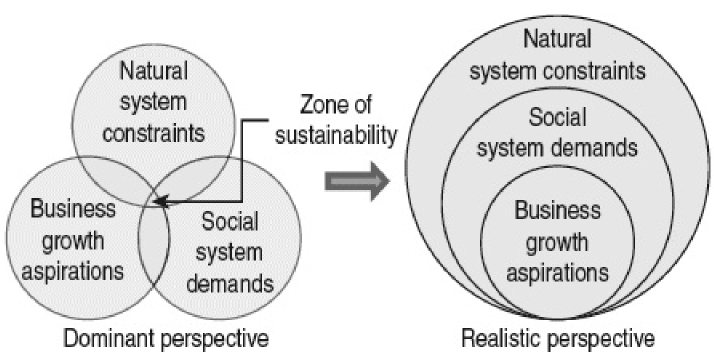
Environmental sustainability refers to the ability of organizations to deliver products and services without compromising the balance between natural systems and living beings. Only with such a balance, natural resources will be available over a longer period of time. Merely pursuing an agenda of economic sustainability may not be feasible for several reasons. The scarcity of available resources and handling disposal of end-of-life products and services will pose greater threats even to economic sustainability. Moreover, firms will have to respond to governmental regulations. Environmental sustainability is often related to waste reduction, pollution reduction, energy efficiency, emissions reduction, a decrease in the consumption of hazardous or harmful or toxic materials, a decrease in the frequency of environmental accidents, and so on.

Therefore, OM practices will have to change to address these aspects. They may have to account for the energy and other resources they use and the resulting ecological footprint they leave behind. Supply Chain structure may also need some change to respond to these requirements. The new product design philosophy may also require some change to address these.

Social sustainability will relate to the choices made by business organizations that will enable the current and future generations to live a healthy life. What it would mean is that companies need to operate in a prudent and responsible manner and take care of employee health and safety, and the quality of life of the external community. As operations is one of the areas employing the most personnel and having the highest footprint and impact on the external community, it can have a significant effect on sustainability's social dimension.

The notion of sustainability is better understood from the transition required in the mindset of business organizations. Figure 3.1 illustrates this idea pictorially. Sustainability is not achieved by independently pursuing the three dimensions. This is because there are interdependencies between the three, which finally drives the sustainability. Therefore, the current understanding of the notion of sustainability is the intersection of economic, social, and environmental dimensions. However, this understanding may not fully capture essence of sustainability. In order to be truly sustainable, the interactions between the three must undergo a change. The natural systems truly provide the overarching framework in which organizations can design economic systems to address the demands of the social systems, thereby creating sustainable entities for the future. OM gives new opportunities to significantly contribute to sustainability. Sustainable OM is defined as the set of planning and execution methodologies that allow a company to structure its business processes to achieve sustainable performance.

FIGURE 3.1 Alternative perspectives on sustainability



VIDEO INSIGHTS 3.1

Construction is a major industry in a developing country such as India. Developing sustainable practices in the construction sector can play a significant role in developing a sustainable economy. The Energy Research Institute (TERI) has come up with a defining framework for creating sustainable buildings in the country, known as GRIHA. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

3.3 FRAMEWORK FOR SUSTAINABLE OPERATIONS MANAGEMENT

Incorporating sustainability ideas in operations require that several OM practices are modified. For instance, there may be certain changes required in the area of supply chain design. While new products may make use of the traditional supply chains, organizations may have to configure a new supply chain for taking back used products. Similarly, new product development and product design principles may require alternative perspectives. In the area of manufacturing and process planning, technology choices must support clean technologies. Plant layout designs could be done in such a fashion that renewable energy sources are deployed to the fullest extent possible.

> Incorporating sustainability ideas in operations require that several operations management practices are modified.

In order to make these choices in OM, organizations need a basic framework for developing specific options in each area of operations. Figure 3.2 provides a generic framework for developing sustainable OM practices.

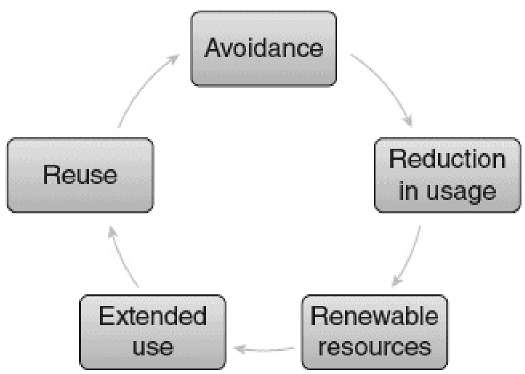
Avoidance is the first strategy in developing sustainable operations. What it means is that every effort is required to avoid use of resources while delivering products and services. This requires that the new product development process makes important changes in the design of the product or service offered so that resources are not used in the first place. For instance, the design of a new service may ensure that paper work is minimized by capturing data directly in digital form. Use of electronic tickets for travel in Indian Railways is an example that promotes avoidance. Similarly, in the design of a public library, innovative design of building, windows, and reliefs can result in minimum use of lights during day time as natural daylight can be harvested very well.

When Lucas TVS supplied starter motors to the nearby Hyundai plant, the earlier practice of individually packing each motor in a plastic cover and a carton and then packing dozens of such cartons in bigger cartons was dispensed with. Instead, trollies with hooks that can hold 50–100 starter motors were specially designed. The finished starter motors were simply hanged on the trolley and wheeled into the Hyundai factory. This completely avoided the use of plastic and cartons, which were strewn and thrown away at the Hyundai factory. A strategy of avoidance puts an organization on a sound footing on matters pertaining to sustainability.

Reduction in usage is the next step where avoidance of resource usage is not possible. Implementing this strategy in operations requires closer coordination and better planning among different entities in the supply chain. For instance, logistics operations can be redesigned in such a manner that fewer trips can be made between supply points and demand points by pooling requirements either by origin or destination. The Japanese practice of frequent deliveries, popularly known as milk runs will be evaluated in the larger scheme of clean technology solutions for the society. Implementation of sensor-based mechanisms to cut-off the use of resources automatically when not needed, can greatly help in the strategy of reduction. Value engineering efforts in design will have the dimension of reduction of critical resources for manufacture, maintenance, and use of scarce resources.

Since most part of services is about handling information, service design will emphasize use of digital resources than physical resources.

FIGURE 3.2 A framework for sustainable operations management



Switching to renewable sources is another strategy for sustainability. Design of factory layouts are undergoing change in line with the principle of sustainability. Passive cooling systems and innovative air circulation design in the shop floor, use of special material for the roof to harvest natural lighting for the factory, exploiting the vast area of roofing and terrace to harvest solar energy through heating and photovoltaic systems, and greater investments in water harvesting methods will be some of the features pertaining to the design of factories in the context of sustainability. Since most part of services is about handling information, service design will emphasize the use of digital resources than physical resources. Music, travel, entertainment, publishing and education, banking and financial services, and several other sectors will need to use electronic market infrastructure to replace non-renewable resources in the chain with digital resources that are relatively more sustainable.

Extended use of products and services will be a major departure in the design philosophy while new generation of products and services are developed. The current dominant paradigm in business is to promote throw-away culture and use it as a basis for running the consumption engine. Designing for planned obsolescence and perceived obsolescence assumes that the world has unlimited resources, and it will be possible to keep tapping them endlessly. As more and more resources are consumed, it will create newer challenges arising out of depletion of resources and problem of disposal of wastes. Therefore, a logical direction for sustainable operations is to extend the use of resources. In the future, it may prove to be a cost-effective strategy also.

Reuse of old products is another dimension in creating sustainable operations. As consumption levels increase, it will be impossible to dispose of used and unwanted items. Therefore, steps will be required to take-back used material and discover economic value out of them. Increasingly, governmental regulations are forcing business organizations to take this approach to manage operations. Major changes may be required in several areas of OM to practice this strategy. Reverse supply chains will be as important as forward supply chains. Inventory planning and control practices will have to be modified as there will be two sources of supply for several components (used as well as new). Remanufacturing, refurbishing, and recycling will be important elements in an operations system. Disassembly of used products will be as important as assembly of new products in a manufacturing system. One possibility to address avoidance and reduction of use of resources is to extend the notion of total quality management to the domain of pollution. What it may mean is that organizations will invest more on pollution prevention than pollution control. Pollution control is *ex-post*. After creating waste and polluting the environment, it needs to be cleaned through a set of activities called pollution control. On the other hand, in pollution prevention, by a proper set of choices in design, process technology and manufacturing methods efforts are made to reduce waste and energy use. Therefore, implementing a sustainable OM system may involve newer systems, skills, alternative philosophy, and approach to several OM practices. There will be benefits for the organizations, customers, and society as a whole in the long run.

ideas at Work 3.2

Reuse through Recycling: A Core Element of Creating Sustainable Operations

Disposal of solid waste is the biggest threat to modern paradigms of living. Big metros in India are facing huge challenges of waste disposal. For instance, in the city of Bangalore there is a three year battle between the Bruhat Bangalore Mahanagara Palike (BBMP) and the residents of nearby villages of Mandur and Mavallipura, where the city’s waste are dumped. The village residents are up against the Bangalore civic agency and have almost blocked the dumping practices by large scale protests. One of the core principles of creating sustainability is to reuse resources. A strategy of reuse creates a closed-loop supply chain and could dramatically bring down the extent to which we need to use landfill for waste disposal. Of late several successful business examples illustrate the value of reuse as a viable method of creating sustainable operations.

Arora Fibres Limited, a factory in the industrial belt of Silvassa in Darda and Nagar Haveli has been reusing the PET bottles and manufacturing Polyester Stable Fibre (PSF) using Korean technology from 1994. The plant has the capacity to process 18,000 tonnes of plastic, which is probably to be increased to 48,000 tonnes in the future. According to the Chairman of Arora Fibres, by recycling 10 billion PET bottles one can save one million square yards of landfill space and eliminate 0.25 millions of CO_2 emissions into the atmosphere. The PSF could be used in other sectors such as automobiles. Moreover, the packaging material for food and beverages, pharmaceuticals, and consumer goods industries could also be manufactured using the PSF.

VA Tech Wabag, a Chennai-based company, has been recycling industrial and municipal waste water for reuse as drinking water or to plough back for industrial use. One of their earlier applications was in the Panipat refinery of Indian Oil Corporation when the farmers in Haryana objected to the waste water discharge from the refinery. The company recycled the entire plant's waste water discharge and almost brought it to the standard of drinking water. In 2012, VA Tech Wabag reported a revenue of ₹10 billion in India.

The amount of e-waste generated in Bangalore alone is estimated to be 200,000 tonnes. Although considered to be highly toxic and dangerous of the solid wastes category, e-waste has precious metals such as gold and platinum. For example, a typical mobile phone may contain about 250 g of silver, 24 mg of gold and 9 mg of palladium. A Laptop contains, in addition to gold and silver, substantial amounts of copper. Cerebra Integrated Technologies, a Bangalore-based company, is building India's largest e-waste recycling plants to extract these precious metals. The plant when fully become operational will be able to process 90,000 tonnes of e-waste.

Although several such examples will crop up in the future, the real value of sustainability lies in our ability to bring the consumption patterns under control. At a more fundamental level, reduced use in the first place is a far better strategy than substantially increasing the consumption levels and finding alternative methods to reuse and recycle.

Source: Based on the report in *Business Today*, June 9, 2013, pp. 89–92.

One possibility to address avoidance and reduction of use of resources is to extend the notion of total quality management to the domain of pollution.

3.4 REVERSE LOGISTICS: A FRAMEWORK

Traditionally business organizations have been concerned only about the forward logistics. Forward logistics begins from the raw material supplier and ends when the finished product or service is delivered to the ultimate customer. In between, it may involve multiple stages of component manufacturing, assembly, packaging, logistics, and distribution through a chain of trading partners. In order to address the issue of sustainability, it is important to address the reverse logistics as well. As the name implies reverse logistics begins at the customer end and eventually ends at the original equipment manufacturer (OEM). If a reverse logistics chain exists, then instead of simply discarding an equipment after useful life, the customer may return it back to the producer. It typically involves several entities, options, and decision points. Figure 3.3

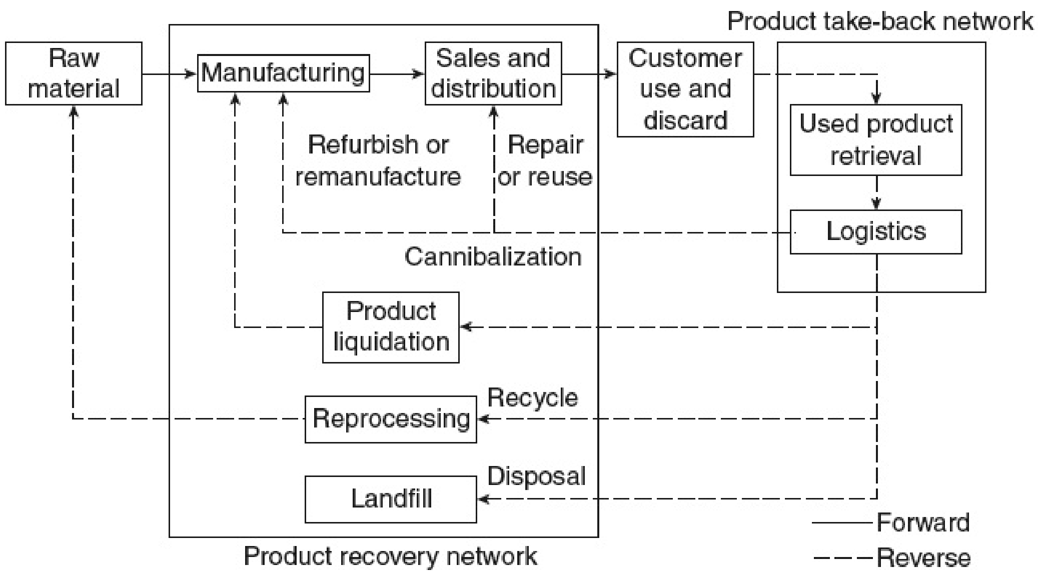
represents a simplified framework for reverse logistics. We can use a three-dimensional classification to describe various aspects of reverse logistics: networks, decision options, and entities.

Networks in Reverse Logistics

As shown in Figure 3.3, the entire reverse supply chain can be segmented broadly in two parts; Product Take-back Network (PTN) and Product Recovery Network (PRN). The PTN pertains to collecting the product from the customer at the end of her use. Product acquisition, transportation, and distribution of used products from consumers to one or more of the product recovery facilities are the major activities of this part of the network. In PRN, several players perform one or more of the several recovery activities such as reuse, repair, refurbishing, recycling, remanufacturing, and disposal (landfill).

> We can use a three-dimensional classification to describe various aspects of reverse logistics: networks, decision options, and entities.

FIGURE 3.3 A generic reverse supply chain framework



Decision Options in Reverse Logistics

Critical decisions interface the two networks and provide overall directions as to how the product collected using the take-back network is eventually recovered and/or disposed in an environmentally safe manner. These decisions, for instance, include which product recovery option to be used, who are the entities involved in each of these options, the competitive behaviour of these entities, and how the economic benefits are shared among the various players. The network and decision options dimensions of the reverse logistics framework suggests that the activities in PRN are merely an operational deployment of the choices exercised under decision options and follows the activities of PTN.

Entities in Reverse Logistics

Multiple entities are involved in a reverse logistics network and have multiple goals and motivation to participate. The customer and the regulatory agencies are important entities in reverse logistics. While the customer actions trigger other activities in the entire network, the regulatory agencies provide overall policy directives through legislation, monitor, and control of several activities and entities involved in reverse logistics. Recent regulatory postures clearly indicate that eventually the OEMs have the ultimate responsibility for product take-back and adhering to recycling targets. For example, the End-of-Life Vehicle Recycling Initiative (1996) of Japan and the EU Directive on End-of-Life Vehicles (2000) mandate that 95% of vehicle must be recycled by 2015. However, the product take-back activities may be organized in multiple ways. OEMs may either have their own setup to collect the used products, or use their trading partners such as retailers to perform the task, or engage third party agencies. Third party logistics providers are often involved in shipping the returns to recovery facilities.

In the PRN, players have different roles to play. The OEMs may take part in all of the product recovery activities such as repair, refurbish, remanufacture, and recycle. Alternatively, they may contract these activities to other players. If there are enough economic incentives, then third-party agencies may collect and recover used products and sell them to secondary markets. However, this may have important marketing and economic implications in the long run. Since there are multiple players and multiple arrangements among these players are possible, an important question that arises is how are the product recovery activities ultimately organized among various entities in order to satisfy environmental goals and expectations of the regulators and the society? Analysing the reverse logistics problem from a perspective of entities requires that the following issues are addressed: the ownership structure (who are the players involved and in which product recovery activities), factors governing the behaviour of the players (the incentives of players to participate in product recovery activities), impact of regulation, and strategic and economic advantages of making these choices.

3.5 DESIGN FOR SUSTAINABILITY

In an organization promoting sustainability as a key value, the design philosophy must be aligned with the framework for sustainability presented in Figure 3.2. Design efforts must focus on minimizing not only pollution from manufacturing but also all environmental impacts associated with the full lifecycle of a product. Specific changes in the design philosophy will include the following:

1. Modular approach to design so that components of a product can be easily remanufactured or refurbished. Modular upgradability is an enabler of sustainable products by allowing single components (rather than entire units) to be

upgraded and hence disposed of.

2. Use of universal components reduces the number of components in a product. Fewer components would mean quicker disassembly, fewer toxic substances, lesser recovery, and recycling costs.
3. Use of recycled material improves the material recovery and reduction in use of scarce resources.
4. Newer assembly methods such as snap-fit assembly will reduce disassembly and recycling costs.
5. Promoting recyclability avoids the use of coatings and paints.
6. Choice of clean technologies for manufacture and maintenance.

> In an organization promoting sustainability as a key value, the design efforts must focus on minimizing not only pollution from manufacturing but also all environmental impacts associated with the full lifecycle of a product.

Design for environment (DFE) is a structured set of methodologies that enable an organization create products and services that are easier to recover, reuse, or recycle. The DFE approach forces the designer to examine the effects of a product and service on the environment and provide for necessary changes in the design. Such an approach will balance the manufacturing considerations with ease of use, post-use disposal, ease of remanufacturing, and consumption of precious resources during the entire life time of the product from concept stage to final disposal. This is typically referred to as cradle-to-grave analysis. Taking such approach would mean for example that the single use camera will be suitably redesigned such that it is possible to remanufacture the returned cameras after use by the customers.

Since the focus is on the entire lifecycle of a product, a structured methodology to assess the environmental impact over the lifecycle may be required. For instance, Nokia uses an externally audited lifecycle assessment methodology to calculate the environmental impact of their products and processes. The assessments will span the entire mobile device lifecycle, from raw material acquisition to the end of the product’s life. They also assess energy efficiency, sustainable use of materials, and small packaging. It helps them identify and focus on the areas where we biggest reductions are possible. As a result of these Nokia has been active in introducing new, more sustainable materials such as bio plastics, bio paints, and recycled metals into their devices. The Nokia 700 uses bio-materials, recycled plastics, and recycled metals. This materials innovation enabled them to reduce their dependency on fossil raw materials and the need for virgin metals, use less energy in raw material acquisition, and introduce more sustainable industry practices.

ideas at Work 3.3

Sustainability—Indian Cultural Ethos

On a visit to any small town in India one can discover the changes in the lifestyle of population. Youngsters sport faded denims and sun-glasses, and drink cans of Coke. There would be heaps of discarded plastic sachets and cups in public places—early signs of the ‘throw-away’ culture entering the Indian ethos. The Indian market has begun to adopt some of these ideas recently. Packaging of consumer goods has become more resource-intensive than ever before. Disposable sachets made of paper and plastics have replaced many traditional materials.

Most of the goods and services produced have been designed with the throw-away criterion in mind. Be it a pack of fruit juice or milk, or a useand-throw camera, they can be discarded and cheap replacements are available. The manufacturing sector makes several design choices on the basis of the throw-away philosophy. Automobile engines are no longer assembled with bolts and nuts; smart robots deal with them; and the engine can be replaced rather than repaired.

This approach to life has resulted in alarming levels of consumption of natural resources, paper, and plastic products. Moreover, such a lifestyle poses a serious ecological threat. To imagine that the net outcome of the throw-away philosophy is to fuel growth by spurring economic activity is at best a short-sighted understanding of the issues involved. It is becoming increasingly clear that a throw-away model to business and society will place an enormous strain on natural resources.

A recent study showed that in the US it takes 12.2 acres to supply the average person’s basic needs, eight acres in the Netherlands and less than an acre in India. Most strikingly, one estimate is that if the entire world lived such as those in North America do, it would take three planet Earths to support the present population, leave alone the future generations. If we could recreate nature, then this is not an issue at all. Despite $200 million worth of elaborate equipment, an experiment to generate breathable air, drinkable water, and adequate food for just eight people in a manmade 3.2 acre glass and metal dome in Arizona, US, failed after two years. This has put the throw-away model itself into serious question.

It is time to assess the value of Indian austerity as an alternative model of living. Simplicity is the best way to conserve nature and sustain it. Our culture has its roots in worshipping nature as God. It was not uncommon to use every part of a plantain or coconut tree for day-to-day purposes. Such practices ensured two essential things in daily living; bio-degradability of what we consume, and sustainable consumption.

India has a culture of using minimum resources in daily life. Unfortunately, we seem to be losing these values slowly. To recycle and repair goods to prolong their life sounds ‘old-fashioned’. However, that is the future. For instance, California-based Encorel has killed the belief that new wines cannot come in an old bottle. It grosses $3 million a year by collecting cases of empty bottles and selling them back to the wineries. An automobile remanufacturing firm in New Jersey has remanufactured over 400 cars in the last few years. The business community must be more responsible and far-sighted in resource use. Educators need to bring in a high level of awareness. The government and other public organisations need to be aware of these dangers and provide policies within a framework of environmental sustainability. We need to understand the economic value of austerity and bring it into business operations and our daily lives.

3.6 REMANUFACTURING

A key strategy in creating sustainable operations is the deployment of a recoverable manufacturing system that focuses on systems designed to extend product lifecycles through remanufacturing and repair. These are concerned with the management of the flow of materials (known as cores) from the consumer, transformation of these cores into products that satisfies the original quality and finally managing the flow of remanufactured products to the final customer through distribution centres. This forms a closed-loop logistics system. Remanufacturing is the process of restoring end-of-life products (cores), components, modules, and parts to an almost new condition in a manufacturing environment. The restoration or recovery process is probably to be energy saving, less material consuming, and often have a lower impact on the environment than traditional manufacturing, which makes brand-new products from virgin materials. The basis of a recoverable manufacturing system is remanufacturing.

Several items are remanufactured now-a-days. The most frequent examples are rechargeable batteries for automobiles and printer ink cartridges. Other products that are remanufactured include machine tool, medical instruments, copiers, automobile parts, computers, office furniture, mass transit, aircraft, aviation equipment, telephone equipment, and tires. Remanufactured parts are sometimes used as service parts. This can be especially attractive if the product itself is in the final phase of its lifecycle ad is being withdrawn. In that phase, manufacturing new parts can be expensive as they are no longer needed in large quantities. A viable strategy, therefore, could be remanufacturing parts that are disassembled from returned products.

> Remanufacturing is the process of restoring end-of-life products (cores), components, modules, and parts to an almost new condition in a manufacturing environment.

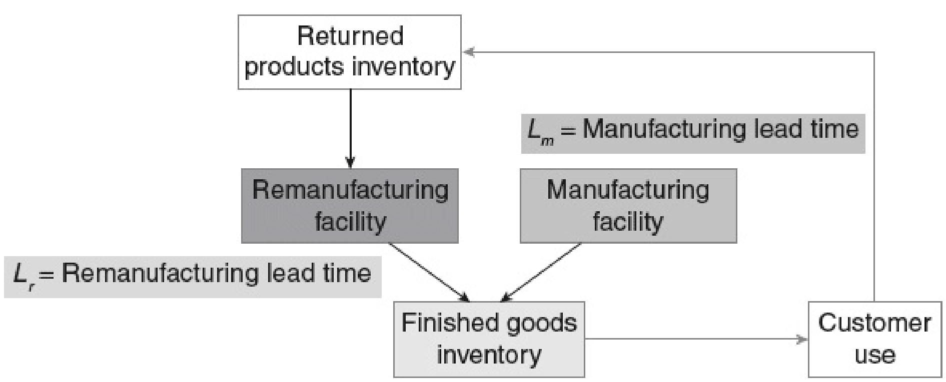
For a remanufacturing operation to function effectively, an organization must be concerned not only with the planning for the traditional forward flows of goods to the customer but also the reverse flow of returned products from end users. Unlike the forward flow, the reverse flow of used products poses certain challenges. First, there is uncertainty in the quantity, quality, and timing of the reverse flows. This is because of the usage pattern of the customers, individual preference of the customers about what constitutes useful life and how disposal needs to be done. The installed base of the product also influences the quantity of inflow of returned products. Organizations can resort to buy-back practices to partly address the quantity and timing uncertainty. However, the quality uncertainty is hard to address. Furthermore, it introduces complexities in the remanufacturing operations. The other challenge will be the difficulties in logistics. The condition of the returned product, the handling complexities, especially when there are toxic remains in the returned product, cleanliness, and other conditions make it difficult to organize an efficient PTN.

For a remanufacturing operation to function effectively, an organization must be concerned not only with the planning for the traditional forward flows of goods to the customer but also the reverse flow of returned products from end users.

In current industry practice, manufacturing typically constitutes the primary source of satisfying demand and firms resort to remanufacturing as a secondary source to complement manufacturing output. However, an increased emphasis in creating sustainable operations may reverse this trend. An organization with a remanufacturing system will have two sources for raw material. This includes returned and remanufacturable items and new component inventories. In view of the fact that remanufacturing a returned product is on an average less costly than manufacturing a new product, priority is given to remanufacturing in replenishing the finished goods inventory. In a way, manufacturing is treated as a secondary source for satisfying demand, which is used only when there is not sufficient stock of returned products to remanufacture.

Figure 3.4 is a schematic representation of a remanufacturing facility that receives returned products from the customers after useful life. An inventory of returned products is maintained, waiting to be remanufactured. All returned products are fit for remanufacture and after the remanufacturing process are as good as new products. Therefore, there are now two sources for supply of product—the regular manufacturing facility and the remanufacturing facility, although the lead times to supply the product vary between the two facilities. Unlike the simple inventory control models, we need to develop appropriate decisions for both the returned products being manufactured through the remanufacturing facility as well as the new products being manufactured in the manufacturing facility. It is possible to make necessary modifications to existing well known inventory control models to address this requirement. We shall see a variation of the traditional periodic review model of inventory control.[1]

FIGURE 3.4 A schematic representation of a remanufacturing facility



ideas at Work 3.4

Green Manufacturing Excellence Awards

Frost & Sullivan has constituted a green manufacturing excellence award in order to recognize and promote the efforts by business organizations towards sustainable practices. The assessment process is designed to evaluate the progress made by an organization towards identifying and implementing sustainable manufacturing practices in its operations and supply chain. Systematic identification and effective implementation of systems towards mitigating short- and long-term sustainability risks will be assessed. Goal setting and projects deployment for each of these parameters will be evaluated in addition to assessing the long-term objective of this initiative and its business links.

The assessment methodology consists of 11 parameters on which a participating organization will be assessed for their green manufacturing excellence efforts. The total points for all these add up to 1300 and the details are as follows:

1. Goal Setting and Deployment (100 points)
2. Waste (100)
3. Effluents (100)
4. Water (100)
5. Green Procurement (100)
6. Products & Services (50)
7. Society (50)
8. Bio-diversity & General Compliance (50)
9. Material (200)
10. Occupational Health & Safety (150)
11. Energy (300)

At the end of the assessment, the participating organizations will be given a feedback on the strengths and opportunities for improvement. Comparative analysis with other companies in the country will also be shared.

There are three levels of recognition based on the score obtained by an organization. Organizations getting 900 and over are classified as leaders and those between 800 and 900 as challengers. The organizations that score between 700 and 800 are designated as believers. All companies that qualify in any of the three bands will be recognized with their respective 'Certificate of Merit'.

Source: Based on http://www.frost.com/prod/servlet/summits-details-summary.pag?as=attend&eventid=283496670. Last accessed on August 5, 2014.

3.7 PERIODIC REVIEW INVENTORY CONTROL FOR REMANUFACTURING

A periodic review inventory control system works on the basis of reviewing the inventory in fixed intervals, known as review period (R). During every such review, decisions are made with respect to the quantity of material to be ordered so that a firm incurs minimum cost of the overall inventory plan. Similar to the periodic review inventory control for manufacturing inventory (see

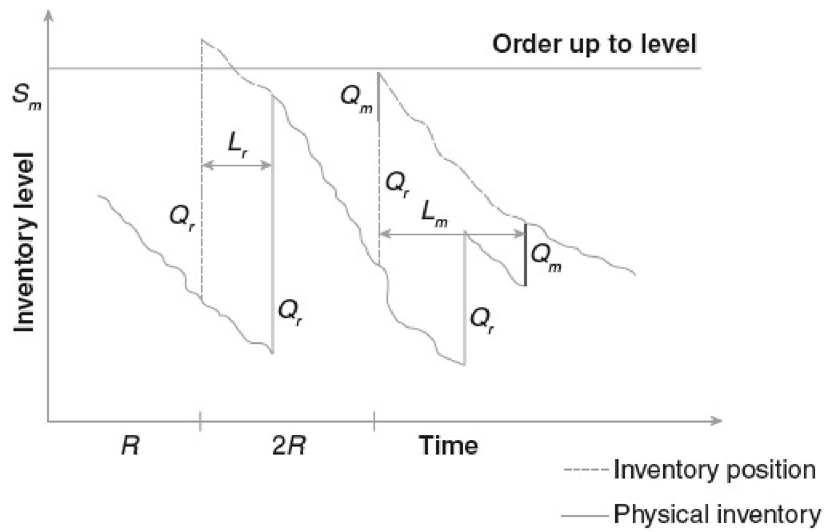
Chapter 17, Section 17.6 for details), there will be an order-up-to level, S, which will eventually influence the inventory ordering decision.

The remanufacturing production process could be controlled by a periodic review, push policy that operates as follows. Every R periods, all returned inventory is pushed into the remanufacturing facility. Let this quantity be denoted by Q_r. Since returns are uncertain, this quantity will vary from one time period to another. I_R denotes the inventory position of the finished goods available for market consumption. Inventory position is the inventory on hand, less backorders, plus any outstanding (manufacturing or remanufacturing) orders. If, after releasing the remanufacturing batch, I_R is less than the manufacturing order-up-to level S, then an order Q_m, is placed in the manufacturing facility to bring inventory position up to S. Therefore, $Q_m = \max(0, S - I_R)$. Figure 3.5 illustrates the working of the system. The total relevant cost (TC) for the plan is the sum of inventory carrying costs for returned products and finished goods and backorder costs. The decision variables S and R determine the overall performance of the system.

Establishing parameters R and S are critical for effective functioning of the system. Choosing R is relatively easier of the two. R can be chosen on the basis of setup times and batch sizes using an economic lot sizing algorithm. Alternatively, other managerial considerations such as preferred reviewing cycles could be the basis for fixing R. However, there are no straightforward methods to fix S. This is because both the demand for the finished goods in the market as well as the quantum of returned goods are stochastic. Therefore, use of heuristic methods and simulation can help identify a near optimal value for S. One can use the traditional models and make simple intuitive adjustments to them in order to suit the current requirement. Such attempts often provide promising results and enable practitioners fix the parameter S easily.[2]

The remanufacturing production process could be controlled by a periodic review, push policy of inventory control.

FIGURE 3.5 Periodic review inventory control system for remanufacturing



3.8 CHALLENGES IN CREATING SUSTAINABLE OPERATIONS

Despite the mounting importance of sustainability, organizations are still making scanty efforts to inculcate a culture of sustainability. Strategy making process and the operational choices in functional areas of business are still not emphasizing sustainability. There are several reasons attributed to these.

Lack of Regulatory Framework

Public policy and government organizations are increasingly taking a tougher posture on matters pertaining to sustainability. The multi-lateral global summits are also putting pressure on the government to bring in new legislations. The emission norms for vehicles (such as Bharat Stage IV), regulations on disposal of e-waste, and product take-back regulations are a few examples. In a country such as India, while some of the emission control norms have been put in place, regulations such as product take-back are still not enforced. Furthermore, there is a serious deficiency in enforcement of the existing regulations. In the years to come, we will see tighter control, better enforcement, and strict compliance reporting requirements on the part of business organizations.

VIDEO INSIGHTS 3.2

Implementing sustainable operations requires changes in several aspects of doing business. This ranges from developing new products, altering the manufacturing facility and office buildings, helping the customers identify new opportunities, and educating the society at large. Grundfos India is engaged in some of these aspects of sustainability. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Mindset Inertia

Organizations are used certain ways of working. The new changes demanded by sustainability norms force them to change their mindset with respect to many activities that they perform. For example, the design philosophy must undergo major changes as we saw already. Management control systems must promote use of better materials and recycling and remanufacturing activities. These changes are less probably to happen immediately as there is no perceived value in these in a direct fashion. Operations managers and design engineers will see these as needless new complications in their ways of working.

> The new changes demanded by sustainability norms will force operations managers and design engineers to change their mindset with respect to many activities that they perform.

Lack of Top Management Vision

In order to address the mindset inertia issues in an organization, the top management must step in and lead the change. The employees need to be adequately communicated of the need to create sustainable organizations for the future and the nature of changes required to make this transition. They also need to be appraised of their changed role in the process. Furthermore, on account of introduction of new technology to address sustainability they need training and reskilling. Top management must play a significant role in this change management process. If the top management suffers from a lack of clarity and vision, then it will pose greater challenges in creating a sustainable organization.

Inability to See the Big Picture

One of the important reasons for the top management having less commitment in creating a sustainable organization for the future is their inability to see the big picture ahead. In the future, only organizations with a clear vision and strategy of honouring the overall principle of sustainability are probably to survive. If this idea is not well understood, then the top management will not be able to see the big picture ahead. Failure to see the big picture introduces several problems in the organization's journey towards creating a sustainable organization. For example, it will be difficult for the top management to lead the efforts as there will be lack of conviction. They will find it difficult to communicate the changes required and carry on the rest of the organization with them. There will be lack of clarity when it comes to making significant investments in the transition.

Need for Substantive Investments

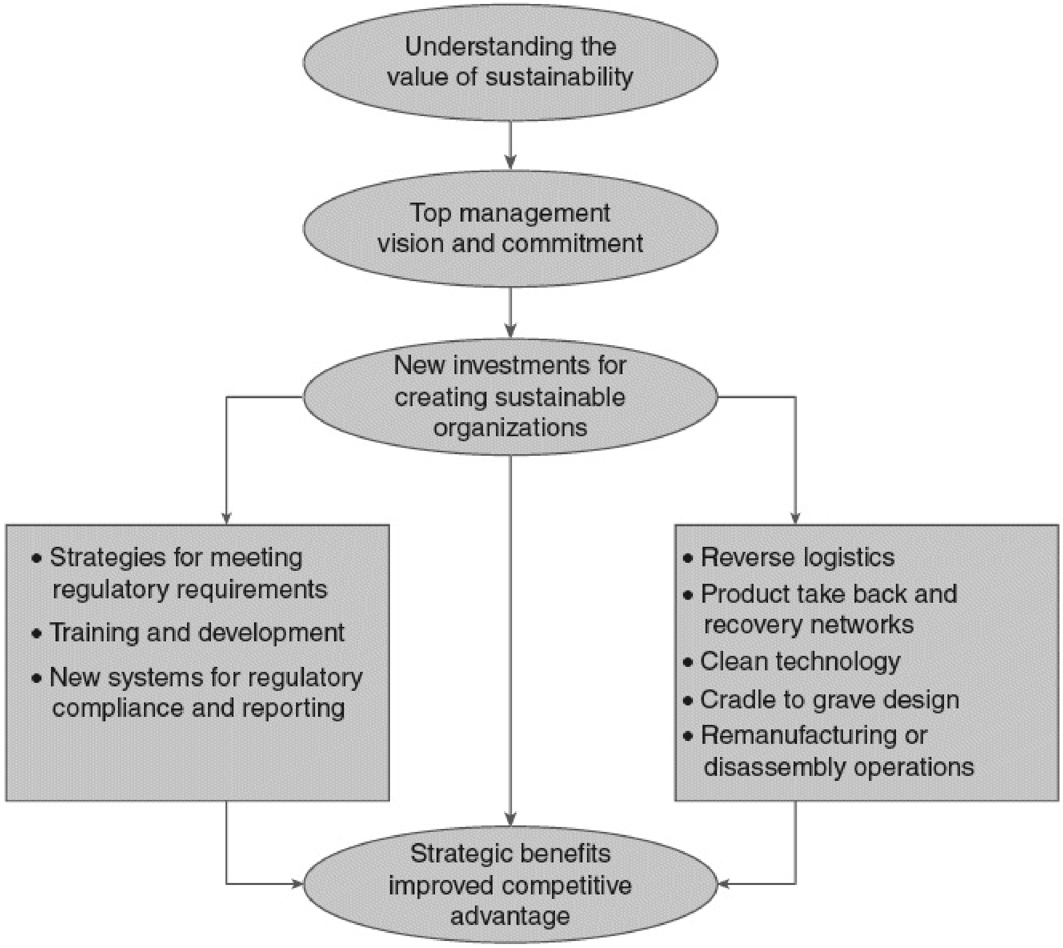
Creating a sustainable enterprise requires substantial new investments. For instance, the entire approach to facilities design may need a change. Investment in LED-based lighting systems, harnessing natural lighting, air circulation cooling, wind energy, and solar energy may require structural alteration of physical facilities, and addition of new infrastructure. Similarly, major changes will be required in energy usage patterns, choice of material and technology. On the other hand, products and services will go through design changes, and the manufacturing and process technologies will also be modified. All these require substantial investments and a traditional pay-back and quick ROI methods of investment justification will fail miserably and block introduction of the proposed changes.

Benefits are Notional, not Obvious

In the current state of affairs, the benefits arising out of creating sustainable organizations are notional. We are yet to reach a situation that the consequences of not being sustainable are costly operations and shrinking market share. On the other hand, customers are not yet ready to pay a premium for products and services that are responsible towards nature and environment. Therefore, organizations need to get motivated by other reasons to create sustainable operations. Leadership traits such as taking a long-term view of things, a passion to be more harmonious with nature are some of the reasons that can drive an organization towards being sustainable.

> Creating a sustainable enterprise requires substantial new investments. A traditional pay-back and quick ROI methods of investment justification will fail miserably and block introduction of the proposed changes.

FIGURE 3.6 A framework for creating sustainable organizations



Crisis Is Yet to Blow Over

The most important impediment in creating sustainable organizations is that there is no imminent threat to the operations of the organization. Even though we pollute and exploit natural systems by and large, the market seems not to punish organizations for their unsustainable acts. Nor are there strict regulations and enforcement by governmental organizations. In the absence of strict regulations, these organizations will have no motivation to create sustainable operations. They will merely pay lip service and act in a slow manner.

For these reasons, organizations really need prior thinking and careful planning to create sustainable operations. Figure 3.6 portrays some of the step that an organization may sequentially take to truly imbibe sustainability. The first step in the process is the leadership team developing a clear understanding of the value of sustainability and the long-term benefits that can accrue to the organization. With such an understanding a vision for creating a sustainable organization will emerge unambiguously. This will guide the organization towards developing a set of medium-term action plans. Several areas will be identified that requires new investments. This will be of two types. One set of investments is to develop physical structures, technology, and associated things. The other set of investments will be in softer systems pertaining to training, development, development of new reporting and compliance systems, and new software. A proper understanding of the value of creating sustainable organizations and appropriate investments in systems will reward the organization with strategic benefits in the market place. The perceptions of the customers about the organization and the products and services it offers will change. In the long run, the organization will improve its competitive advantage vis-à-vis its competitors.

SUMMARY

- The economic viability of organizations may be threatened if the issue of sustainability is not factored into organizations.
- Sustainability pertains to development that meets the needs of the present without compromising the ability of future generations to meet their needs. From a business perspective, the operational definition of sustainability will encompass three dimensions: social, environmental, and economic.
- Implementing a sustainable operations management (OM) system may involve newer systems, skills, alternative philosophy, and approach to several OM practices in an organization.
- In an organization promoting sustainability as a key value, the design efforts must focus on minimizing not only pollution from manufacturing but also all environmental impacts associated with the full lifecycle of a product.
- Design for environment is a structured set of methodologies that enable an organization create products and services that are easier to recover, reuse, or recycle.
- Reverse logistics begins at the customer end and eventually ends at the original equipment manufacturer. It consists of a product take-back network and a product recovery network. There are several entities involved in reverse logistics.
- Remanufacturing is the process of restoring end-of-life products (cores), components, modules, and parts to an almost new condition in a manufacturing environment. For a remanufacturing operation to function effectively, an organization must be concerned about the reverse flow of returned products from end users.
- The remanufacturing production process could be controlled by a periodic review, push policy of inventory control.
- Despite the mounting importance of sustainability, organizations are still making scanty efforts to inculcate a culture of sustainability. There are several reasons attributed to these.

REVIEW QUESTIONS

1. What do you understand by the term sustainability? What are the dimensions of sustainability that an organization must focus on?
2. Do you agree with the statement, ‘Organizations may greatly benefit from creating sustainable operations’? Substantiate your argument with examples.
3. What do you mean by sustainable operations?
4. Identify three areas of operation management that will undergo significant changes in an organization promoting sustainability.
5. Why should organization perform a ‘cradle-to-grave analysis’ while designing new products and services? 6. How does a product take-back network promote sustainability in operations?
7. Distinguish between the following terms:
    a. A manufacturing system and a remanufacturing system
    b. Forward logistics and reverse logistics
    c. Product take-back network and product recovery network
8. What are the impediments an organization faces in its journey of creating sustainable operations? How can these be addressed?

NET-WISE EXERCISES

The Nokia People & Planet Report covers the key ethical, socioeconomic, and environmental issues relevant to Nokia's business and stakeholders. It covers Nokia's approach to sustainability and the focus areas, and reports their progress against the set targets. Visit the URL http://company.nokia.com/en/about-us/people-planet/sustainability-reports to access the sustainability reports. Read the Nokia People & Planet Report 2013 to understand various steps taken by Nokia with respect to sustainability.

ITC believes that a company's performance must be measured by its Triple Bottom Line contribution to building economic, social, and environmental capitals. Adopting this approach, the company has unleashed multiple drivers of growth in India, ensuring long-term sustainability and competitiveness of its businesses. It is a voluntary disclosure initiative on the part of ITC Ltd. Read the ITC Sustainability Report 2013 by visiting the URL http://www.itcportal.com/sustainability/sustainability-report-2013/sustainability-report-2013.pdf.

Based on your understanding of the issues discussed in these reports answer the following questions:

a. How does Nokia and ITC approach the issue of sustainability? Compare and contrast their approaches to the issue of sustainability.
b. Identify the major operations management practices that have been affected by sustainability at Nokia and ITC.
c. Comment on the measures of performance chosen by Nokia and ITC to measure their progress on matters pertaining to sustainability.

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CHAPTER 4

Project Management

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- How does the planning and control of projects differ from other operating systems?
- What are the various phases in project management? What are the organizational mechanisms employed for effective planning and control of operations in a project?
- What are the elements of a network analysis of projects? What are the alternative methods by which a project can be graphically depicted for the purpose of analysis?
- What do you understand by the critical path method (CPM) and the programme evaluation and review technique (PERT)? How can various aspects of CPM and PERT be used for decision making in project planning and control?

There are several occasions when organizations perform large-scale activities in a non-repetitive manner. These include building a manufacturing facility, designing new products, constructing bridges and roads, and designing new services. Project management helps in the planning and control of these activities by providing the required tools and techniques.

ideas at Work 4.1

Terminal Three at Indira Gandhi International (IGI) Airport, New Delhi

Delhi International Airport Limited (DIAL) is a joint venture consortium of GMR Group, Airports Authority of India (AAI), Fraport, and Malaysia Airports Holdings Berhad (MAHB). In January 2006, the consortium was awarded the concession to operate, manage, and develop the Indira Gandhi International Airport (IGI) following an international competitive bidding process. DIAL entered into Operations, Management, and Development Agreement (OMDA) on 4 April 2006 with the AAI. The initial term of the concession is 30 years extendable by a further 30 years.

In March 2010, DIAL has completed the construction of integrated passenger terminal (Terminal three). The integrated terminal handles both the international and domestic passengers. The first phase of the airport has been designed to handle 60 million passengers per annum. Built over a 5.4 million square feet area the structure is a nine-level passenger terminal building with two piers each 1.2 km long. The baggage handling system has a capacity to handle 12,800 bags per hour. There are six common check-in islands housing 168 check-in counters. In order to handle the international traffic, the airport has 95 immigration counters (49 outbound and 46 inbound immigration counters). There are also 78 passenger boarding bridges (including three passenger boarding bridges for A380 or similar sized aircraft).

There are several passenger amenities integral to the airport. The airport has a 100-room transit hotel for domestic and international passengers (68 rooms for domestic transit and 32 rooms for international transit). For the convenience of the passengers the airport has 96 automatic travelators /walkways (longest one being 118 metres in length). It also has over 20,000 square meters of retail space and a multi-level car park to accommodate 4,300 cars.

The two tier terminal building features the departure complex on the upper level and the arrivals on the lower level. The roof of the building has stylized incisions to allow daylight and has been angled to protect the interior from direct sunlight. The effect creates a calm environment and maximizes the sense of volume, space, and light inside. The use of natural light will reduce the dependency on artificial light during day-time. Access to the new terminal would be via a six lane approach road. The airport has been connected through dedicated high speed metro line connecting to the city centre. Terminal three was inaugurated on 3 July 2010.

Available information suggests that project pertaining to building terminal three of IGI airport has been executed very well. The table below shows the comparative performance with other similar airports in the world.

TABLE 4.1 Comparative Project Management Performance

Airport	Capacity	Time
Changi Airport – Singapore (*T*3)	22 Million	76 months
Heathrow *T*5 – London, UK	25 Million	60 months
Beijing Airport New Terminal for Olympics – *T*3, China	45 Million	60 months
IGI Airport – *T*3, New Delhi, India	34 Million	37 months

Building such a mammoth airport requires a different set of tools and techniques adopted by a typical manufacturing or a service company engaged in known set of activities which are typically repetitive in nature. Further, it calls for greater degree of coordination among multiple stake holders spanning over several years. The work will be characterized by large size and complexity leading to unprecedented levels of uncertainty. The collective set of tools used to handle such situations is called project management. We shall see more details in this chapter.

Source: http://www.newdelhiairport.in/master-plan.aspx, http://www.newdelhiairport.in/our-company.aspx

Project management offers alternative tools and techniques to address the planning and control issues pertaining to large-scale activities performed in a non-repetitive manner.

There are several occasions when organizations perform large-scale activities in a non-repetitive manner. These include building a manufacturing and service facilities, designing new products, the construction of bridges and roads, and designing new services. These activities differ greatly from the normal manufacturing and service operations. Typically, these are one-off activities done at less frequent intervals. Several sets of activities need to be performed in a particular order to accomplish the task. Moreover, the complex resource and time requirements for performing these activities, as well as the possibility of simultaneous occurrence of events, requires one to deploy systematic methods for planning and control. Moreover, the planning and control of these activities requires a different set of tools. **Project management** offers alternative tools and techniques to handle the planning and control of the activities described above and we focus on this issue in this chapter.

4.1 CHARACTERISTICS OF PROJECT ORGANIZATIONS

Before we discuss the available tools and techniques for project management, it is important to understand how project organizations differ from other organizations. Such an understanding is important, as it provides some guidelines for managers to effectively plan, monitor, and control these organizations. We identify four attributes to characterize a project organization.

1. **Different from mainstream activities:** Projects involve activities that are clearly different from mainstream activities. Take, for example, the designing of a new product. The type of activities involved in designing a new product is different from other regular activities that an organization may perform, such as planning for production, purchase of material, or production scheduling. As we will see in Chapter 11, new-product development involves understanding customer needs, market offerings, the technology available at the time of design, and the methods to be utilized for designing and manufacturing the product. Normally, organizations put together a team of resource persons to accomplish this task to meet time and cost targets. Clearly, these activities are different from the mainstream and tend to be non-repetitive in nature.
2. **No expertise currently available:** In several organizations, when certain types of expertise are not available at a time, a committed set of resources and people are required to acquire the new expertise in a finite time. Achieving this target has several features common to the earlier example of new-product development. It calls for planning activities that are different from the mainstream. Think about Chandrayaan, the lunar mission of the Indian Space Research Organisation (ISRO), which was launched in October 2008. When the project started, ISRO would have had very little expertise for Chandrayaan. Similarly, think about how ISRO develops its next generation of satellites and satellite launchers through a systematic process of acquiring the required technology, talent, and resources. The manner in which they do this is different from the normal production methods employed in any manufacturing organization. In such a situation, the organizational forms, the performance standards, and the planning and control tools required are likely to be different from the normal production-oriented tools. Having a project-oriented organization fulfils the requirements for achieving this objective.

   In several other situations, although a new product or service is available, the areas of competency are not yet demonstrated. In such cases, sustained dedication of resources and a time-bound approach to acquire the competency is required. For example, in an organization that has recently purchased a new gas turbine for in-house generation of power, installation and maintenance of gas turbine is done using alternative planning and control tools until sufficient experience is gained in handling the equipment. Normal methods of performance evaluation and control are not applicable to this situation until the personnel acquire sufficient competency.
3. **The product or service offered is large scale:** When the product or service offered is of very large scale, it introduces problems that are normally not encountered in regular operating systems. Therefore, the tools already available for operations management are not appropriate for the planning and control of such systems. Very large systems introduce the following additional problems that require alternative methods for planning and control:
   a. *Going from a subsystem to a total system*: Consider a situation in which the quantum of effort required to complete the task is large, as in the case of building a multi-storied commercial complex of over 1,000,000 square feet. Such a case involves multiple entities (architect, engineers, government regulatory bodies,

construction workers, the local community and society, and so on). It also involves multiple stages of the process (designing of the building, the foundation, the superstructure, the electrical systems, the heating and air-conditioning system, the carpentry, the plumbing, fabrication activities, acoustics, landscaping, horticulture, and so on). Managing such a large set of activities requires different methods of planning and control. It is useful to break down the set of activities into several subsystems and provide methods of linking one subsystem with the other.

b. *Long lead times*: The characteristics we just discussed invariably also indicate long time periods for completion. For example, in the case of developing the next generation of satellites by ISRO, the total duration will be anywhere between five and eight years. Similarly, the time required from developing the initial concept to commercial production of a passenger car could be in the order of two to three years. Managing activities over such a long span of time is not possible with the traditional tools available for production planning and control. Therefore, alternative tools and techniques are required. Moreover, it is also desirable to break down the entire set of activities and classify them under shorter time periods for the purpose of planning and control.

4. **High degree of customization:** Several manufacturing and service systems may offer a smaller number of products and services. Yet, there could be considerable amount of customization involved in the process. The Nuclear Engineering Division at Bharat Heavy Electricals Limited (BHEL), Tiruchchirappalli, has been manufacturing several components for nuclear reactors for the last two decades. Yet, each product that it delivers to a customer could vary substantially from the earlier orders. The manufacture of power plants and large power transmission systems are similar examples. Planning and control tools used for repetitive manufacturing are not appropriate for these activities.

VIDEO INSIGHTS 4.1

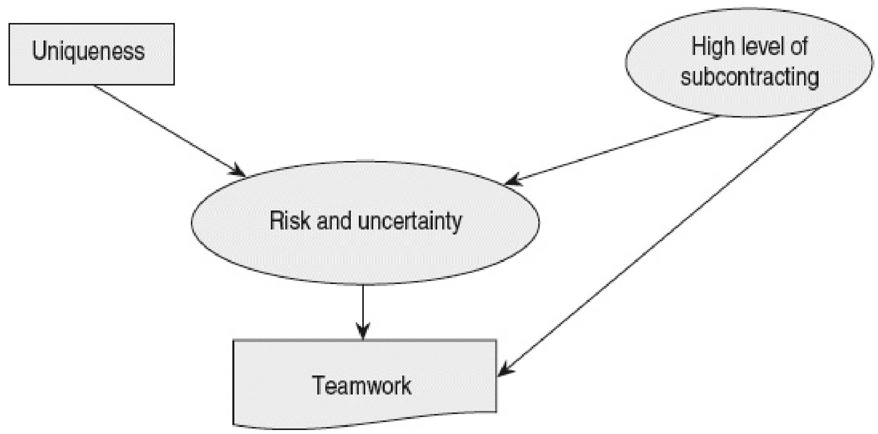
Building a large airport terminal is a good example to illustrate the multi-faceted nature of project management and the unique challenges that one is possibly to face. A case in point is the Terminal 2 of Chatrapathi Shivaji International Airport, Mumbai. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

There are several common features in these situations. First, the degree of uncertainty in all these cases is likely to be significant. Planning tools that incorporate this uncertainty are greatly required to manage such situations. Second, the number of entities involved in accomplishing the various tasks is many. Furthermore, these entities have numerous complex interactions among them. The performance standards of one entity or deviations from the specifications at one part of the system have a significant impact on the other. If any set of activities involved in an organization has any of the above attributes, then such activities could be planned and controlled using tools and techniques collectively known as project management.

Project activities are likely to be unique and may involve high levels of subcontracting, breaking down the system into several subsystems, and managing these and their interfaces.

Figure 4.1 brings out the salient features of project activities. Project activities are likely to be unique and may involve high levels of subcontracting, breaking down the system into several subsystems, and managing these and their interfaces. Due to this, the risk and uncertainty of task completion are likely to be high and may call for appropriate organizational mechanisms to mitigate these. Appropriate organizational forms that promote teamwork—not only among the various functional areas within the project organization but also between other organizations and participating subcontractors—will be an important requirement.

FIGURE 4.1 Salient features of project activities



4.2 THE PHASES OF PROJECT MANAGEMENT

Managing any project involves four key phases (see Figure 4.2). In the first phase, activities focus on conceptual details pertaining to the project. The broad objectives of the proposed project are first set. After that, based on a conceptual design and an initial project appraisal, the feasibility of the project is established. This is followed by a budgeting exercise. Targets for the time and the cost of the project are also established during this phase.

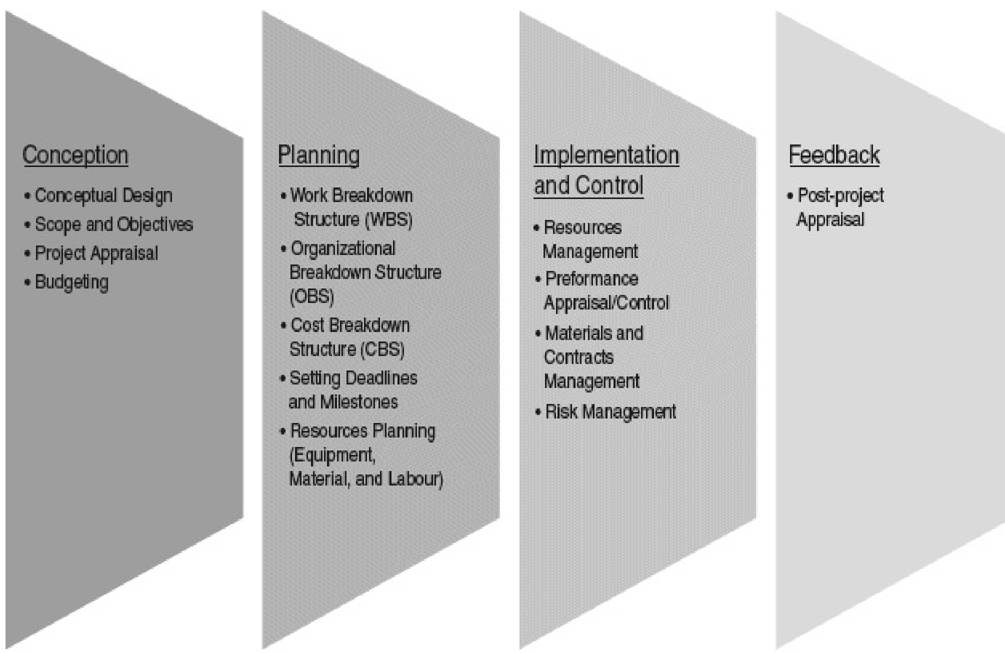
> Managing any project involves four key phases: *conceptual detailing, planning, implementation,* and *post-project appraisal.*

Let us consider the case of setting up a Mass Rapid Transit System (MRTS) for the city of Bangalore as an example. In the conceptual phase, the project promoter—in this case Bangalore Metro Rail Corporation Limited (BMRCL)—will have to arrive at the objectives of the project. The objective could be to provide alternative channels for the public to travel in the city or an affordable mode of transport. On the other hand, the objectives could also be reducing the pollution levels in the city or de-congesting the main business areas in the city by January 2016. Depending on the objective, various elements of the design should be worked out. For instance, meeting the objective of providing an affordable mode of transport may influence the choice of technology, the time frame for completion, major elements of design, and the budgeting differently, as compared to meeting the objective of de-congesting the city by January 2016.

Planning constitutes the second phase in project management. In this phase, detailed planning is carried out and milestones for completion, review, and control of the project are established. Since projects are often huge and get completed over several years, it is useful to break it down into smaller systems. Furthermore, to have tighter control and monitoring, a hierarchy of levels needs to be established in the project. For each of these levels, targets for completion time, cost, and an organization structure could be established. At the detailed planning level, activities that need to be performed along with their interaction with other activities would have been identified. Using this information, a network or a graphical representation of the project could be made and used for the purpose of planning and control.

In our example, the total distance to be covered by the MRTS would be split into three or four stages of completion. For each stage, the activities would be grouped on some basis. Acquiring land for the project would have been one group, civil engineering activities another, electro-mechanical could be the third, track-laying and signalling could be another, and so on. Within each group there could be further subdivisions: For example, under civil engineering, constructing stations and amenities could be one subgroup and building bridges could be another. Once such groups are identified, the resources, time, and cost involved for each activity could be estimated. Finally, all these could be represented in the form of a graph and used for planning, analysis, monitoring, and control.

FIGURE 4.2 The four phases of project management



In the implementation phase, the focus shifts to the execution of the plans. Managing the resources and the interactions among a large number of contracting organizations is one main activity. Measuring the performance of the project and its progress and reacting to real time issues such as time and cost overruns are done during this phase. More resources are sometimes employed to hasten the project and restore schedule adherence. Since the degree of uncertainty in projects is likely to be high, certain corrective measures need to be taken to bring the project back on track. A good performance-monitoring and review system is required to take several decisions during the implementation phase.

Returning to our example, in this phase, cost and time targets established for each subsystem and activity of the MRTS project would be constantly monitored. Completion of bridges might have been scheduled for September 30, 2014. If this activity gets delayed, then the project review and monitoring system would bring it to the attention of the decision makers. Alternatives will be evaluated to bring the project back on track. These may, for instance, include employing more people at the site, resorting to alternative manpower planning, revising cost estimates and in some cases, the completion date itself.

Projects often tend to be one-off activities. Nevertheless, several elements of planning and control employed in a project could be utilized in future projects. Therefore, post-project appraisal is the logical end and is important in any project. The key learnings from a project need to be documented, analysed and archived for future reference. Such a practice pushes an organization up in the learning curve, no matter how unique the executed projects are.

4.3 A FRAMEWORK FOR PROJECT MANAGEMENT

While the previous section details the various steps required for project management, it does not show how exactly an organization could go about the task. A good framework for project management must answer some key questions that a manager faces while planning and executing projects (see Figure 4.3):

- How should the large set of activities be systematically broken down and used as the basis for planning and control?
- How should the manager allocate the resources for the project (that is, who should be responsible for execution and monitoring of various activities in a project)?
- What are the targeted costs for completion of each element of the project?
- When should each of these elements be scheduled for execution?
- How well has the project been progressing?

> **Work breakdown structure (WBS)** is an organized methodology used to split an overall project into non-overlapping components and identify deliverables for each component.

A good framework for project management will provide the project manager with tools and techniques for answering these questions.

We shall look at these questions in some detail and understand the methods employed for answering them.

Work Breakdown Structure

Work breakdown structure (WBS) is an organized methodology used to split an overall project into non-overlapping components and identify deliverables for each component. For the example of the satellite telemetry tracking station discussed at the beginning of the chapter, the network representation of the project shows one level of WBS. The civil engineering group may consist of several sets of activities. Identifying them and grouping them homogeneously into a few components will constitute the next level. Depending on the complexity of the project, multiple levels are created. At the lowest level, however, specific work packages and the nature of resources required to complete each work package are clearly identified.[1] Therefore, at this level, it is possible to establish deliverables in terms of time of completion and cost to be incurred. WBS resembles a typical bill of material in a production planning scenario.[2]

FIGURE 4.3 A framework for project management

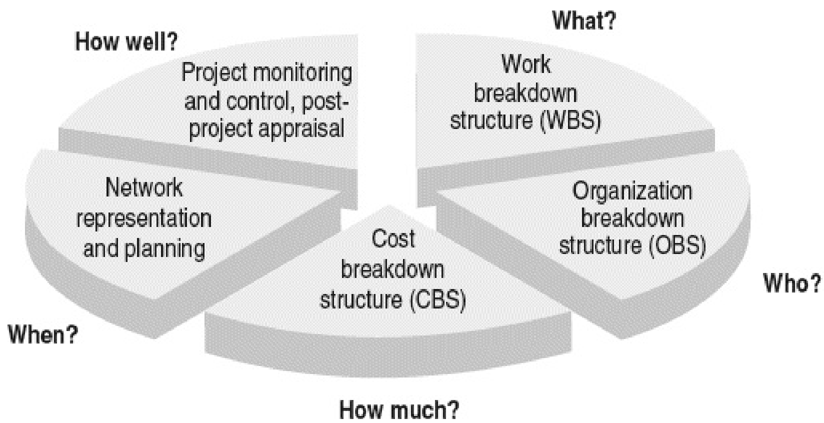
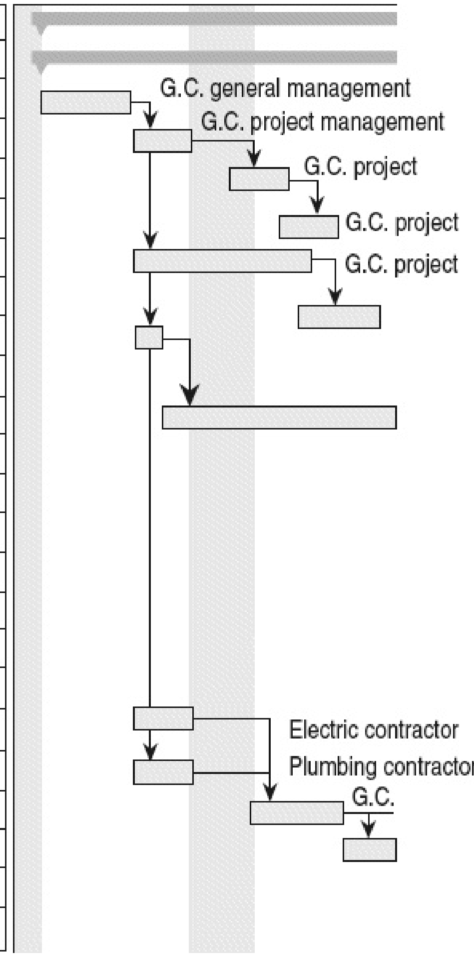


FIGURE 4.4 A partial list of a work breakdown structure for a construction project

⊟ Three-story office building (75,000 square feet)	**344 days**
⊟ General conditions	**17 days**
Receive notice to proceed and sign contract	3 days
Submit bond and insurance documents	2 days
Prepare and submit project schedule	2 days
Prepare and submit project schedule	2 days
Obtain building permits	4 days
Submit preliminary shop drawings	2 weeks
Submit monthly requests for payment	1 day
⊟ Long lead procurement	**70 days**
Submit shop drawings and order long-lead items	2 weeks
Submit shop drawings and order long-lead items	2 weeks
Submit shop drawings and order long-lead items	2 weeks
Submit shop drawings and order long-lead items	2 weeks
Submit shop drawings and order long-lead items	2 weeks
Submit shop drawings and order long-lead items	2 weeks
Detail, fabricate and deliver steel	12 weeks
⊟ Mobilize on site	**10 days**
Install temporary power	2 days
Install temporary water service	2 days
Set up site office	3 days
Set line and grade benchmark	3 days
Prepare site: lay down yard and temporary fence	2 days
⊟ Site grading and utilities	**35 days**



WBS serves the important task of providing a clarified view of the activities to be performed in a project and provides the reference for estimating activity duration, network representation of the project, planning, monitoring, and control. It also helps the manager to understand the interaction among the activities and the need to manage the interface points as the project progresses. Furthermore, it provides a basis for creating an appropriate project organization and establishing milestones and control points for project evaluation. Figure 4.4 shows a partial list of a work breakdown structure for a three-storey commercial building construction project.

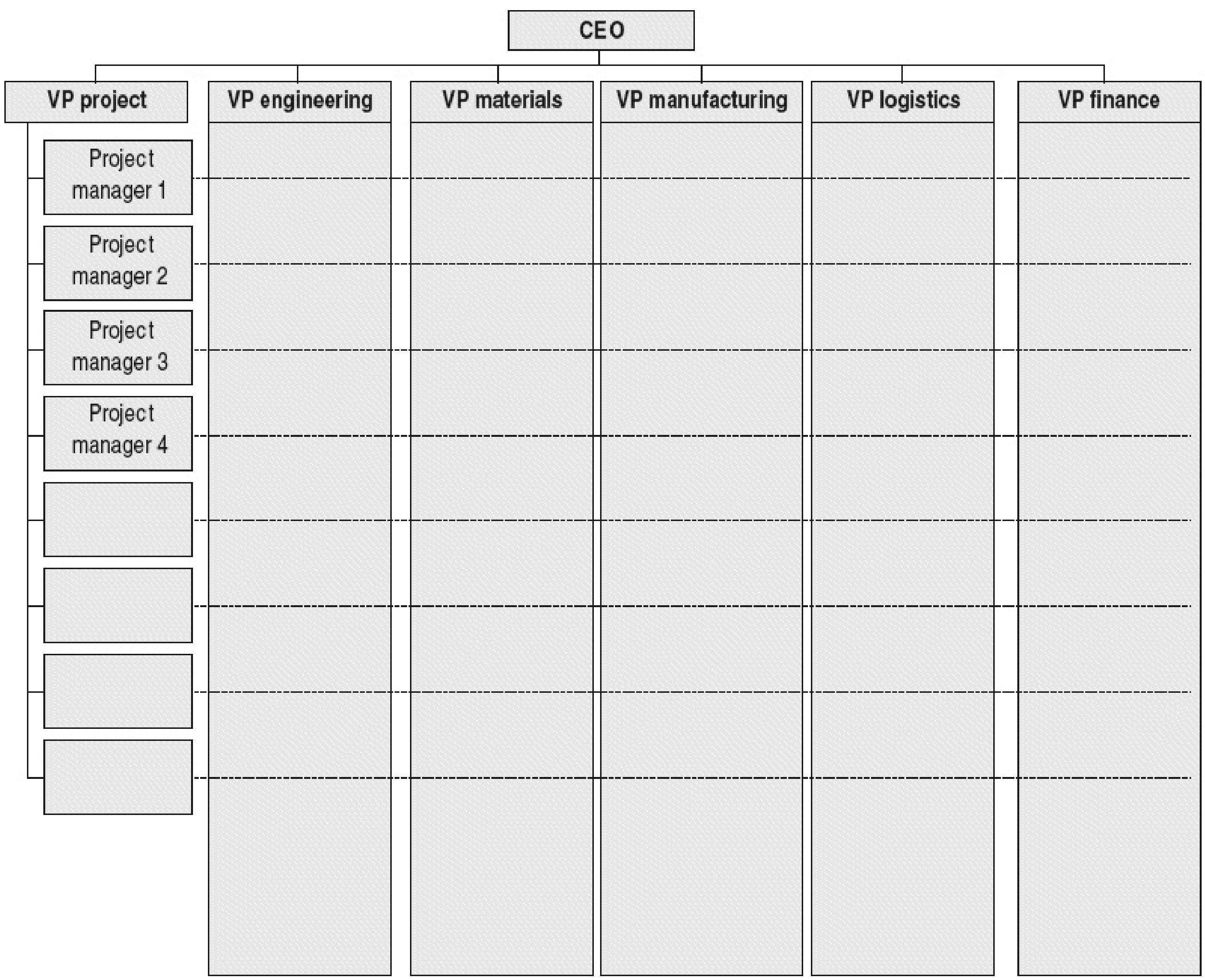
Organization Breakdown Structure

While WBS identifies what needs to be done for project execution, a logical fallout of this exercise is to identify an **organization breakdown structure (OBS)** to execute the tasks listed under each work package. Based on the nature of tasks involved, the functional expertise required is identified for each element of WBS. This complementary structure is known as OBS.

> An **organization breakdown structure (OBS)** identifies an appropriate organizational structure to execute the tasks listed under each work package.

At the highest level, the OBS essentially addresses an appropriate form of organizational structure for a project. A matrix type of organization is often found to be appropriate for project organizations at this level. Figure 4.5 depicts a typical matrix organization structure. In a matrix organization structure, a project manager has a dual role.[3] With respect to project completion and targets, a project manager has a subordinate relationship with the VP (Projects). On the other hand, on functional matters of how the project needs to be executed, the project manager has a direct reporting relationship with the chief of the respective functional area. Such an organization structure enables the optimal utilization of specialized resources in multiple projects. It also facilitates managing the interface areas identified through a WBS.

FIGURE 4.5 Matrix structure for a project organization



Cost Breakdown Structure

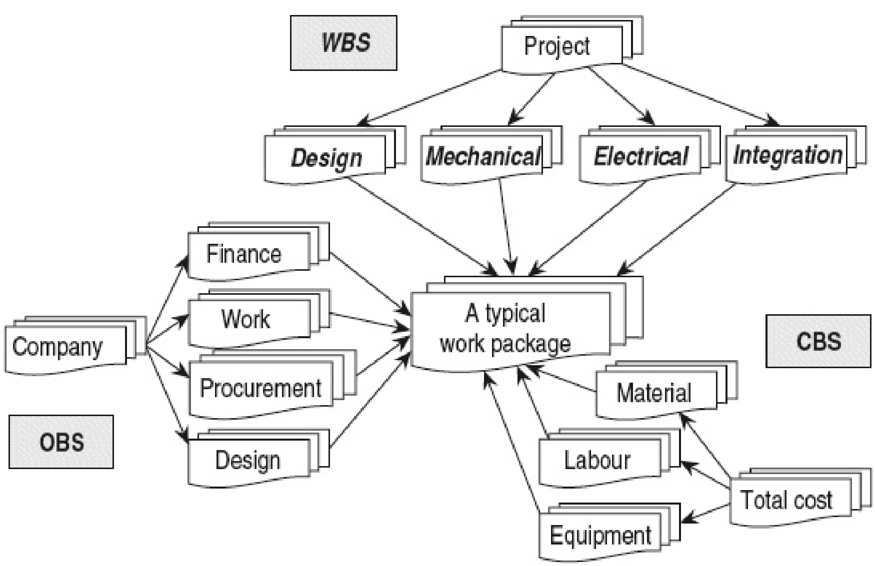
Cost breakdown structure (CBS) is a methodology that links the individual elements in a WBS to a dimension of cost. By estimating the cost of each work package that constitutes an element in the WBS structure, CBS enables a project manager to set up a project monitoring and control mechanism. At higher levels, CBS provides useful means for budgetary control and review. Project management has greater emphasis on cost control, therefore, CBS is an integral part of project management.

Figure 4.6 is an example of the three-dimensional perspective of WBS–OBS–CBS. As is evident from the example, these three together provide a structured approach to project planning and control. Using this framework, it is possible to clearly identify the nature of tasks involved, the type and number of resources to be allocated, and the cost that is likely to be incurred in the execution of each work package. The usefulness of this methodology will be evident in a large-scale project involving multiple entities and spanning a longer time horizon.

Clearly identifying the "what, how, and how much" of every work package is fundamental to planning and control of projects. Using this information one can identify the relationship among various activities and estimate the duration of each activity. Further, it is also possible to estimate the number and type of resources required for every activity and the cost of performing each activity. Using this information, a project manager can construct a network representing the project and identify the duration of the project. He can also address the resource allocation issue and make alternative plans for shortening the duration of the project. We shall address these issues in the rest of the chapter.

> **Cost breakdown structure (CBS)** is a methodology to link the individual elements in a WBS to a dimension of cost.

FIGURE 4.6 WBS–OBS–CBS: A three-dimensional perspective Adapted from: F. Harrison and D. Lock, *Advanced Project Management*, (Gower Publishing Company, 2004).



We shall now take a look at the various tools and techniques that a manager can use in project management.[4] In the rest of the chapter, we shall focus on the following important areas of application:

a. Developing a network representation of a project
b. Analysing project networks
c. Addressing time and resource constraints in projects
d. Handling uncertainty in project completion

Developing a Network Representation of a Project

One of the most widely used tools for project management is developing a network representation of the project. The **network representation** provides a visual aid to a manager in understanding the various activities involved and their interactions with other activities. It also provides ample opportunities to analyse the problem and to develop a good understanding of issues related to project completion. Using this, the project manager can easily identify the activities that are more likely to delay the project completion and the leeway that he/she may have in rescheduling some of the activities.

> The **network representation** provides a visual aid to a manager in understanding various activities involved and their interactions with other activities.

Activity precedence

The elementary unit of analysis in a project network is an activity. An activity constitutes an amount of work done towards the completion of the project. Each activity consumes a set of resources and takes a finite amount of time for completion. Moreover, every activity may have certain technological or logical constraints that link it with its preceding and succeeding set of activities. Clearly, activities constitute the basic building blocks of any project network. A simple example will clarify the above characteristics of an activity.

ideas at Work 4.2

The Chainsa–Gurgaon Pipeline Project

With the objective of meeting the additional demand of natural gas in the National Capital Region (NCR) and to secure uninterrupted gas supply to Delhi consumers, Gas Authority of India Limited (GAIL) executed a pipeline project from Chainsa (Faridabad) to the Maruti Udyog Terminal at Gurgaon during 2002– 2004. The pipeline was 60 km long. Prior to this, there was a single pipeline, where, in the event of any breakdown in the pipeline and allied systems, there would be disruptions in the entire NCR.

The scope of the project included the following: (a) Laying a 16-inch diameter 60-km long pipeline along with optical fibre cable, (b) building two sectionalizing valve stations, a dispatch terminal at Chainsa and a receiving terminal at Gurgaon, and (d) installing supervisory control and data acquisition (SCADA) and telecommunication systems. The project was cleared for execution in April 2002 and was completed in March 2004. At the highest level, the project was divided into six work breakdown structures—engineering, tendering, ordering, manufacturing, inspection and delivery, and construction and commissioning. The scheduled monthly progress for each of the WBS elements was prepared for reporting and monitoring the progress.

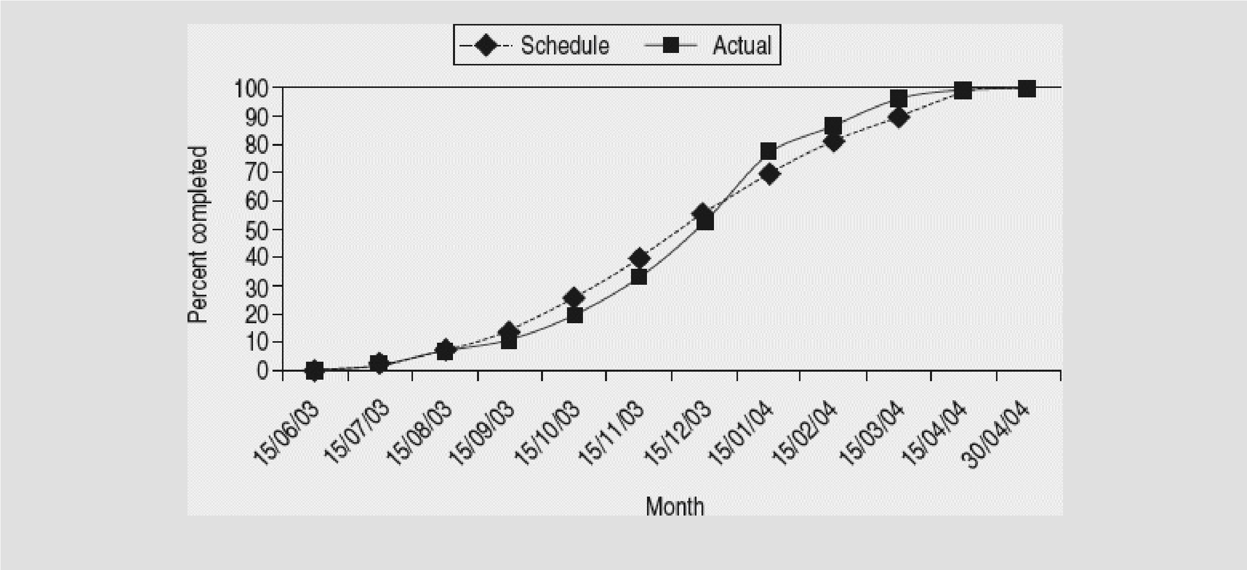
Several vendors and contractors needed to be engaged for project execution. However, three firms were mainly engaged in the project. A project management consulting firm was engaged for planning and executing all the activities identified in the WBS. Another firm was primarily responsible for coating and transportation of line pipes, and the third firm was engaged for pipeline laying and composite works. Figure 4.7 depicts the overall progress of the project.

A project of this nature poses complexities and challenges that are uncommon. For instance, in this project, the pipeline passed through 30 km of city area with dense population, two national highways, one railway network, two major canals, 15 minor canals/ water bodies and 28 metalled roads. Project execution demanded careful planning, obtaining clearance from multiple agencies including the local and the central governments, statutory and regulatory bodies, seeking cooperation from the civil society, and adhering to safety precautions. Furthermore, climatic and weather conditions could also affect the progress of the project. On account of these factors, timely completion of the project was a challenging issue.

As we can see, this project has several characteristics of a typical project. This includes long lead time, involvement of multiple agencies, higher level of uncertainty and the need for closer interaction among the agencies, monitoring and control. With better project planning and management tools, GAIL was able to complete the project ahead of time at a cost lower than 28 per cent of the estimated cost.

Source: Based on an application submitted to National Petroleum Management Programme for Excellence in Project Management Award in 2005 by GAIL (India) Ltd.

FIGURE 4.7 The overall progress of the project



Let us consider a new product launch project. The broad set of activities involved is as follows:

a. Identify market needs
b. Develop the conceptual design
c. Develop the detailed design
d. Create marketing infrastructure
e. Plan production
f. Reach the market

TABLE 4.2 Sample Product Launch Layout

Activity	Predecessor	Successor
A	None	B
B	A	C, D
C	B	E
D	B	F
E	C	F
F	D, E	None

Each of these can be considered as an activity. It is easy to recognize that each of these activities consumes some resources and time for completion. There are also some constraints in the order in which the activities could be performed. For example, without understanding the market needs, it is not possible to develop the conceptual design. Likewise, without the conceptual design, it is not possible to develop the detailed design. On the other hand, some activities can be performed simultaneously. While planning for production after developing the detailed design, the organization could also initiate the process of creating the required marketing infrastructure. In other situations, two or more activities should be completed before an activity can be taken up. In our example, unless production is planned and the required marketing infrastructure is created, it may not be possible to make the product reach the target market ultimately. Based on an understanding of the problem and the constraints, one can develop a table depicting the predecessors and successors for each activity. Table 4.2 has this information for our example.

> The elementary unit of analysis in a project network is an *activity*.

Constructing the network

Since a project has a set of activities that are interlinked with each other in some fashion, a graphical representation of the project simplifies the portrayal of these relationships. One can use the standard components of a graph, that is, nodes and arcs to develop a network. Essentially, we begin from the left with a start node, connect it to other nodes using several directed arcs, reach the right side, and terminate it in the end node. Two conventions exist in constructing a network: representing the *activity on arc (AOA)* and representing the *activity on node (AON)*.

> Two conventions exist in constructing a network: representing the *activity on arc (AOA)* and representing the *activity on node (AON)*.

In AOA, as the name implies, activities are represented on the arc. Since a pair of nodes connects each arc, the start node for the arc represents the beginning of the activity and the end node, the end of the activity. Therefore, each node represents a milestone in the completion of the project. A pair of successive nodes can be connected by only one unidirectional arc. Therefore, sometimes it is necessary to have dummy activities in a network. Dummy activities are fictitious entities having zero duration. They do not affect the project completion schedules or violate precedence and succession constraints.

In contrast, in an AON, each node represents the activity itself. The arc from one node to the other represents the precedence relationship between the activities. An AON network requires one "start" node and an "end" node. Although an AON is much simpler to construct, AOA was the first to be developed and widely used until recently.[5] We shall illustrate these concepts with Examples 4.1 and 4.2.

Analysis of Project Networks

Once the basic network is constructed, it is possible to draw some analysis using the network. Since project performance is all about time schedules and associated costs, time analysis is most frequently employed to begin with.

Project completion time and critical path

Returning to Example 4.2, we can make the following observations:

a. There are alternative paths leading from the start to the end point in any project. In this example, the paths are:

Path 1: 1–2–3–5–7–8

Path 2: 1–2–3–4–5–7–8

Path 3: 1–2–6–7–8

Path 4: 1–2–3–5–6–7–8

Path 5: 1–2–3–4–5–6–7–8

b. The sum of the activity times along each path indicates the total time to complete the set of activities in that path. This is the duration of the project along that path. In our example, the total duration for Path 1 is obtained by summing up all activity times in that path, i.e. (8+12+8+2+2 = 32 weeks). One can compute the duration along all the five paths in this manner. The path durations are as follows:

Path 1: 32 weeks

Path 2: 28 weeks

Path 3: 16 weeks

Path 4: 35 weeks

Path 5: 31 weeks

c. The time required for the completion of the project is the maximum of the duration of all paths in a network. The path that has the maximum duration is the **critical path**. Obviously, a delay in one or more activities on a critical path will directly mean a delay in the scheduled completion of the project. In our example, the critical path is 1–2–3–5–6–7–8 (Path 4) and the duration of the project is 35 weeks.

The path that has the maximum duration is the **critical path**.

EXAMPLE 4.1

Consider a set of interconnected activities and their precedence relationships representing a project, as given in Table 4.3. Construct a network to represent the project using AOA and AON.

TABLE 4.3 Interconnected Activities and their Precedence Relationships in the Project

Activity	Predecessor	Successor
A	None	B
B	A	C, D
C	B	E
D	B	E, F
E	C, D	G
F	D	H
G	E	None
H	F	None

Solution

Figure 4.8 shows the AOA network. Activity B has A as the predecessor and C and D as successors. Similarly, Activity F has D as predecessor and H as successor. These representations are fairly straightforward. Let us consider Activity E, which has two predecessors, C and D. Since two arcs cannot connect Nodes 3 and 4, we direct Activity D to another node, Node 5, and connect Nodes 4 and 5 using a dummy activity (shown by dotted lines). This is the only way to satisfy the precedence relationship.

As explained earlier, the AON network is simpler to construct. The AON network always starts with a “start” node and ends with an “end” node. All intermediate nodes are constructed keeping in mind the predecessor and successor relationships among the activities. The AON network is given in Figure 4.9.

FIGURE 4.8 The AOA network

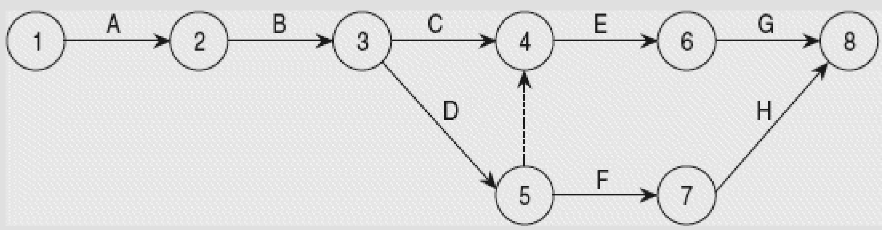
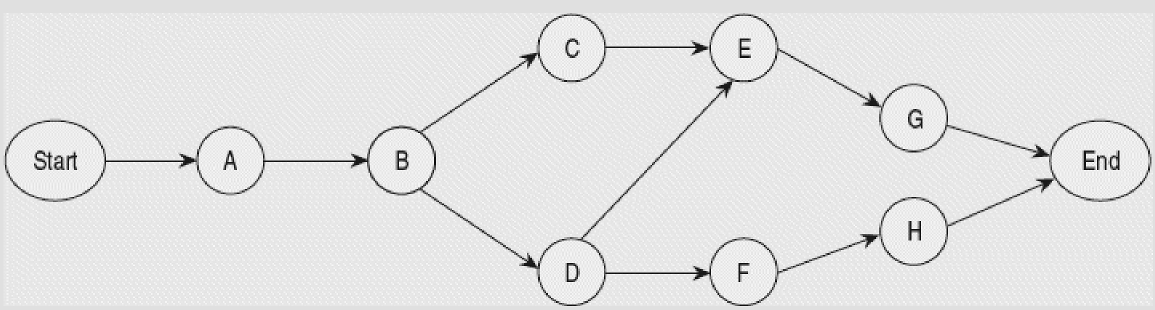


FIGURE 4.9 The AON network



EXAMPLE 4.2

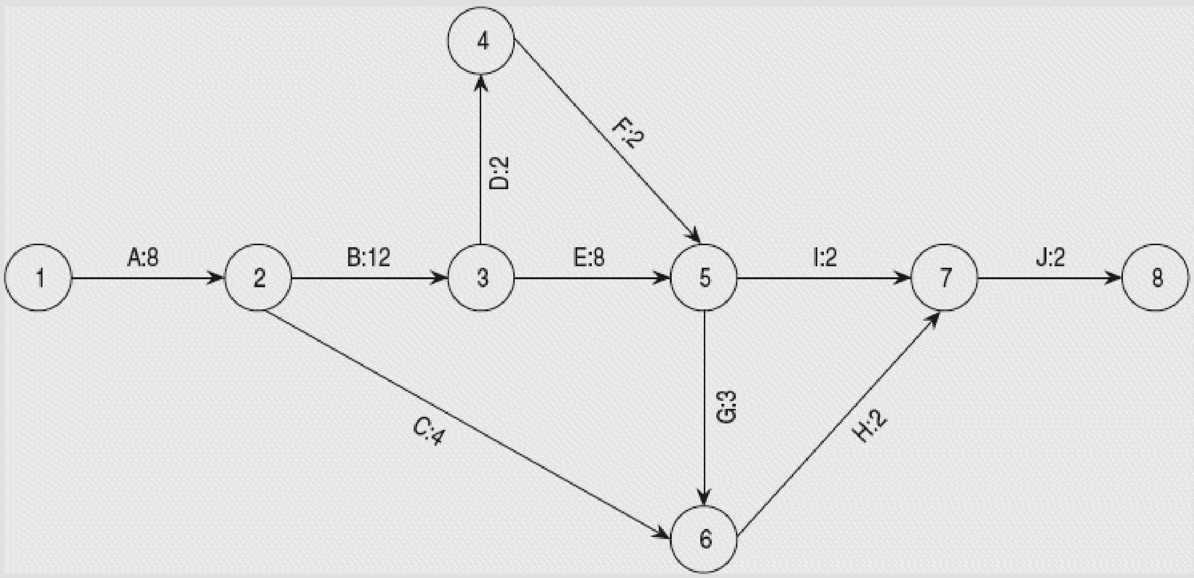
Cool Homes (P) Ltd specializes in constructing quality homes in the city of Bangalore. Cool Homes is known for timely completion of its projects. Consider one of the projects of Cool Homes. Table 4.4 lists the activities, their precedence relationship with other activities and their duration. Construct a network for the project, clearly depicting the activities and their inter-relationships.

Solution[6]

Figure 4.10 has the AOA representation for the problem. In the network representation, each activity is followed by a number that represents the duration of the activity in weeks. There are parallel activities in the project.

TABLE 4.4 The Activities, their Precedence Relationship with Other Activities and their Duration

FIGURE 4.10 The AOA representation



Note: In the figure, the numbers following each activity represent the duration of the activity

For instance, wall plastering/laying floors (Activity G) and obtaining power and water connections for the site (Activity I) could proceed simultaneously. On the other hand, some activities can be started only when more than one activity is completed. Final testing and handover (Activity J) can be done only when power and water connections are obtained (Activity I) and sanitary and electrical fittings are fixed in the house (Activity H).
These interactions and simultaneous occurrences throw up both opportunities and challenges for planning the project completion, as we shall see later.

Early start and late start schedules

There are several activities in a project that are less critical. Shifting the commencement of these activities back or forth to an extent may not have an adverse impact on project completion. Let us look at Example 4.2. Activity C could start as soon as Activity A is over (8 weeks). However, even if we delay commencement of Activity C by as much as 19 weeks, the project completion will still not be affected. In other words, the earliest start schedule for Activity C is Week 8 and the latest start schedule is Week 27. One can compute the early start schedules for all activities by going from the beginning to end of the project. The earliest finish of the predecessor becomes the earliest start for an activity. In the case of multiple predecessors, the maximum of the earliest finish of all the predecessors is the early start for the activity.

Similarly, one can compute late finish and late start schedules by going from the end to the beginning of the project.[7] Activity J needs to be completed by Week 35. Therefore, the late finish for this activity is Week 35. The late start for the activity is the difference between the late finish and the activity duration. In the case of Activity J, the late start is Week 33. One can continue in this manner and compute the late finish and late start schedules for all activities. In the case of multiple successors to an activity, the late finish is the minimum of the late start of all the successors.

Slack for an activity

Clearly, the notion of early and late start times shows that some activities may have slack. **Slack** is the difference between the late start and the early start schedules of an activity (or the difference between the late finish and the early finish schedules). Non-zero slack for an activity indicates the possibility of shifting an activity without disturbing the project completion time.[8] In our example, Activity C has a slack of 19 weeks, thereby suggesting that shifting the activity within this window of 19 weeks will not have an adverse impact on project completion. The slack information has key managerial implications. It can be used to manage resource allocation decisions (as we shall see later in this chapter). Moreover, if an activity takes away all the **slack**, then the remaining activities become critical to timely project completion. Therefore, it may call for close monitoring and control of such activities.

> **Slack** is the difference between the late start and early start schedules of an activity.

This methodology of computing the critical path, the early and late schedules for activities, and the slack and using this information for addressing resource- and cost-based issues is known as the **critical path method (CPM)**. The formulae for computing the various schedules, slack, and project completion are as follows:

Start time for the project = S (usually 0)

Early start time (*ES*) for Activity *i*:

If it is a beginning activity, $ES(i) = S$

Otherwise, $ES(i) = \max\{EF(\text{all predecessors of } i)\}$

Early finish time (EF) for Activity $i = EF(i) = ES(i) + t(i)$, where $t(i)$ is the activity duration.

Project completion time T:

Late finish time (*LF*) for Activity *i:*

If it is an ending activity, $LF(i) = T$

Otherwise, $LF(i) = \min\{LS(\text{all successors of } i)\}$

Late start time (*LS*) for Activity *i*: $LS(i) = LF(i) - t(i)$, where $t(i)$ is the activity duration.

Total slack (*TS*) for Activity *i*: $TS(i) = LF(i) - EF(i)$, or $LS(i) - ES(i)$

> The **critical path method (CPM)** is a methodology of computing the critical path, the early and late schedules for activities, and the slack and using this information for addressing resource- and cost-based issues.

In Figure 4.11, we have the network for Example 4.2 with early and late schedules for the activities. The critical path is also shown in the network with a bold line. The accompanying Table 4.5 has the early start/early finish and the late start/late finish schedules for all activities.

FIGURE 4.11 The network for Example 4.2 with early and late schedules

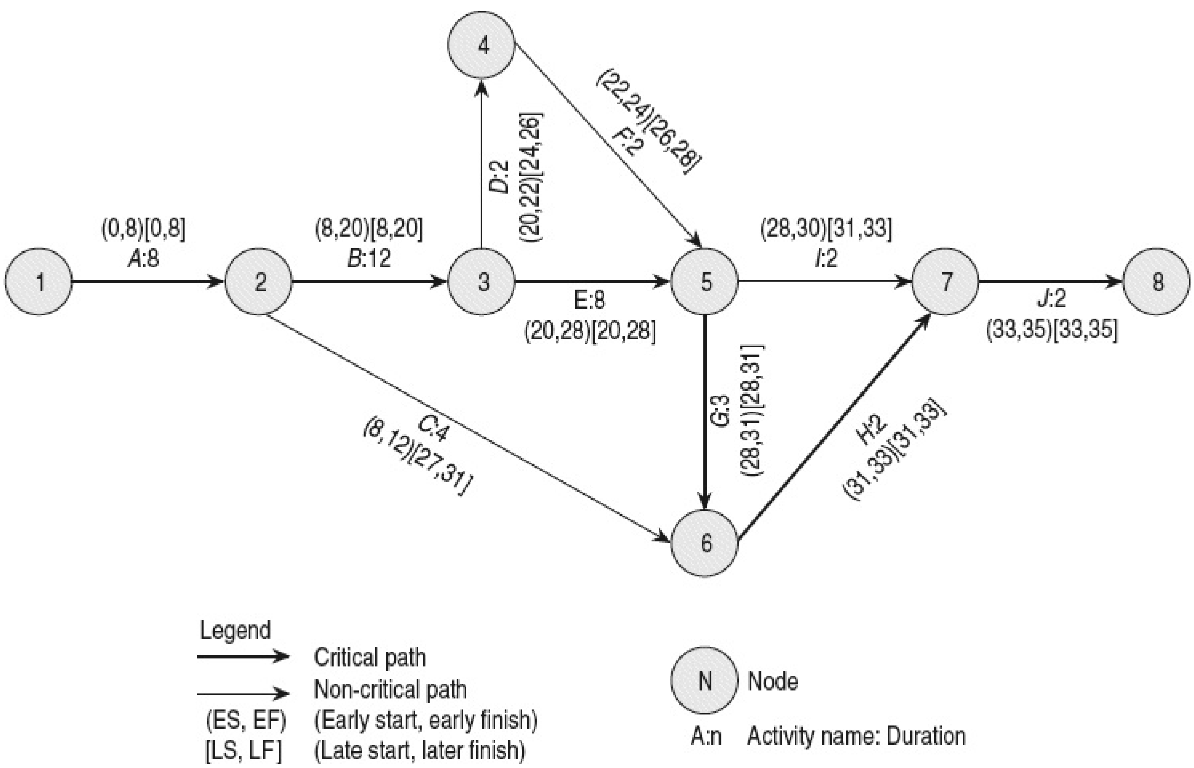


TABLE 4.5 The Start/Finish Schedules for Example 4.2

Activity	Description	Duration (Weeks)	ES	EF	LS	LF	TS
A*	Design/approval of plan	8	0	8	0	8	0
B*	Foundation/superstructure	12	8	20	8	20	0
C	Select and order accessories	4	8	12	27	31	19
D	Wiring for the building	2	20	22	24	26	4
E*	Carpentry works	8	20	28	20	28	0
F	Laying of roof	2	22	24	26	28	4
G*	Wall plastering/laying of floors	3	28	31	28	31	0
H*	Fixing fittings (sanitary, electrical, etc.)	2	31	33	31	33	0
I	Wall, door and exterior painting	2	28	30	31	33	3
J*	Final polishing, handover	2	33	35	33	35	0

Note: *Indicates that these activities are on the critical path.

4.5 ADDRESSING TIME AND RESOURCE CONSTRAINTS

The basic analysis of projects gives the necessary information to a manager to understand the likely schedules for completion of projects and the options available for the manager to shift some of the activities without compromising on the project completion. We shall see how managers could use this information to fine-tune their planning while reacting to changes that were originally not anticipated. For instance, resource availability could pose some additional constraints in starting certain activities at a particular time. On the other hand, there could be delays in some of the activities, jeopardizing the project completion and introducing more activities into the critical path. We shall address these two common concerns and introduce some tools that are available to address these.

Resource Levelling

Earlier, we saw that information on slack could help managers in addressing resource issues in an organization. In order to understand this, we need to know the type and the amount of resources that each activity requires. Once this information is included in our analysis, we begin to see additional information about the project. This includes the mismatches between availability and requirement, the peaks and valleys in resource consumption, and the need to look for better schedules that demand resources evenly. Example 4.3 will help us understand these issues better.

EXAMPLE 4.3

Let us consider Example 4.2. Assume that Table 4.6 shows the manpower required for each activity of the Cool Homes project. Based on this additional information, analyse the following:

a. What impact will an early start schedule-based project have on resource requirements?

b. Is there a basis on which the resource requirement could be levelled? If so, what are the changes required in the schedules of activities in the project?

Solution

In the absence of any additional information, every project manager would like to schedule the project either with early start schedules or with late start schedules. Such an approach is intuitively appealing and simple to set up. However, it can place significant demands on resources. The accompanying network representation (Figure 4.12) has the early start schedule for the project. The activities in the critical path are laid out at the centre. The numbers indicate the weeks during which the activity ends and the dotted line indicates the slack available.

During Weeks 9–12, both Activities B and C are scheduled, thereby demanding a total manpower of 18 (15 + 3). During Weeks 21–28, Activity E is scheduled. While it progresses, two other activities are scheduled during that time (Activity D during Weeks 21–22 and Activity F during Weeks 23–24). Similarly, during Weeks 29–30, two activities are scheduled (Activities G and H), whereas during Week 31 only Activity G continues. During Weeks 32–33, only Activity H is scheduled. Based on this, the week-wise manpower requirement can be computed. The resultant manpower loading pattern for the early start schedule is plotted in Figure 4.13.

As is evident from the figure, there is considerable amount of unevenness in the use of manpower. This may call for frequent hiring and firing of workers or frequent shifting of the workers across other construction sites. Such frequent changes could potentially lead to poor morale of the workers, eventually reflecting on the quality. Project management organizations actively pursue alternative schedules to minimize such effects in projects.

TABLE 4.6 Manpower Required for the Cool Homes Project

Activity	Manpower Required
A	16
B	15
C	3
D	3
E	12
F	3
G	12
H	6
I	6
J	6

FIGURE 4.12 Early start schedule for the Cool Homes project

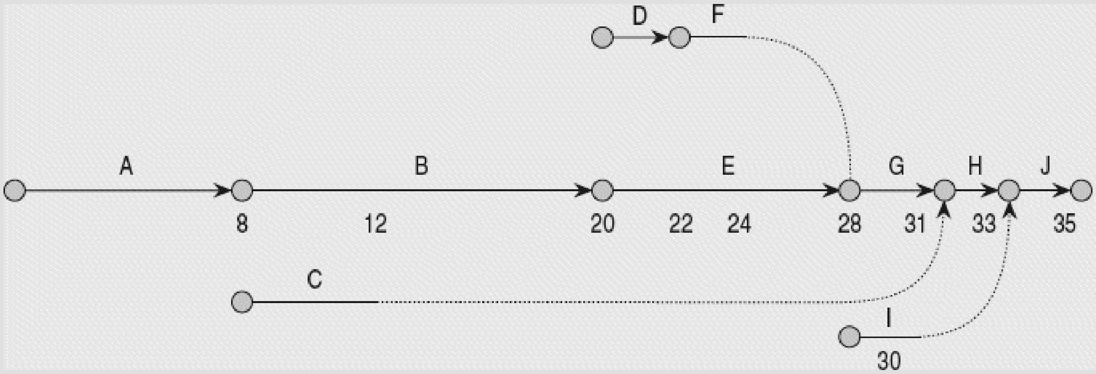


FIGURE 4.13 Manpower loading pattern for early start schedule

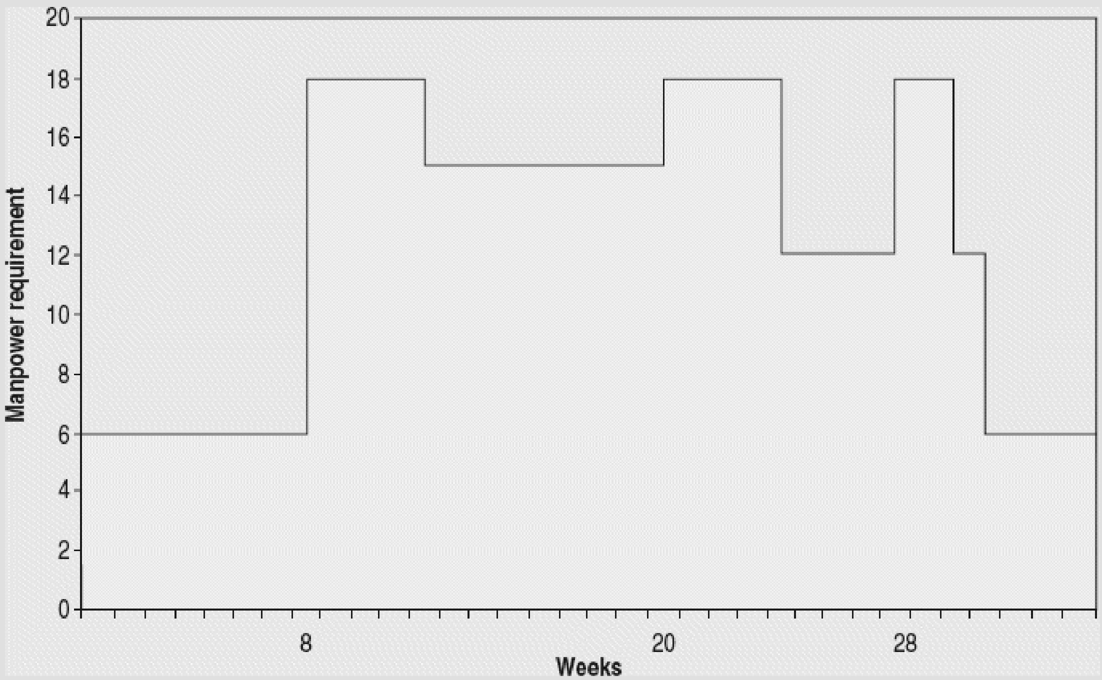


FIGURE 4.14 An alternative project for the Cool Homes project

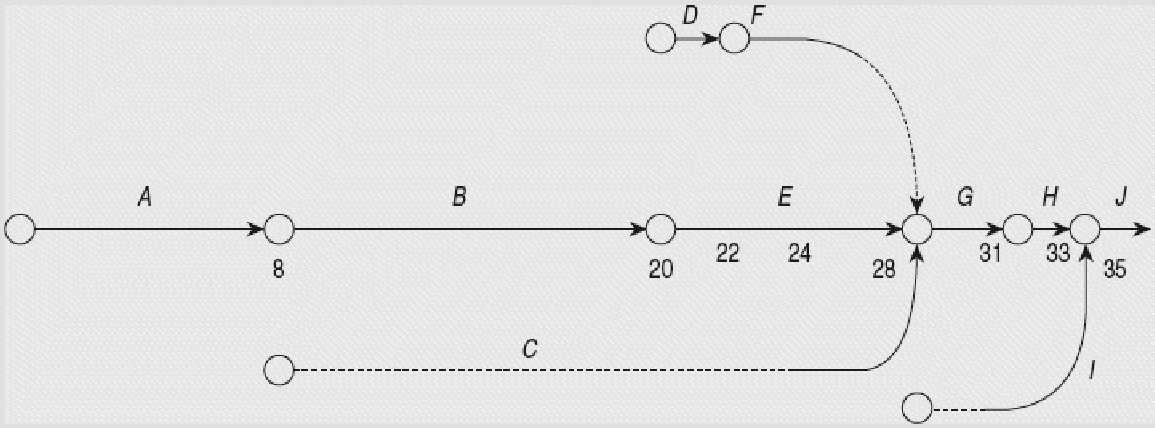
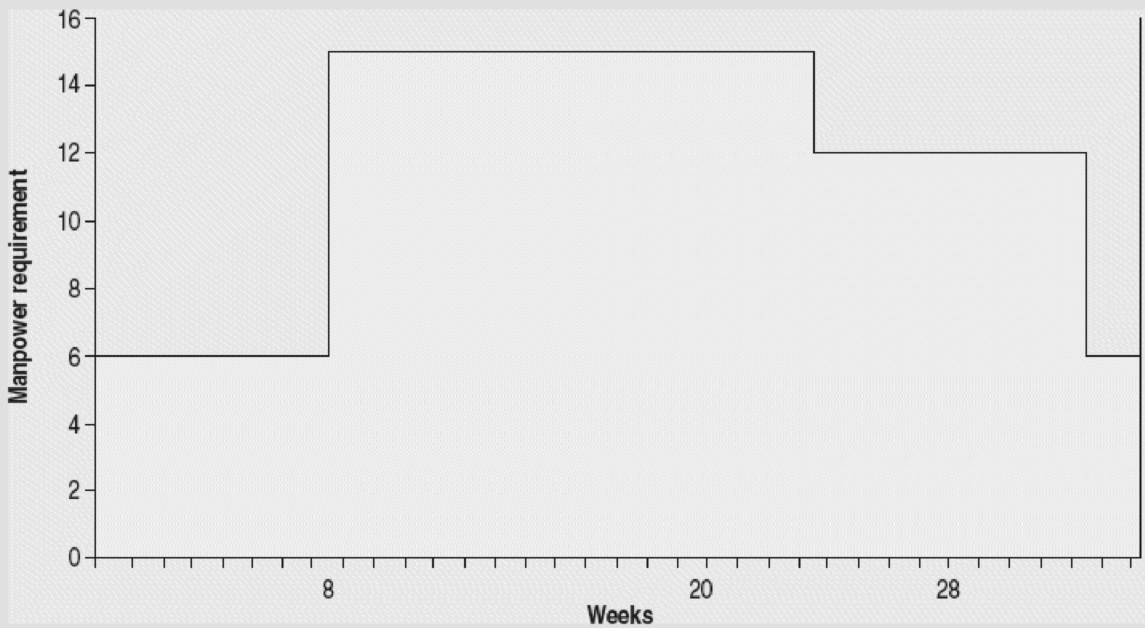


FIGURE 4.15 The revised schedule and manpower loading pattern



Developing an Alternative Schedule

There are three time zones where peaking of the resource requirement takes place in the early start schedule. The first is during Weeks 9–12, then during Weeks 21–24, and finally during Weeks 29–31. One can utilize the slack information to shift activities during this period to a later time and achieve better levelling of resource requirement. In Example 4.3, Activity C can be shifted to Weeks 25–28 and Activity I to Weeks 32–33. The revised schedule and manpower loading pattern are given in Figures 4.14 and 4.15, respectively.

The underlying logic behind shifting activities and computing the revised manpower loading patterns are general and simple to apply to a real life situation involving multiple resources and a large number of activities. Software packages adept at providing this information to a project manager simplify the scheduling process greatly (see Figure 4.16 for a sample plot from Microsoft Project 2002).

FIGURE 4.16 A sample screenshot from a resource allocation routine in Microsoft Project 2002

Time–Cost Trade-offs in Projects

Minimizing the cost of the project is as important as meeting the project completion schedule. As some of the activities get delayed, there is a possibility of a slippage in the project completion deadline. Every project manager knows that by employing more manpower and other resources, it is possible to reduce the project duration. This phenomenon is known as *crashing* in project management. There are several ways to “crash” a project and all of them imply higher costs directly attributable to the activity being crashed. For instance, more workers and equipment could be employed. Alternatively, existing resources could be employed on an overtime basis.[9]

The fundamental premise in crashing is that two sets of costs operate in an opposing manner in projects and managers are better off by striking a balance between the two. When activity duration is reduced, it tends to have an impact on direct costs related to the activity. On the other hand, when the project duration is longer, it significantly affects the indirect costs of maintaining project-related activities. These include site management, supervision, and several fixed costs related to monitoring and control of an ongoing project (see Figure 4.17 for a graphical representation of this). Therefore, it may be desirable to investigate the trade-off. In several other situations, managers would like to evaluate the impact of finishing a project ahead of time. Certain incentive mechanisms for early completion may outweigh the additional costs of crashing a project.

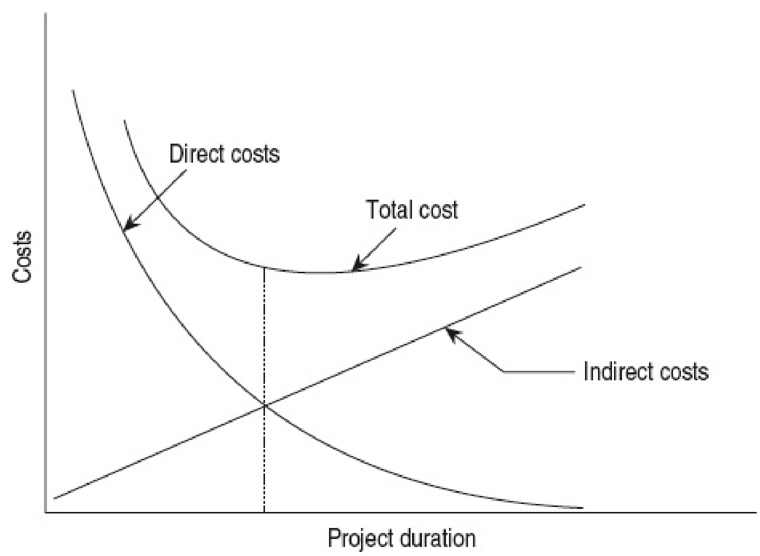
Let us use the following notations to analyse the crashing of networks:

Normal duration of the activity: *NT*
Shortest possible duration for the activity: *CT*
Normal cost for an activity (₹): *NC*
Crash cost for the activity (₹): *CC*
Indirect cost for the project per unit time (₹): *FC*
Maximum possible crashing of the activity: $NT - CT$
Additional cost of crashing: $CC - NC$
Since the maximum possible duration of crash is $(NT - CT)$,

$$\text{The crash cost per unit time} = \frac{(CC - NC)}{(NT - CT)} \qquad (4.1)$$

It follows from the above that if the project duration is reduced by one unit time by crashing an activity, there will be a reduction in the indirect cost to the extent of *FC* and increase in the project cost to the extent given by Eq. 4.1 for the activity. Using this information for each activity, it is possible to analyse the cost–time trade-off in project management. Example 4.4 illustrates these issues.

FIGURE 4.17 Cost–time trade-off in project management



EXAMPLE 4.4

Let us return to Example 4.2 and suppose additional information is available to the project manager of Cool Homes regarding crashing of some activities in the project. Analyse the time–cost trade-off involved in crashing the project duration and identify the optimal crash length for the project. The relevant information is available in Table 4.7:

The indirect cost for the project is estimated to be ₹5000 per week.

Solution

The Cost of the Project With No Crashing

The critical path for the problem does not change. Therefore, the project duration is 35 weeks (refer to Example 4.2 for details). Since the indirect cost for the project is ₹5,000 per week, the total indirect cost for the project is ₹175,000. Also, from the information available in Table 4.7, we can add the normal cost of all activities to get the direct cost for the project when there is no crashing. The direct costs for the project is ₹108,000. Therefore, the total cost of the project with no crashing is ₹283,000.

TABLE 4.7 Cost and Time Data for the Cool Homes Project With Estimates for Crashing

Cost Per Week of Crashing the Activities

From the data in Table 4.7, we see that three activities cannot be crashed. Therefore, our focus is only on the remaining activity. We first compute the cost of crashing per week using the data in Table 4.7 and Eq. 4.1. Let us consider Activity A. The normal cost is ₹12,000 and the crash cost is ₹20,000. Since the activity could be crashed by two weeks, the cost per week of crashing is ₹4,000. Table 4.8 has the computation for cost per week of crashing for all the activities.

Computing the Cost of Crashing

The only way to reduce the duration of the project is to select an activity in the critical path and reduce its duration by crashing. Clearly, we would like to select the activity with the least cost of crashing per week and crash it to its maximum allowable time before selecting the next one. In our example, Activity J has the lowest cost of crashing per week and is also on the critical path. The revised computation is performed as follows:

TABLE 4.8 Computation for Cost Per Week of Crashing for All the Activities

Cost of the project (with no crashing): ₹283,000.00

Number of weeks crashed: 1 week

Cost of crashing the project by one week: ₹2,000.00

Reduction in direct cost (at ₹5,000 per week): ₹5,000.00

Total cost of the project after crashing J: ₹280,000.00

Revised project duration: 34 weeks

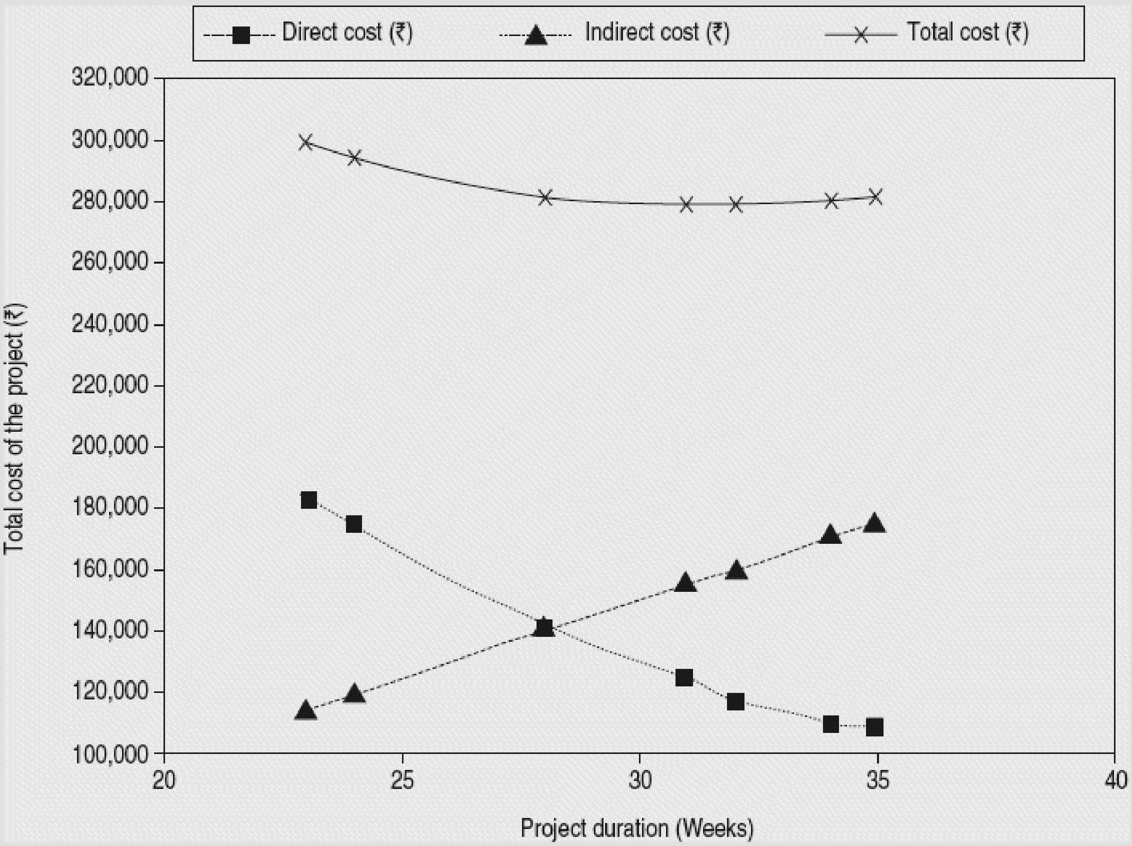
Revised critical path: 1–2–3–5–6–7–8 (unchanged)

We repeat this procedure until no more activities exist for crashing the project. In our example, although Activity F can be crashed, it does not have an impact on the project duration, as it is not on the critical path. Therefore, we stop the procedure.

TABLE 4.9 The Cost–Time Computation Involved in Crashing the Project

Table 4.9 has the detailed computation for crashing. We see from the table that the optimum duration for crashing is 32 weeks. By crashing the project beyond this, the cost of the project increases. Similarly, if the duration of the project is longer than 32 weeks, the cost of the project increases. The accompanying plot of these results graphically portrays the cost–time tradeoff involved in crashing the project (see Figure 4.18).

FIGURE 4.18 Graphical depiction of cost–time trade-off



4.6 HANDLING UNCERTAINTY IN PROJECT COMPLETION

For reasons mentioned in the beginning of the chapter, the degree of uncertainty is likely to be high in several projects. Therefore, project managers need additional tools for managing uncertainty in projects. Uncertainty stems mainly from the non-repetitive nature of the activities and the inability of managers to accurately estimate time and resource requirements for completion of activities. In order to analyse the network when uncertainty in time estimates exist, a framework known as the **programme evaluation and review technique (PERT)** was developed during the Second World War. PERT assumes that the activities that constitute a project and their relationships to other activities are known with certainty. However, there is considerable difficulty in estimating the time required for an activity. PERT uses several important assumptions in analysing projects with uncertainty. It is important to know them before we proceed with the details of the technique.

The **programme evaluation and review technique (PERT)** enables managers to analyse the network when uncertainty in time estimates exist.

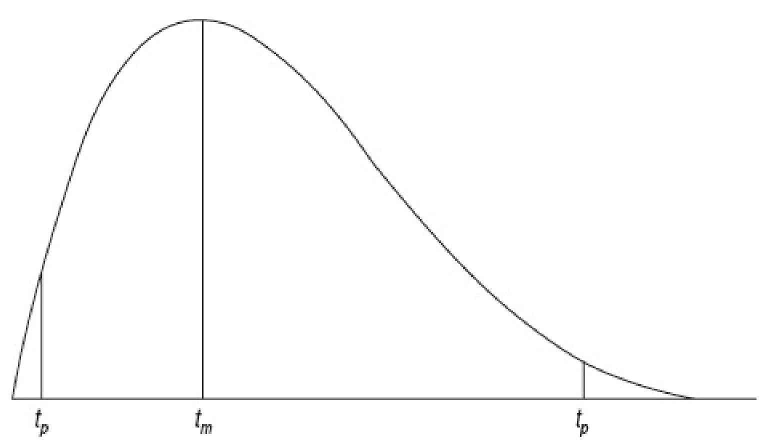
1. PERT relies on the subjective expertise of the managers actively involved in such projects to estimate the duration of activities, about which considerable uncertainty exists. Three time estimates are made for each activity:
   a. Most likely estimate of activity duration: t_m
   b. Most optimistic estimate of activity duration: t_0
   c. Most pessimistic estimate of activity duration: t_p
2. The activity duration is assumed to follow a beta distribution. Unlike a normal distribution, beta distribution has a skewed right tail. The choice of beta distribution seems reasonable because unique and large-scale projects may have occasionally large activity duration due to uncertainty. Figure 4.19 is a graphical representation of a beta distribution with the three time estimates.
3. The expected time for each activity and the variance of the activity duration can be approximated using the following equations:

Expected activity duration is given by the equation $t_e = \dfrac{t_0 + 4t_m + t_p}{6}$ (4.2)

The variance of the activity duration is given by $\sigma^2 = \left(\dfrac{t_p - t_0}{6}\right)^2$ (4.3)[10]

4. Since mean is an unbiased estimator, the summation of the expected activity durations (t_e's) in a path is the expected duration of the project along the path. It is assumed that the expected duration of alternative paths follow a normal distribution.[11] For a similar reason, the variance of the duration of the project along a path is the sum of the variance of the individual activities in the path.

FIGURE 4.19 The beta distribution with three time estimates



5. For example, let us consider one path, Path p, in a network consisting of four activities, a, b, c and d. Then, by our definition,

The expected duration for Path p is given by $T_p = t_e(a) + t_e(b) + t_e(c) + t_e(d)$ (4.4)

The variance of duration for Path p is $\sigma^2{}_p = \sigma^2(a) + \sigma^2(b) + \sigma^2(c) + \sigma^2(d)$ (4.5)

The expected project duration T_c is the critical path for the network and is given by:

$$T_c = \max_p (T_p) \tag{4.6}$$

6. Since the expected duration of the paths in a network follow normal distribution, it is possible to estimate the probability of completion of the project for a given Path *p*, within a targeted due date D, using the standard normal variate given by:

$$Z_p = \left(\frac{D - T_p}{\sigma_p} \right) \tag{4.7}$$

Since T_c is the critical path for the project, the probability of completion of the project by a due date is obtained by replacing the subscript *p* with *c* in Eq. 4.7.

Several of these assumptions are considered reasonable for practical applications. The inaccuracies in these assumptions far outweigh the additional insights that the analysis provides to a manager in handling the uncertainty. We shall use an example to demonstrate these ideas.

EXAMPLE 4.5

Let us return to Example 4.2. Suppose Cool Homes have no prior experience in the kind of construction project that they have currently undertaken. Consequently, there is considerable uncertainty in estimating the activity duration. Assume that the senior management at Cool Homes has collectively brainstormed and arrived at the following estimates for time duration (see Table 4.10).

Use the PERT technique to compute and analyse the following:

a. What is the expected duration for each activity in the network?
b. What is the variance of the duration for each activity in the network?
c. Compute the expected duration for all the five paths in the network.
d. What is the probability of completing the project by the end of Week 45?
e. What are the key inferences that one can draw from these results?

Solution

Computation of the Expected Duration and Variance for Each Activity

Using Eqs. 4.2 and 4.3, one can compute the expected duration and variance for each activity. Table 4.11 has the details.

Computation of the Expected Duration and Variance for Each Path

One can compute the expected duration and variance for each path using Eqs. 4.4 and 4.5 (see Table 4.12). The relevant calculations are available in the table. As in Example 4.2, Path 4 continues to be the critical path for the network. However, the path durations have increased in all the cases compared to Example 4.2 due to uncertainty. Consequently, the expected project duration is 40 weeks compared to 35 in the case of Example 4.2.

Probability of Completion

Due to the uncertainty in activity completion times, the likelihood of completion of the project is best estimated in probabilistic terms. In this case, probability of completion by a due date D of 45 weeks can be computed using Eq. 4.7. The computation of the normal variate, the probability of completion of the project, and a graphical representation of the normal variate (see Figure 4.20) are as follows:

TABLE 4.10 Management Estimates for Time Duration

TABLE 4.11 The Expected Duration and Variance for Each Activity

Activity	Optimistic	Most Likely	Pessimistic	Expected Duration	Variance
A	4	8	18	9	5.44
B	11	12	25	14	5.44
C	3	4	11	5	1.78
D	1	2	3	2	0.11
E	6	8	22	10	7.11
F	2	2	8	3	1.00
G	2	3	4	3	0.11
H	1	2	3	2	0.11
I	1	2	3	2	0.11
J	1	2	3	2	0.11

TABLE 4.12 Computation of the Expected Duration and Variance for Each Path

Path Description	Activities in the Path	Expected Duration	Variance
Path 1: 1-2-3-5-7-8	A, B, E, I, J	37	18.21
Path 2: 1-2-3-4-5-7-8	A, B, D, F, I, J	32	12.21
Path 3: 1-2-6-7-8	A, C, H, J	18	7.44
Path 4: 1-2-3-5-6-7-8	A, B, E, G, H, J	40	18.32
Path 5: 1-2-3-4-5-6-7-8	A, B, D, F, G, H, J	35	12.32

$D = 45$

$T_c = 40$

$$\sigma_c^2 = 18.32$$

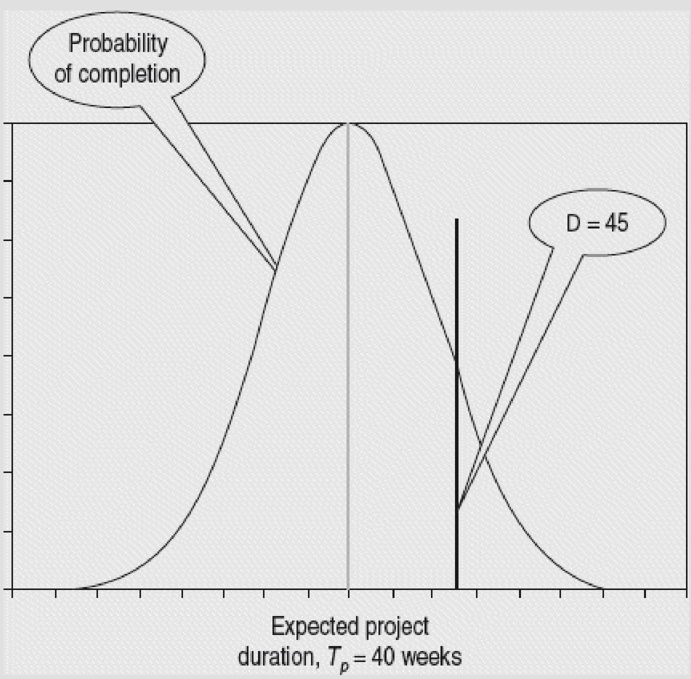
$$\sigma_c = 4.28$$

$$Z_c = \frac{(45-40)}{4.28} = 1.168$$

From a standard normal table, the probability is obtained to be 0.879.

One can draw several key inferences from the above computations. The introduction of uncertainty into a project management analysis framework tends to increase the expected duration of the project. Moreover, one can no longer talk in terms of a definite completion date but rather the probability of completing by a certain time. In our example, although the expected project duration is 40 weeks, there is only a 50 per cent chance of completing the project by that date. Even after 45 weeks, the probability of completion by that time is only 88 per cent. Although, not directly evident from our example, it appears that if the near critical path had a much higher variance, then the probability of completion of this path could be lower than the "official" critical path. These issues point to the fact that it is important to understand that the distribution of completion times and probabilities is more meaningful than a single completion date, as in the case of the deterministic case.

FIGURE 4.20 A graphical representation of the normal variate



Simulation of Project Networks

The above example clearly brings out issues pertaining to handling uncertainty in projects. The focus in handling uncertainty in projects shifts from uniquely computing the project completion and critical path to that of identifying tendencies for alternative paths and activities to influence project completion. Therefore, a better understanding of the issues related to project management comes from obtaining a distribution of critical paths, activity slacks and project completion times.

One way to obtain this information is to perform a simulation of the network. Based on an appropriate distribution for the duration of each activity, one can sample values for all activity durations for one run of the simulation. Using the sample, one can estimate the activity slacks, the probability of project completion by a desired due date, and identify the critical path.[12] By repeating this sampling and computation procedure it is possible to fit a distribution of key information, including activity slacks, project completion probability, and duration. It is also possible to establish a criticality index for each activity to indicate how often the activity fell in the critical path. For example, let us consider a simulation run of 10,000. If Activity A was on the critical path 7,500 times and Activity B was in the critical path 1,500 times, then the criticality index for Activity A is 0.75 and that for Activity B is 0.15. Clearly, a particular activity such as A, which has a higher criticality index, may need special managerial attention.

> In PERT, a distribution of completion times and probabilities is more meaningful than a single completion date as in the case of CPM.

ideas at Work 4.3

Critical Chain: Application of the Theory of Constraints to Project Management

Critical chain project management (CCPM) is a method of planning and managing projects that places the main emphasis on the resources required to execute the project tasks. It was developed by Eliyahu M. Goldratt from the theory of constraints that he proposed. Goldratt introduced this idea through his business novel, *Critical Chain*, published in 1997.

In the traditional critical path and PERT methods, the focus is on tasks and their relationships in terms of constraints for scheduling. The issue of resource availability and resource consumption patterns is not considered at the time of computation of the critical path but later. On the other hand, in a CCPM network, the emphasis is on keeping the resources levelly loaded. According to Goldratt, the critical chain in project management is the sequence of both precedence and resource-dependent terminal elements that prevent a project from being completed in a shorter time, given finite resources. If resources are always available in unlimited quantities, then a project's critical chain is identical to its critical path. Critical chain is used as an alternative to critical path analysis.

The main features that distinguish the *critical chain* from the *critical path* are:

- the use of resource dependencies in the analysis and identification of the critical activities for a project,
- the use of buffers as a mechanism to ensure the completion of the project as per plan, and
- a project-monitoring mechanism that is linked to the consumption rate of the buffers rather than the individual task performance to schedule.

A project plan is created in much the same fashion as with critical paths. The plan is worked backwards from a completion date, with each task starting as late as possible. Two durations are entered for each task: a "best guess" (typically with a 50 per cent probability duration, as in the case of the CPM), and a "safe" duration (with a higher probability of completion, depending on the amount of risk that the organization can accept). Resources are then assigned to each task, and the plan is resource levelled using the 50 per cent estimates. The longest sequence of resource-levelled tasks that lead from the beginning of the project to the end is then identified as the critical chain.

Recognizing that tasks are more likely to take more time due to random events, idiosyncrasies and statistical fluctuation "buffers" are used to establish dates for deliverables and for monitoring project schedules and financial performance. The "extra" duration of each task on the critical chain—the difference between the "safe" durations and the best guess—is the buffer at the end of the project. In the same way, buffers are computed at the end of each sequence of tasks that feed into the critical chain.*

Note: *For more details on critical chains, see http://www.critical-chain.co.uk/

SUMMARY

- The planning and control of operations in project organizations differ from other operating systems on account of high levels of uniqueness, risk, and uncertainty in the former.
- Project management typically involves four phases. These include conception, planning, implementation and control, and post-project appraisal.
- A structured approach to project management involves a three-dimensional framework. The three dimensions are the *work breakdown structure*, the *organizational breakdown structure*, and the *cost breakdown structure*.
- Projects can be graphically portrayed using *activity on node (AON)* or *activity on arc (AOA).* Such a representation helps the project manager perform certain analyses of projects.
- The *critical path method (CPM)* helps understand several important aspects of controlling projects such as the likely duration of the project, activities that could be scheduled with some flexibility, opportunities for resource levelling, and identify activities that need to be crashed to reduce the project duration.
- PERT enables a project manager analyse projects that have high degree uncertainty with respect to activity durations. It provides a structured approach to estimate the probability of completion of the project by a target time.

FORMULA REVIEW QUESTIONS

Early start time $ES(a) = \max\{EF(\text{all predecessors of } a)\}$

$ES(a) = S$, for a beginning activity

Early finish time $EF(a) = ES(a) + t(a)$

Late finish time $LF(a) = \min\{LS(\text{all successors of } a)\}$

$LF(a) = T$, for an ending activity

Late start time $LS(a) = LF(a) - t(a)$

The total slack $TS(a) = LF(a) - EF(a)$ or $LS(a) - ES(a)$

Crash cost per unit time = $\dfrac{(CC - NC)}{(NT - CT)}$

Expected activity duration = $t_e = \dfrac{t_o + 4t_m + t_p}{6}$

Variance of activity $\sigma^2 = \left(\dfrac{t_p - t_o}{6}\right)^2$

The expected duration for path $P, T_p = \sum_i t_e(i)$

The variance of duration for path $P, \sigma_P^2 = \sum_i \sigma^2(i)$ (i is the set of activities in path P)

The expected project duration $T_c = \max_p(T_p)$

Standard normal variate for a path P, Z_P= $P,\ Z_P = \left(\dfrac{D - T_p}{\sigma_P}\right)$

REVIEW QUESTIONS

1. Is managing a project system any different from other manufacturing and service systems? Why?
2. Recall our discussions in Chapter 4 about volume– variety–flow. Use these parameters and show how project organizations can be described in these terms.
3. Give three examples each from manufacturing and service systems that call for project management techniques for planning and control.
4. What is meant by work breakdown structure? Why do you need this in project management?
5. Consider the design and development of a new executive health check-up for preventive healthcare for senior executives. Develop a two-level work breakdown structure for this project.
6. Why should the project manager compute the slack of activities in a project?
7. Will there be paths in a project network with zero slack for all the activities in that path? If so, what can one infer from that?
8. What are the key differences in using CPM and PERT in a project? List the key implications for the project manager.
9. Give three examples of situations that may require use of PERT for project management.
10. Projects involve direct as well as indirect costs and project managers need to use this information in project management. Comment on this statement.

11. What is criticality index? How can project managers use this information?

PROBLEMS

1. A project consists of ten activities. Table 4.13 depicts the precedence relationships between these activities. Develop a network representation of the project.

TABLE 4.13 Data for Problem 1

Activity	Predecessor	Successor
A	—	D, E
B	—	F
C	—	G, H
D	A	F
E	A	J
F	B, D	J
G	C	J
H	C	I
I	H	—
J	E, F, G	—

2. Consider a project consisting of nine activities. Table 4.14 gives the precedence relationship among the activities. Draw an AOA and an AON network representing the project. What are your key observations of this exercise?
3. An organization is considering the launch of a new product in the national market. This project consists of ten major activities. The precedence relationship and the estimated duration of each of the activity are given Table 4.15.

   a. Draw a network of the above project
   b. What is the total duration of the project?
   c. Identify the critical path. Do you have any specific observation to make?
   d. Suppose the duration of Activity F was wrongly estimated and the revised estimate is 10 weeks. What is the implication of this change?

TABLE 4.14 Data for Problem 2

Activity	Predecessor	Successor
A	—	C, F
B	—	D, E
C	A	H
D	B	H
E	B	H
F	A	I
G	B	I
H	C, D, E	I
I	F, G, H	—

TABLE 4.15 Data for Problem 3

Activity	Predecessor	Duration (in Weeks)
A	—	2
B	A	3
C	A	6
D	A	4
E	B	3
F	B	8
G	C,E	6
H	F,G	3
I	D	4
J	H,I	2

4. A project consists of seven activities. Table 4.16 depicts the precedence relationships between these activities. Develop a network representation of the project and answer the questions given below:

TABLE 4.16 Data for Problem 4

Activity	Predecessor	Successor
A	—	B, C, D
B	A	E
C	A	G
D	A	F
E	G	G
F	D	G
G	C, E, F	—

a. Is it possible to execute certain tasks simultaneously? If so identify these tasks.
b. Identify the activities that are certainly to be found in the critical path.

5. A project management organization is preparing a network for one of the projects that it has recently bid for. The client demands that the project needs to be completed and delivered at its site by Week 25. The organization has identified the list of activities to be performed and estimated the duration of each of the activities. The details are given in Table 4.17. Use this information to draw a network and help the organization answer the following questions:

TABLE 4.17 Data for Problem 5

Activity	Predecessor	Duration (Weeks)
A	—	8
B	A	3
C	A	6
D	A	4
E	B	5

F	B	4
G	C, E	6
H	D	6
I	F	6
J	D	4
K	G, H, I	3
L	J, K	3

a. Will the organization be able to meet with the customers' deadline of 25 weeks?
b. If the organization cannot, identify the set of activities that need to be considered for a possible reduction in duration.
c. If the cost of reduction of duration is ₹10,000 per week and the organization will have to pay a penalty of ₹7,000 per week of delay in completion in addition to paying a fixed amount of ₹20,000, what will your recommendation be to the organization with respect to reducing the duration?

6. Consider a project having seven activities and the precedence relationship illustrated in Table 4.18.

TABLE 4.18 Data for Problem 6

Activity	Predecessor	Duration (Weeks)
A	—	6
B	A	3
C	A	4
D	A	6
E	C	4
F	B	2
G	D,E,F	2

a. Draw a network of the project and identify the critical path for the project.
b. Calculate the slack for the activities in the network.
c. Suppose the project manager is likely to face some problems arising out of resource constraints. In your opinion, which of the activities could the manager consider for rescheduling to optimize the resource utilization?

7. In the metropolitan city of Bangalore, the Bangalore Development Authority is undertaking several construction projects. Many of these projects involve construction of huge multi-level flyovers and the organizations involved in the work do not have adequate prior experience of constructing similar flyovers. Moreover, the process is riddled with considerable uncertainty due to political and public interference. Consequently, although estimation of activities is possible, estimation of the duration of the project is difficult. Table 4.19 gives the list of activities, and three possible time estimates for the activities. Use this information to analyse the problem of uncertainty by answering the following questions:

TABLE 4.19 Duration of Each Activity: 3 Estimates

Activity	Prede-cessor	Optimistic (Months)	Most Likely (Months)	Pes-simistic (Months)
A	–	2	4	9
B	–	2	3	8
C	B	4	7	14
D	A	4	5	16
E	B	5	7	12
F	C,D	2	4	8
G	C,D	6	8	14
H	E,F	6	7	14
I	G,H	2	3	9

a. Compute the expected duration for all the activities in the project.
b. Draw a network of the project and identify alternative paths in the network.
c. For each path, compute the expected duration and hence identify the critical path and the near critical path for the problem.
d. What is the probability of completion of the project by 36 months?
e. If the organization wants to ensure 80 per cent probability of completion, what date should it set for project completion?
f. Suppose the client feels that the due date for completion is too late, what options does the organization have in reducing the project duration?
g. Compute the probability of completion of the project for the near critical path. Do you observe anything interesting in your results? Comment on the analysis.

8. A manufacturing organization has received a turn-key project for manufacture of custom-made equipment for one of its clients. The project involves several activities and Table 4.20 has the details on the activities, duration and normal and crashing costs for the activities. Since it is a turnkey project, the organization incurs a cost of ₹6,000 per week towards special supervision of the project. This cost is incurred for the length of the project duration. The project manager would like to know if there is some merit in crashing the project duration. Evaluate the cost–time trade-offs involved in the project and suitably advise the project manager.

TABLE 4.20 Data for Problem 8

Activity	Predecessor	Normal Duration (Weeks)	Crash Duration (Weeks)	Normal Cost (₹)	Crash Cost (₹)
A	–	6	5	10,000	15,000
B	–	4	3	12,000	14,000
C	A	5	NA	16,000	NA
D	B	3	NA	18,000	NA
E	C	4	2	11,000	17,000
F	D	4	2	24,000	32,000
G	C	4	3	12,000	18,000
H	D	9	6	50,000	68,000
I	E, F	2	NA	16,000	NA
J	G, H, I	3	2	10,000	11,000

9. Consider Problem 6. If the manpower requirements for the activities have been estimated as per the data given in Table 4.21.

TABLE 4.21 Data for Problem 9

Activity	Manpower Required
A	80
B	30
C	30
D	40
E	30
F	40
G	80

a. Prepare a manpower loading chart on the basis of early start schedules for the project.
b. Are you satisfied with the loading pattern? If not, devise an alternative schedule for the manpower loading.
c. The organization maintains a constant workforce of 70 workers and hires and lays off workers depending on the requirement on a week-by-week basis. If the hiring charges are ₹2,500 per worker hired and the layoff charges are ₹4,000 per worker laid off, evaluate the impact of the two schedules that you have proposed for manpower loading.

10. A new construction work has 10 work packages designated as *A* to J. Table 4.22 has pertinent details for the project.

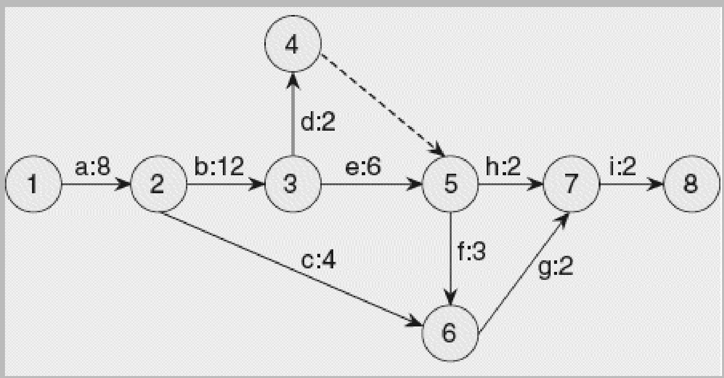
TABLE 4.22 Data for Problem 10

Activity	Predecessor	Duration (Months)
A		4
B	A	7
C	A	7
D	A	6

E	B	3
F	B	3
G	C	6
H	D, F	6
I	E	4
J	G, H, I	8

a. Make a network representation of the project and identify alternative paths in the network
b. What is the project duration?
c. The project management team realized a major omission in one work package. The omitted work package (designated as *K*) has '*C*' as the predecessor and '*H*' as the successor. The duration of this work package is 4 months. Will there be a change in the project duration after inclusion of this work package into the project?
d. Identify the work packages with non-zero slack.

11. Consider the Activity on Arc (AOA) representation of a project given here:



a. Using this network fill in the table with relevant information.
b. Represent the project as an AON network. Do you see any difference between this representation and that given in the figure?

Activity	Predecessor	Successor	Duration (Months)
A			
B			
C			
D			
E			
F			
G			
H			
I			

12. Table 4.23 here has the details pertaining to a new product launch programme of a company. Since the product line is new, they have no prior experience.

TABLE 4.23 Data for Problem 12

Activity	Prede-cessor	Optimistic (Months)	Most Likely (Months)	Pessimistic (Months)
A		1	2	3
B	A	11	14	20
C	A	12	14	22
D	A	1	3	8
E	D	10	12	16
F	B	7	9	15
G	C, F	1	3	6
H	B	4	6	9
I	D	7	8	12
J	H, G, I	8	10	18
K	J	3	5	8

a. Represent the data in a network and identify the critical path for the project ignoring the uncertainty in the project. (Hint: Use most likely estimates for activity duration).
b. Based on the data available compute the expected project duration for the product launch.
c. What is the additional project duration attributed to the uncertainty of project execution?
d. Compute the expected project duration for a probability of completion of the following:
    i. 50%
    ii. 75%
    iii. 90%
    iv. 95%

13. An engineering consulting firm has recently bagged an order to provide turnkey consulting services for preparing a detailed project report (DPR) for off-shore drilling of wells for ONGC. The firm has no direct experience in this kind of project although they have executed several similar projects on shore. The firm is in the planning phase and is expected to quote a time frame for preparation of the DPR. It is keen to answer several questions. The DPR preparation project consists of 10 activities and the time estimates of these activities are given in Table 4.24:

    The firm requires answers to the following questions to help it plan the execution of the project better:

a. How long is the project likely to take for completion?
b. Which are the three activities likely to delay the completion of the project?
c. What is the implication of committing a deadline of 42 weeks? What if it quotes 45 weeks?
d. Suppose the firm is competing with another one, which has been doing this type of job for several years, what is the likely time the other firm will quote for this project?
e. Use the Monte Carlo simulation and prepare a criticality index for each activity. Using this information, what advice can you give to the firm?

TABLE 4.24 Data for Problem 13

			Time Estimates for the Activities (Weeks)		
Activity ID	Predecessor	Successor	Most likely	Optimistic	Pessimistic
A	–	C, D	6	3	15
B	–	F, I	4	2	14
C	A	E, G	8	5	12
D	A	H	6	3	9
E	C	H	10	6	18
F	B	H	4	2	12
G	C	J	5	3	9
H	D, E, F	J	6	4	14
I	B	–	9	6	20
J	G, H	–	4	2	6

MINI PROJECTS

1. Visit the URL: http://www.infogoal.com/links.php? *n* = 12 and pursue the links there to study alternative software for project management. Choose three software packages from the list and visit their websites.

    a. Collect relevant information and submit a report outlining the key features offered by the three vendors, their relative strengths and weaknesses.
    b. Explain how the key concepts covered in this chapter have been implemented in the software.
    c. Are there any noticeable differences between the theory and practice that you have observed? If so, what are the possible reasons for this deviation?

2. Read the book *The Critical Chain* by Eli Goldratt (The complete bibliographical details for the book are available in the Suggested Readings section of the chapter) and prepare a 10-page report on the book. While preparing the report answer the following questions:

    a. In the opinion of Eli Goldratt, what are the key problems that a project organization faces?
    b. What is the relevance of the theory of constraints in project management?
    c. Do you see any advantages in applying the theory-of-constraints framework to project management? Are there any potential problems?
    d. In the context of project management, what new things have you learnt from this book?

CASE STUDY

Distribution Transformer Company Limited (DTCL)

Distribution Transformer Company Limited (DTCL) is a private limited company manufacturing transformers for the power sector. Till 2004, DTCL concentrated only on the domestic market. The company faced a severe financial crisis during the year 2003–2006, because of delayed payments from State Electricity Boards. It was then that DTCL took a strategic decision to tap the export market. To begin with, DTCL concentrated on the South Asian markets. Since then the company's exports started growing rapidly and crossed ₹1 billion in 2006-2007. Till 2005, the company's principal export item was the single phase transformer. Then, it started exporting distribution transformers during 2006, and is planning to expand in a big way into the global market where there is lot of potential for this product.

The variations in specifications of these distribution transformers are likely to be more as there are different customers from different countries. Because of this, DTCL is facing several problems. Its engineering department is taking more time to come out with clear specifications for these new materials, which sometimes creates confusion among different departments. Consequently, developing materials with new specifications is taking longer lead times, and sometimes they are getting rejected at the last minute due to quality problems.

Because of the reasons mentioned, the company is unable to execute the orders in time. The marketing department is unable to negotiate on delivery times with the customer while accepting the orders, as information about the time required to execute the orders is not known. Therefore, DTCL ends up paying huge penalties to its customers for delayed deliveries. DTCL has realized that poor delivery reliability will erode the reputation of the company and will make it much tougher to compete in the global market.

The working capital turnover ratio of DTCL is 1.8:2.2 for the last three financial years whereas the company's targeted ratio is about three to four times the current ratio. The reasons for the low turnover ratio could be (a) more cycle time in order execution, and (b) delayed collections from customers. Even other products (power and single phase transformers) are getting affected because of poor working capital management.

Export orders require a very competitive delivery quote and a highly reliable delivery schedule. DTCL does not have any structured method to estimate the time for execution of the orders. Nor does it know the specific areas that could be improved to bring down time. Therefore, as a first step, there is a need to understand clearly the time taken to execute the orders. Once this information is available, alternatives could be explored for cutting lead time.

Estimation of Order Execution Time

A team was set up at DTCL to estimate the time for execution of an order. With this, it would be possible to focus on overall lead time reduction in DTCL so as to reduce cost, improve delivery, and flexibility. Using the information, the team was also expected to come out with alternative ideas and a framework to execute orders with minimum time. The team identified all activities—from the receipt of the customer order to the point of dispatch—to map out the exact cycle. These are detailed in Table 4.25.

TABLE 4.25 A List of Activities for Execution of an Order at Dtcl

Activity no.	Description
01	Processing and circulation of customer order
02	Preparation of customer drawings
03	Customer drawings to marketing

04	Checking and forwarding to customer
05	Getting approval from customer
06	Preparation of manufacturing drawings
07	Issuing manufacturing drawings to planning
08	Issue from planning to other departments
09	Material procurement—prototype
10	Processing tools required for manufacturing
11	Manufacturing—prototype
12	Material processing—final order execution
13	Manufacturing—final order execution
14	Organizing customer inspection through
	marketing
15	Getting dispatch instruction
16	Dispatch

After the customer order is received by marketing, it is reviewed by them and then circulated to all the concerned departments. The engineering department then prepares the electrical designs, which sent for customer approval through the marketing department. After the customer approves the drawings, they are sent back to the engineering department. However, if the customer makes any comments, then it will take a minimum of three days for processing in between the marketing and engineering departments to address the comments. If the customer asks for technical discussions, the engineering department shall attend to it.

After the drawings are sent to the marketing department, for customer approval, the engineering department then prepares manufacturing drawings and informs the materials department regarding

a. the material requirement for making prototypes,
b. details of materials with long lead times, and
c. tools and dies required for manufacturing.

On receiving the approved drawings from the customer, the engineering department then issues manufacturing drawings to the production planning and control (PPC) department for the distribution of the same.

The planning department then issues the drawings to the concerned departments. For all revisions to the drawings and for the distribution of BOMs (Bill of materials) the process is the same. For every revision, it takes two days time to process it through the PPC department. The materials department then takes action for the procurement of the materials.

After the jobs have passed the internal testing, information is given to the marketing department to organize for customer inspection. Sometimes, advance notice is given to the marketing department regarding the probable dates of completion of jobs so that customer inspection could be planned immediately after production. Sometimes, the customer may have to wait for the final inspection due to communication delays between the departments. After the inspection is over, dispatch clearance is taken, and then the manufactured goods are dispatched.

Based on the steps explained above, the data was collected for a sample of four orders executed last year and interpreted as follows. Of these, two were domestic orders and the other two were export orders. In each of these categories, one representative order and another worst-case order have been considered. Of the two export orders, one was the worst case in which two-thirds of the order was cancelled because of late deliveries whereas the other is a smooth-going case. The Relevant details of these work orders as well as their execution times are given in Table 4.26.

TABLE 4.26 Order Execution Details: A Sample Analysis*

Description	Domestic Order 1	Domestic Order 2	Export Order 1	Export Order 2
Processing and circulation of customer order	2	2	3	3
Preparation of customer drawings	30	18	13	16
Customer drawings to marketing	2	3	1	1
Checking and forwarding to customer	2	1	3	3
Getting approval from customer	447	98	396	93
Preparation of manufacturing drawings	400	120	400	23
Issuing manufacturing drawings to planning	2	3	17	1
Issue from planning to others	1	2	2	1
Material procurement (prototype, final order execution)	603	228	486	167
Manufacturing (prototype, final order execution)	341	160	36	5
Dispatch	8	130	18	15

Note: *All the numbers in the table indicate the number of days for the activity.

QUESTIONS FOR DISCUSSION

1. Develop a network representation of the execution of an order for distribution transformers at DTCL.
2. Use the network and develop time estimates for execution of the order. What are the key activities that require better managerial control?
3. Can you identify activities that require immediate attention in order to reduce the execution lead time? How can DTCL organize the manufacture of transformers so that there will be a significant reduction in execution lead time?

SUGGESTED READINGS

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Part II

Operations and the Value Chain

CHAPTER 5

Supply Chain Management

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What do you understand by the term “supply chain management"? What are the elements of a supply chain?
- Will the structure of a supply chain have any impact on its overall performance?
- What do you mean by the bullwhip effect? What causes the bullwhip effect in supply chains?
- What are the metrics for assessing supply chain performance?
- How can an organization design supply chains for innovative and functional products?
- What is the role of third-party logistics in a supply chain?

A supply chain includes the chain of entities involved in the planning, procurement, and production and distribution of products and services. The dabbawala network in Mumbai is an example of a supply chain in the service sector.

Source: Image taken with approval from www.mydabbawala.com, the official Web site of Dabbawala

ideas at Work 5.1

Mother Dairy: A Case for Supply Chain Management?

Imagine not getting your milk packet early in the morning. It will have a cascading effect on individuals and their work routines. D. Sharma, Deputy Manager (Marketing), Mother Dairy, New Delhi, says, “We have not had a single day since 1974 when our tankers have not supplied milk”. Supplying milk everyday without fail essentially means putting several principles of supply chain management to work. To understand supply chain management, let us consider the nature of activities and the entities involved in supplying milk to customers.

Mother Diary obtains its milk from hundreds of cooperatives located in Gujarat, Haryana, Punjab, Rajasthan and Uttar Pradesh. The milk collected from these cooperatives is transported to the Patparganj plant in East Delhi, where it is homogenized, pasteurized, and then stored in special tanks until it is loaded into tankers for distribution. Mother Diary has a processing capacity of 650,000 litres per day. Nearly a hundred of its tankers criss-cross Delhi and supply milk to about 568 booths located in every nook and corner of the city. Besides its own booths, Mother Dairy also sells loose milk through over 200 manually operated insulated containers set up in shops in congested areas and also through 300 cycle-rickshaws, which home-deliver milk in some localities. Furthermore, it also sells milk through 1400 retail shops in polythene packs. It also markets its products through its 1000 exclusive outlets.

Over the years, Mother Dairy has increased its variety of offerings. Skimmed, toned, double toned, and full cream milk is available in half- and onelitre polythene packs. Several milk derivatives are also offered. For example, Mother Dairy offers over 30 flavours of ice creams. Managing such a large variety requires accurate methods of forecasting and demand management. Since milk is a perishable commodity with a very short life cycle, logistics planning, demand estimation and production scheduling are very crucial.

After further expansion mother dairy sells about 3.2 million litres of milk daily in the markets of Delhi, Mumbai, Saurashtra and Hydrabad.

Networking with milk-producing cooperatives and developing lasting relationships is crucial to ensuring an assured supply of good quality milk on a daily basis. Upkeep of the processing plant, maintenance, and modernization are important aspects of the production process. The distribution of the processed milk and a large variety of milk derivatives require efficient network design, distribution requirement planning, logistics, and transportation planning. Finally, managing information, material, and funds flow across the different entities is crucial for business growth and profitability.

For a commodity that has a low shelf life and criticality of time, appropriate measures of supply chain performance are required. Responsiveness, availability, timeliness, cost of distribution, and levels of inventory at various points in the system are a representative set of measures. Good supply chain management pays attention to all these details.

Source: Based on Punam Thakur, "The Milk Route," *Business India* (March–April 1999): 108; www.authorstream.com/Presentation/sivakkk-1392531-mother-dairy. Last accessed on may 10,2014

Supply chain management (SCM) has gained considerable importance in recent years in the manufacturing and services sector of our economy. Good supply chain management helps organizations secure high quality input materials and purchase goods at competitive prices. It also allows organizations to respond to customer orders faster. Often, with good management, organizations have benefited from reduced costs throughout the supply chain.

5.1 WHAT IS A SUPPLY CHAIN?

Every organization is engaged in providing some goods and services to its chosen set of customers. In a typical manufacturing firm, they begin this process with sourcing raw materials, converting them into intermediate components, and later into finished goods. The goods are finally delivered to the customer. Similar activities occur in the case of many service industries also. Typical examples include hotels, healthcare, and automotive repair and maintenance. In the case of hotels, raw materials and specialized services procured are converted into useful service offerings and finally distributed to customers. Therefore, in every organization, materials flow through a continuous chain, beginning from raw material suppliers, through intermediate manufacturers to the final assembler, and to the distributors and retailers before it reaches the end customer.

Supply chains are equally relevant to service organizations. Let us consider an example to understand this. Consider the personal finance sector and a product such as fixed deposits marketed by a firm such as Sundaram Finance Limited (SFL). Offering fixed deposits and servicing various customer requirements involves several players, both within and outside SFL. Typically, there are four major external players in SFL's supply chain. Brokers play a key role in providing reach and aiding SFL in business development by taking care of the distribution aspect of the overall chain. Moreover, since they come into direct contact with customers, their performance plays a significant role in overall customer satisfaction.

Banks play the role of handling financial transactions in the system. They also influence the **supply chain** costs by providing additional features for the company in transferring funds from one location to another. The registrar's role in this business is crucial. The Reserve Bank of India and other government regulations require that systems for processing fixed-deposit application forms, printing fixed-deposit receipts and interest warrants, and maintaining relevant information are adequately robust and foolproof. Finally, the Indian postal service and private courier companies also form a part of the supply chain. They provide logistics support to the entire operation.

> A **supply chain** includes the chain of entities involved in the planning, procurement, and production and distribution of products and services.

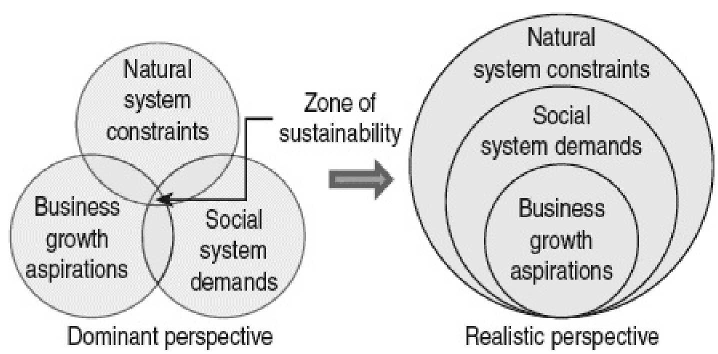
Another service example is the *dabbawala* network in the metropolitan city of Mumbai. The forward supply chain begins at the households, where home-prepared food packed in "tiffin boxes" is collected from housewives and ends at the point of delivery at the respective customer's office. Similarly, collecting the empty boxes from the customers' office and delivering them back at the respective household constitutes the reverse supply chain. In both these cases, all issues of supply chain management need to be addressed. These include designing the distribution network and appropriate capacities for the supply chain, demand management and forecasting, development of appropriate metrics for supply chain performance, and cost and quality control. Material flow, information flow and funds flow are characteristic features of such supply chains, as is the case in any manufacturing supply chain.

Figure 5.1 presents a schematic representation of this idea. As shown in the figure, procurement of input material and services, production of goods and services, and distribution to the end customers are the three major processes in any supply chain. A **supply chain**, as the name suggests, includes a chain of these entities involved in delivering products and services to the end customer. Consider Liberty, the well-known shoe manufacturer. The dummy foot for the shoes is created in Italy, Korea, Spain, or Germany. The mould for soles also comes from Italy and Germany. The upper portion is designed using the company's own CAD/CAM facility and some specialized designs are bought from design studios in Europe. The final manufacturing is done at their factory and marketing is done by the company's exclusive dealers as well as through other retail outlets.

Central to our definition of supply chains is the fact that every organization is just one entity in a continuous chain of the value-creation process. Such a perspective helps every organization to understand the complex interactions across organizationally and physically separated operating units and the need to collaborate with them in order to create value for the ultimate customer. Supply chain management principles require every entity that makes up the chain to work in collaboration with the other entities rather than in isolation. In the absence of collaboration, the value created in one part of the value chain is unwittingly destroyed in some other part of the value chain. Therefore, planning is a major process in supply chain management.

Recent competitive pressures have made several Indian organizations realize that individual companies by themselves cannot face up to competition. A well-designed product and sound manufacturing technology may not ultimately deliver value to the customer. These strengths may sometimes be offset by a poor set of suppliers or an inefficient distribution network. The key requirement of supply chain management is the ability to network with several other business entities having complimentary skill sets. This unique combination of several business entities provides a value stream to the ultimate customer.

FIGURE 5.1 Schematic representation of a supply chain



A unique combination of several business entities engaged in various stages of the supply chain provides a value stream to the ultimate customer.

For instance, consider Chennai-based Lucas TVS and Bangalore-based Bosch Limited, which are manufacturers of auto-electrical components. It is well known that Lucas TVS and Bosch market competitive offerings in a certain range of electrical components. Due to this, it is customary to think that Lucas TVS competes with Bosch. However, principles of supply chain management have transformed this impression. Lucas TVS competes with Bosch not merely on the basis of what it does in its factory but also on the basis of its relationship with suppliers and customers and the strength of its distribution system. In this case, the supplier, the customer, the logistics partner, and Lucas TVS together constitute the supply chain and provide a unique value stream. Therefore, it is reasonable to assume that the value stream provided by Lucas TVS competes with the value stream provided by Bosch.

The Need for Efficient Supply Chain Management

Consider the following statistics: The number of new-product introductions in the U.S. food industry increased from 2000 in 1980 to 18,000 by 1991. The number of watch models produced by Titan Limited was 850 in 1993. It increased severalfold by 1999. In 2002–2003 alone, Titan brought out 180 new models. Asian Paints maintains over 2,800 stock-keeping units. These range from 50-ml packs of paints to over 5-kg cans. If the number of colours and shades are added to this, the variety is mind-boggling. Department markdowns[1] as a percentage of sales went up in the United States from 8 in 1971 to 33 in 1995. The annual wastage arising out of poor supply chain coordination in the United States was estimated to be USD 30 billion in 1999. These statistics bring out the nature of issues that organizations the world over are facing today.

What happens when the number of new-product introductions increase? Amongst other things, organizations face shrinking product life cycles. The Ambassador car has been sold for several decades with very few variations and model ranges. However, with the introduction of more products and models into the market, the life cycle of passenger car models today is not more than five years. Most shoe manufacturers such as Liberty end up designing a product from scratch and launch it every 18 months. They also continue to modify the product once in three months. In certain sectors such as computers and electronic goods, the life cycle of the product is shortening rapidly. Even in the services sector, we find that the life cycle of specific service offerings are shrinking. For example, in the telecommunication sector, old tariff plans are withdrawn and new schemes introduced often. Look at the new menus offered in the fast-food industry or the new health and fitness programmes introduced by the fitness industry. These share similar issues arising out of shrinking life cycles.

The second effect of faster new-product introductions is the dramatic increase in product variety. When product variety increases, demand volatility also increases. Organizations find it increasingly difficult to forecast demand and plan effectively for procurement, production and distribution. Consider the case of consumer appliances such as colour TVs. Samsung and LG offer several models of colour television sets to their customers. While it may be relatively easy to forecast the demand for their brand of colour televisions at an aggregate level, getting the exact numbers for each variation is difficult. Since estimating model-wise demand becomes more and more difficult, organizations need to plan the production as near as possible to the point of demand, in order to reduce the risk of non-moving inventory. This calls for shorter lead times for procurement, manufacture, and delivery.

The third effect is the change in market dynamics. In an era of wide variety and faster new-product introduction, organizations also face competitive pressures while trying to retain their share of the market. Shrinking delivery windows at the marketplace demand greater responsiveness on the part of organizations. Reducing the lead time and cost and recasting the overall supply chain structure are some of the immediate steps required to face these competitive challenges.

In the light of these challenges, today’s organizations face several questions pertaining to managing the supply chain: Will the structure of the supply chain have any impact on the overall performance? What are the strategies for improving inbound logistics? What kind of planning tools are useful for supply chain management? Are there workable strategies for managing scenarios such as product variety and short product life cycle? What are the appropriate measures for supply chain performance? Good supply chain management practices seek to address several of these questions and provide alternative viewpoints to develop a basis for addressing these questions.

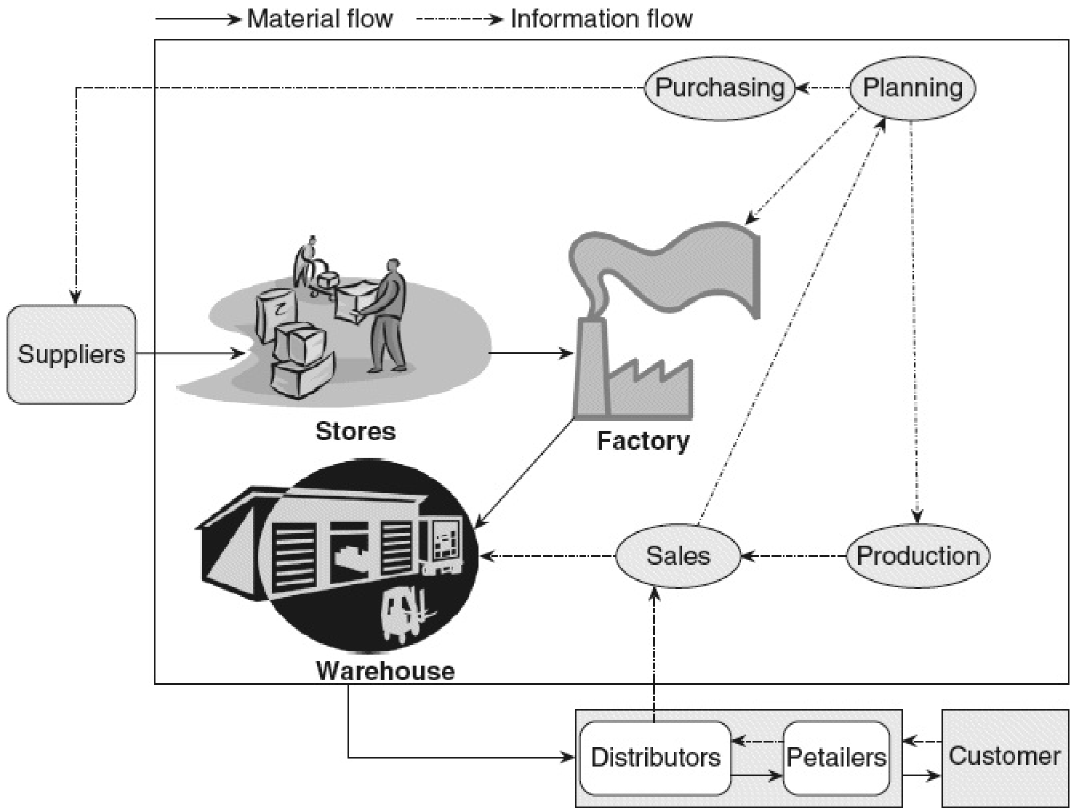
Information and Material Flows in the Supply Chain

Figure 5.2 shows the three entities and the nature of material and information flow across the supply chain. Material flows from the raw material and component suppliers (back end) through the production system and the distribution chain to the ultimate customers (front end), whereas information flows in both directions. Information pertaining to the market demand and the actual order entry status flows from the front end of the supply chain in the reverse direction. For instance, when a customer buys a 500-gram refill pack of a beverage such as Boost from a retail chain of stores such as Foodworld, the information is captured by the point-of-sale system and immediately fed into the centralized planning and warehousing division located in the city.

The information is further processed and sent backwards towards the factory to schedule production and subsequently to order material from suppliers. Continuing our example, the centralized planning system at Foodworld will aggregate this information from all retail outlets in the city and schedule an order with the beverage distributor or the manufacturer. This constitutes information flow in the reverse direction (from the front end to the back end of the supply chain). Similarly, information pertaining to the actual supply of material by the supplier to Foodworld, actual scheduling, and dispatch of goods to all the retail outlets of the chain in the city constitutes information flow in the forward direction.

However, the information flow is not only bi-directional but also more complex in any supply chain. For instance, when a customer modifies a confirmed sales order by amending the delivery schedule and/or quantity, it triggers a host of information flows in the supply chain and may also call for major changes in the material flow. Production planning may be modified, material requirement planning may require updating, and some of the impending deliveries from the suppliers may be moved forward or backward. Collaborative planning and information-sharing practices will streamline the information flow in the supply chain. SCM involves developing a set of management practices that will ensure that these three flows are smooth.

FIGURE 5.2 Information and material flows in the supply chain



In the future, sustainable operations may demand that used products are taken back by the manufacturers. Therefore one can expect a reverse material flow (from the customer to the manufacturer). This is called reverse supply chain. We discuss this issue in Chapter 3 of the book.

5.2 SUPPLY CHAIN COMPONENTS

Supply chains are made up of three distinctive entities: the inbound supply chain, the in-house supply chain, and the outbound supply chain. The *inbound supply chain* includes a host of raw material and component suppliers. These suppliers respond to the production plan of the manufacturer by supplying raw materials and components. The *in-house supply chain* engages in the conversion process through which the raw material and components supplied by the vendors are scheduled for production and final assembly. Finally, *the outbound supply chain* comprises the distribution network. This may involve third-party logistics providers, distributors and retailers.

> The supply chain is made of three distinctive entities: the inbound supply chain, the in-house supply chain, and the outbound supply chain.

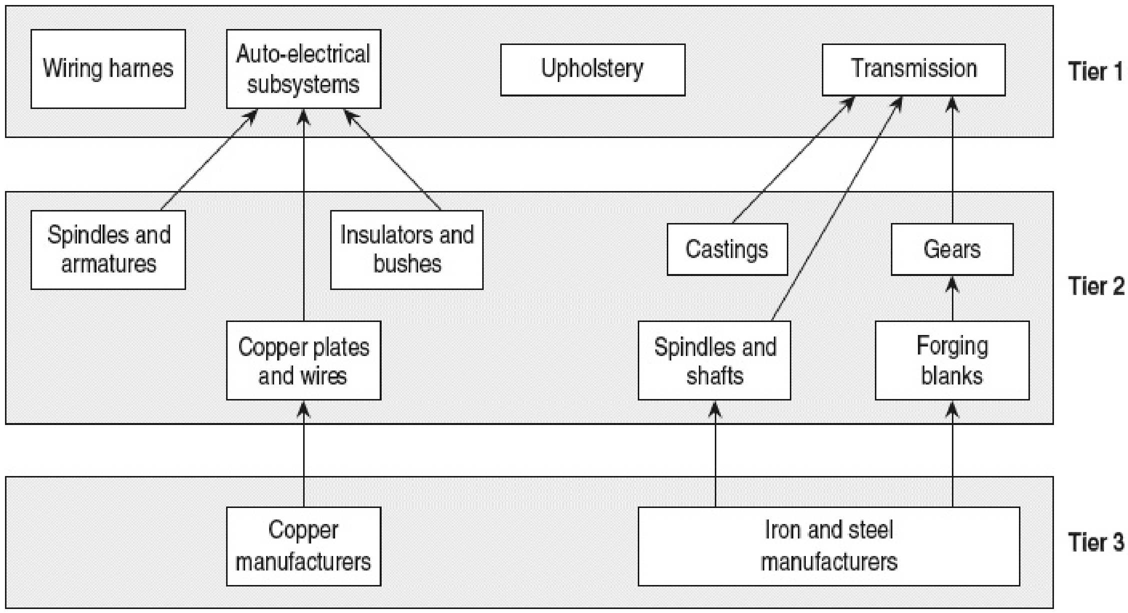
The Inbound Supply Chain

The **inbound supply chain** pertains mainly to providing raw materials and components to an organization. For example, a manufacturer of machine tools may require several varieties of rolled steel, steel ingots, and steel bars. It may also require several semi-finished components, castings, forgings and moulded plastic components. Several other input materials include finished sub-assemblies such as motors and drives, pneumatic and servo control systems, and electro-mechanical items. In several cases, suppliers provide machining capabilities that are either not available in-house or are insufficient. Similar examples exist in the case of service organizations too. In the case of the hospitality industry such as a chain of hotels, suppliers provide transportation facilities, ticketing and reservation, laundry facilities to the guests, and even professional shows and special skills such as medicare to handle emergency requirements.

> The **inbound supply chain** pertains mainly to providing raw materials and components to an organization.

One method to organize the inbound supply chain is to create tiers of suppliers. Figure 5.3 provides an illustration of the tiers in an inbound supply chain in the case of the automotive industry. Tier 1 consists of OEM suppliers who supply key subsystems. For instance, there will be a few suppliers providing wiring harnesses, upholstery, transmission, and auto-electrical subsystems. At Tier 2, there will be a set of component suppliers related to each subsystem. In the case of transmissions, there will be suppliers of castings, forgings, spindles, and shafts. Tier-2 suppliers coordinate with Tier-1 suppliers and respond to their production plans. Tier-2 suppliers often source their requirements from metal-manufacturing and ore-processing firms. In the case of transmissions, the Tier-2 manufacturers may require alloy steel in the form of ingots, rolled coils, and rods. They obtain these from iron and steel manufacturers. Similarly, in the case of auto-electrical subsystems, copper manufacturers provide the basic material for Tier-2 suppliers.

FIGURE 5.3 Inbound supply chain: an example from the automotive industry



One method to organize the inbound supply chain is to create tiers of suppliers.

A greater degree of coordination is required between the manufacturing, planning and procurement functions in an organization to effectively manage an inbound supply chain. This is due to the fact that inbound SCM primarily deals with issues related to identifying sources of supply, developing strategic relationships with these sources, and creating competitive positions on the basis of these relationships. In Chapter 7, we shall discuss these issues in detail.

The In-house Supply Chain

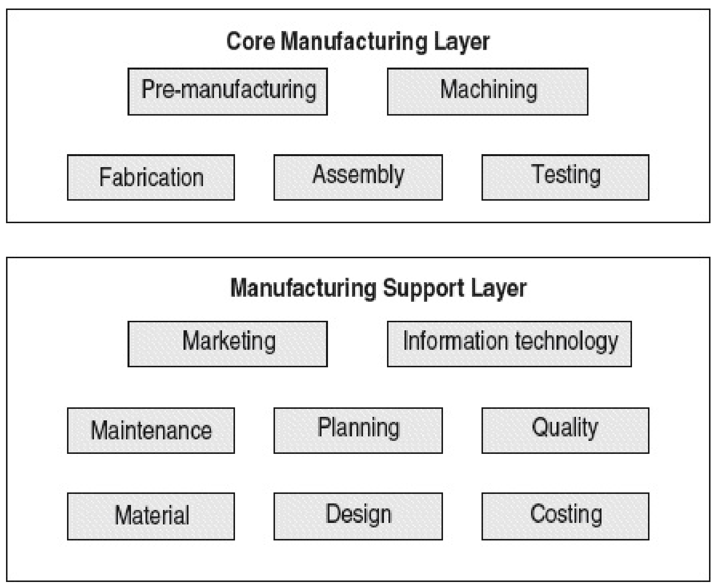
The **in-house** component of the supply chain relates to the physical configuration of the conversion process. The raw materials and components sourced from various suppliers are launched into the production system and converted into useful finished goods. Managing this component of the supply chain involves designing of the manufacturing system, facilities management, layout and location of resources and material handling. The in-house supply chain can be broadly divided into the core manufacturing layer and manufacturing support layer. Figure 5.4 is a schematic representation of a typical in-house supply chain.

The **in-house** component of the supply chain relates to the physical configuration of the conversion process.

The core manufacturing layer consists of various physical resources for the conversion process. The first operation is done in pre-manufacturing where the raw material is cut to the required shapes and some pre-processing is done. In several cases, the conversion process involves some fabrication and machining activity before the various components are assembled and tested. An appropriate organization of these resources is required for the conversion process, and maintenance of these resources is part of the in-house supply chain management.

Since the conversion process is a critical link in the entire supply chain, it will assume the central role in the overall supply chain collaboration. For instance, the manufacturer of a consumer durable will have to initially estimate the demand for the product and communicate this information to the rest of the supply chain to devise a strategy for meeting the demand. This may include directing the inbound supply chain to schedule delivery of certain components and raw materials, ensuring the manufacture of the product according to plan, and scheduling dispatch of the product through logistics infrastructure to the appropriate parts of the outbound supply chain. The manufacturing support layer in an organization performs these activities.

FIGURE 5.4 A typical configuration of an in-house supply chain



Apart from the physical location of the resources for the conversion process, planning is a crucial aspect of the in-house supply chain. The first major activity is demand management. It includes forecasting and demand estimation, order entry and customer order fulfilment. In order to meet delivery promises, a host of production planning and control activities will be required as part of the in-house supply chain. Since the in-house supply chain plays the major role of collaboration, both within and outside the organization, several functional areas are involved in the process. The cooperation of several functional areas, including planning, materials and procurement, marketing, production, and logistics will be a critical aspect of the working of an in-house supply chain.

The Outbound Supply Chain

The **outbound supply chain** pertains to the distribution of goods and services to end customers. This includes distribution network design, warehousing, logistics planning, channel management, channel coordination, and customer interface management. Consider Asian Paints, for example. In the decorative paints business, the critical factors for success are the availability of a wide range of shades and an extensive distribution network. Asian Paints has four manufacturing facilities and more than 2,800 stock-keeping units. These are supported by six regional distribution centres, which cater to 55 depots. Each depot has a branch manager for supervision of several salespersons who cater to more than 14,500 dealers in more than 3500 big and small cities all over the country. Moreover, Asian Paints has consistently improved its IT systems over the years. It has already linked all of its factories and 55 depots through V-SAT terminals, which in turn has helped in streamlining the distribution channel. Inter-functional coordination between manufacturing, planning, and marketing is an important aspect of outbound supply chain management in organizations.

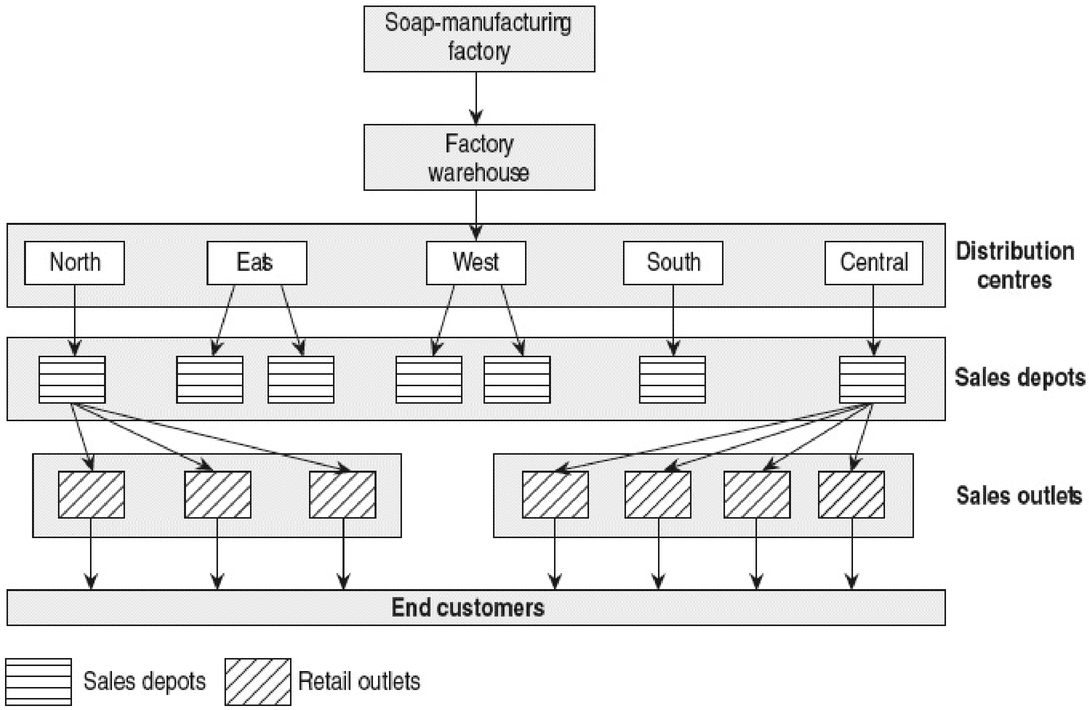
> The **outbound supply chain** pertains to the distribution of goods and services to the end customers.

Figure 5.5 is a typical outbound supply chain for fast-moving consumer goods, such as soaps and detergents, which consist of four levels. The first level is the factory warehouse where the finished goods are stocked. At the next level, there will be regional distribution centres (DCs) that cater to a wide geographical area. Each DC will, in turn, serve a number of sales depots or regional stock points. For instance, the South Zone DC will cater to the requirements of Tamil Nadu, Kerala, Karnataka, Pondicherry and Andhra Pradesh. At the fourth level, the sales depots will serve the retail outlets. The sales depot located in Bangalore may, for example, serve over 500 retail outlets in and around the city. The retail outlets finally sell the product to the customers.

VIDEO INSIGHTS 5.1

A large chunk of the Indian population lives in rural areas. Therefore, building supply chains that can reach deep rural pockets can help organizations expand market share as well as address the needs of the rural folk. To know more about the initiatives of Hindustan Unilever in addressing the last mile problem of the rural supply chain network, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

FIGURE 5.5 A typical example of an outbound supply chain



Distribution network design

A distribution network refers to the manner in which a set of outbound supply chain entities are geographically located to stock products and serve end customers by satisfying the demand in a responsive manner. These entities may include company-owned distribution centres, independent distributors, stockists, retailers, and third-party logistics (3PL) providers. For instance, a manufacturer of air-conditioners had the following entities in its distribution network:

- Two factories manufacturing air-conditioners,
- Eight branch offices across the country,
- 16 sales depots (each branch office controlled two depots),
- 800 dealers (each sales depot served about 50).

The dealers served the end customer by dealing with them directly.

Distribution network design refers to the choices made with respect to the nature of entities included in outbound logistics and the manner in which material flow and information flow are managed across these entities. The network design could either result in centralized distribution logistics or decentralized logistics design. For instance, a few years ago, a manufacturer of air-conditioners was considering two alternative distribution network designs as shown in Figure 5.6.

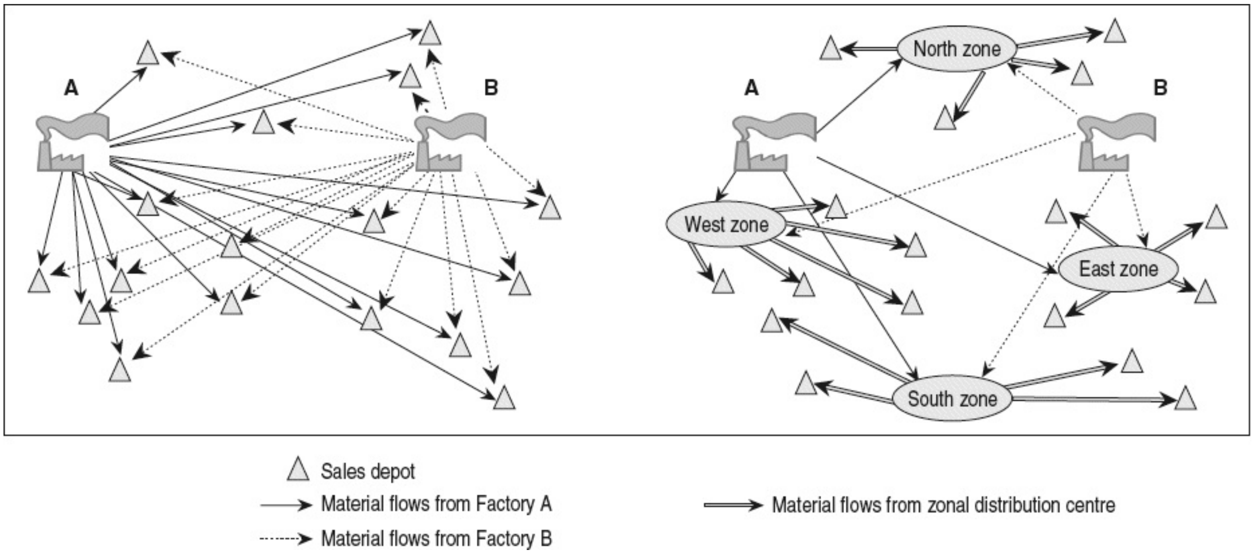
In the first alternative, the two factories were directly sending the goods to the 16 depots. They were held in the depots as inventory until invoiced to dealers. In the second alternative, the sixteen sales depots would no longer be stock points. Instead, inventory would be maintained only in the four zonal DCs. The sales depots would merely act as receiving, dispatching, and invoicing points.

Network design is very crucial, as it will have a significant impact on supply chain performance. The amount of inventory stored in the entire supply chain will vastly differ between the two alternatives. If there are multiple locations in which inventory is stocked, then there is a need to carry safety stock at each location in order to meet uncertain demand. On the other hand, if the inventory is stocked at a centralized point, the safety stock will be much less.[2] This will result in lower cost of operation. However, a centralized design will require an efficient logistics setup to ship inventories to the point of demand. Therefore, the responsiveness of the supply chain will depend on the logistics.

> Distribution network design refers to various choices made with respect to the nature of entities included in outbound logistics.

There is a noticeable trend in recent years to rationalize the supply chain structure. This is partly attributed to advancements in IT infrastructure and availability of better transport infrastructure. For instance, the manufacturing and distribution of HP DeskJet printer was done using a lean structure with just two manufacturing facilities, one in Vancouver in Washington the United States, and the other in Singapore.[3] In the continental United States, vast markets were served from fewer DCs as opposed to the earlier practice of having multiple stock points. Such developments are yet to take place in India. As the logistics infrastructure—including the road and rail network, availability of ports, and connectivity to the ports—and the efficiency of the logistics process improve, there will be a greater shift towards fewer layers in the outbound supply chain and the increased use of centralized DCs. The Golden Quadrilateral Project, proposed and implemented by the Union Government during 1999–2001, is especially important in addressing the supply chain issues of domestic firms.

FIGURE 5.6 Distribution network design: two alternatives



ideas at Work 5.2

Supply Chain Management Solution for Indian Oil Corporation Limited

Indian Oil Corporation (IOCL) is India's number one oil company in terms of size and sales turnover. It is the nineteenth largest petroleum company in the world and has also been recognized as the largest company in petroleum trading among the national oil companies in the Asia-Pacific region. The company has a countrywide sales network of more than 23,000 retail outlets, including more than 10,000 petrol/diesel stations, backed by 165 bulk storage facilities, 95 aviation fuel stations and 85 LPG bottling plants. Its subsidiary, IBP Co. Ltd, has another 3,000 retail sales outlets. IOCL operates 10 of India's 18 refineries with a combined rated capacity of one million barrels per day (bpd). The company also owns and operates the country's largest network of cross-country crude oil and product pipelines of 7,730 km, with a combined capacity of 58.62 million metric tons per annum.

A multi-site refining company such as IOCL faces various supply chain problems to solve. This includes decisions such as which grade of crude to buy, where to process it, how much to buy and make, what to make, and where and how to transport it. Traditionally, different departments or divisions within one organization manage their own disparate portion of this complex process and don't always talk with one another. As a result, decisions are sometimes made based on incomplete data or limited applicability (they cannot be applied across the entire corporation). Clearly, the IOCL supply chain is complex and the company realized that in their journey towards maximizing profitability that better visibility into the supply chain and finding ways to optimize this value chain was critical. IOCL evaluated different supply chain management solutions to address this business problem and how best to implement a solution that integrates five separate refineries. The resulting decision was to implement an integrated, multi-plant planning solution.

IOCL selected Honeywell's supply chain management solution that runs Honeywell's Refinery and Petrochemical Modelling System (RPMS). The models developed with Honeywell's solution covered the entire supply chain of IOCL from crude purchases at the refinery gate or ports to product distribution at the terminals. The Supply Chain Management solution provided by Honeywell consisted of the following modules:

- *Demand planning*: for demand forecasting and aggregation of the final demand numbers
- *Integrated planning*: for the complete IOCL refining supply chain
- *Distribution planning*: for generating operational plans for feedstock allocation and product distribution
- *Refinery production planning*: for generating operational plans for production

The project resulted in several benefits to IOCL. These include better crude selection and allocation which took into account product demands, refinery capabilities and effect of the crude already procured; optimal refinery production planning; and optimal distribution planning considering transportation costs, taxes, duties, and transportation constraints. On account of these, IOCL was able to improve its margins and profitability,

IOCL experienced an improvement in their capabilities in certain areas after the implementation of the Honeywell SCM solution. For instance there was an improved visibility into its supply chain process across the five selected refineries. IOCL was able to perform investment analysis for refinery units, pipelines, etc. and formulate strategies to meet future scenarios like change in specifications. Faster and more effective decision making on exchange strategies, imports and exports, and improved response and execution capability were the other welcome changes after the implementation.

Source: http://hpsweb.honeywell.com/Cultures/en-US/NewsEvents/SuccessStories/success_IOCL.htm. Last accessed on June 15, 2009.

Logistics management

Logistics management refers to the set of activities involved in the physical movement of goods across the supply chain. It may require planning shipments from one part of the supply chain to the next, scheduling carriers, and route planning. The nature of the logistics required is a function of the distribution network design. As demonstrated, a centralized distribution system will require an efficient logistics system to meet the demands of customers spread over a wide geographical area, as opposed to a decentralized design.

> Route planning is an important aspect in logistics management.

Route planning is an important aspect in logistics management. Consider the case of perishable foods such as Onjus orange juice. There are about 1.82 lakh retail outlets in every nook and corner of the country which need to be reached. In the city of Mumbai alone there are

14,460 retail outlets, and good logistics management requires efficient route planning to reach these outlets without delay. Onjus had divided the Mumbai area into 15 territories and scheduled carriers and salesmen such that every salesman covered 80 outlets a day.

Channel management

Channel management is another key aspect of the outbound supply chain. The distribution of goods and services often involves multiple organizational entities outside the manufacturing firm. For instance, in the case of a fast-moving consumer goods (FMCG) manufacturer which produces soaps and detergents, the channel will include dealers, stockists, and retailers. In such situations, channel management involves the smooth passage of information and material flows across the supply chain. The demand estimates and the point-of-sales data form crucial input to production planning and scheduling. Hence, channel management requires systems for efficient data capture and dissemination across the supply chain.

> **Channel management** involves the smooth passage of information and material flows across the supply chain. It requires systems for efficient data capture and dissemination across the supply chain.

Channel management also involves relationship management. Since the lowest level in the channel has direct contact with the customer, they play a major role in customer relationship management. Feedback from customers about the product, problems faced by the customers in using the product, and specific preferences and requirements ignored in the current offering are very important for the entire supply chain. Only when this information flows back quickly and without loss can necessary corrections be done in the supply chain. Conflicts in the channel and motivational issues of the channel partners also have a significant impact on the overall performance of the supply chain.

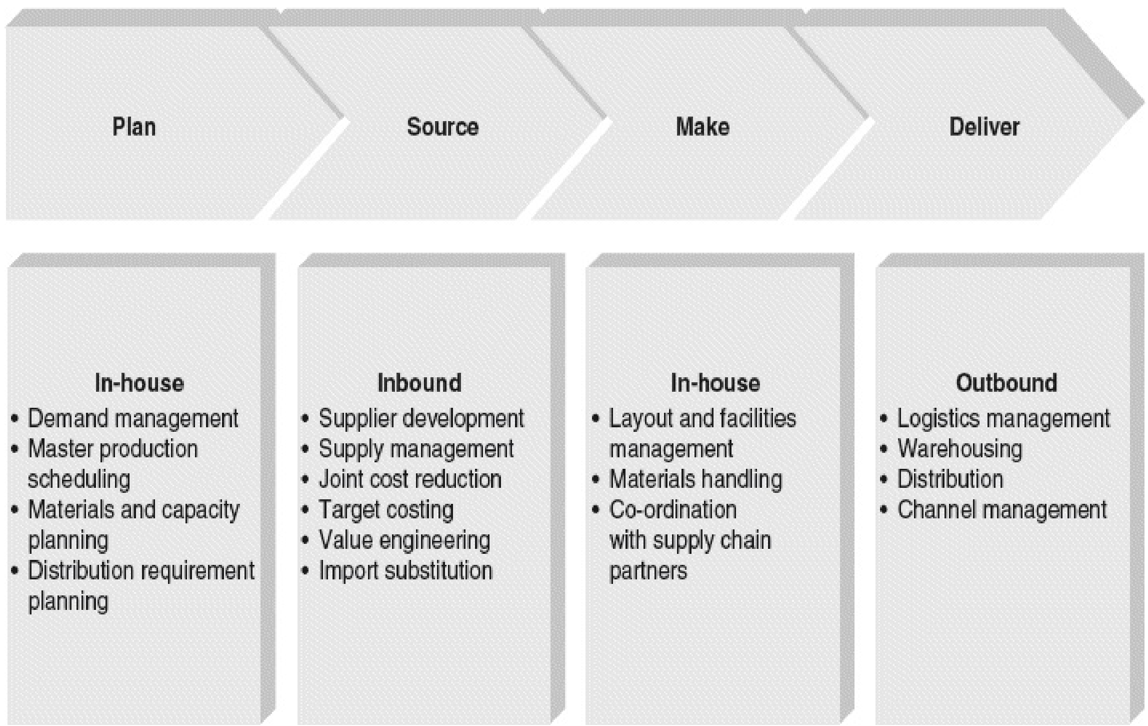
5.3 SUPPLY CHAIN MANAGEMENT: A PROCESS ORIENTATION

In order to understand the various activities pursued in a supply chain, it is useful to take a process view of the entire supply chain. A process approach helps clarify the various roles, categorizes the processes into homogenous units, sets down the set of activities required to complete the process, develops appropriate measurements, and uses them for improvement in the overall performance of the supply chain over time. Figure 5.7 provides a process orientation to the supply chain and its relationship to the components of the supply chain.

> There are four generic processes involved in any supply chain: planning, sourcing, manufacturing, and distribution.

There are four generic processes involved in any supply chain. These include planning for operations, sourcing decisions, manufacturing-related activities, and distribution. Planning is the main activity in the in-house supply chain. Planning establishes the premises for other components of the supply chain. Detailed discussion on several aspects of planning is available in the later part of the book (see Chapters 14–19 for various aspects of planning). Here, we shall take a brief look at planning in the in-house supply chain.

FIGURE 5.7 Process view of the supply chain and its relationship to supply chain components



The inbound supply chain mainly comprises sourcing issues. Sourcing decisions call for supplier development, supply management, purchasing policies, and a host of activities related to cost reduction and new-product development. These have a significant impact on the overall supply chain performance. Chapter 7 deals with these issues.

A considerable amount of planning is involved in in-house supply chain management. Since supply chain entities cut across organizational boundaries, planning plays an important role in supply chain collaboration. For example, on the basis of planning, customers are promised delivery schedules. Schedules for distribution and third-party logistics are also arrived at in a similar way. On the other hand, delivery schedules for component and raw material suppliers are also drawn on the basis of planning.

Demand management is the most crucial amongst all the elements of a supply chain. Based on the information available on various components of the supply chain, planning for future operations is done in order to fulfil a certain demand. Demand management triggers a host of other planning processes including planning for materials, resources, capacity, and distribution.

5.4 SUPPLY CHAIN STRUCTURE

For several companies, the supply chain has a wide span. One can illustrate the complexity of a supply chain with the help of an automobile manufacturer such as Maruti Suzuki Ltd. Their sales network has 3,047 service outlets across 1446 cities. They have 315 Maruti True Value outlets. In addition, they have 1,945 Maruti-authorized sales and service centres and 779 dealership workshops. On the inbound supply chain, they deal with more than 200 suppliers and these suppliers in turn will deal with many more suppliers. One can utilize the notion of the supply chain structure to understand how various entities in the supply chain interact and how it affects the performance of the supply chain.

The **supply chain structure** refers to the set of choices made in assembling the components of a supply chain together. These include choices regarding the number of layers that make up a supply chain, the composition of each layer, the type of information flow across the layers, and the nature of integration achieved between the layers.

> The **supply chain structure** addresses issues pertaining to the number of layers that make up a supply chain, the composition of each layer, the type of information flow across the layers, and the nature of integration achieved between the layers.

FIGURE 5.8 Supply chain structure: an illustration

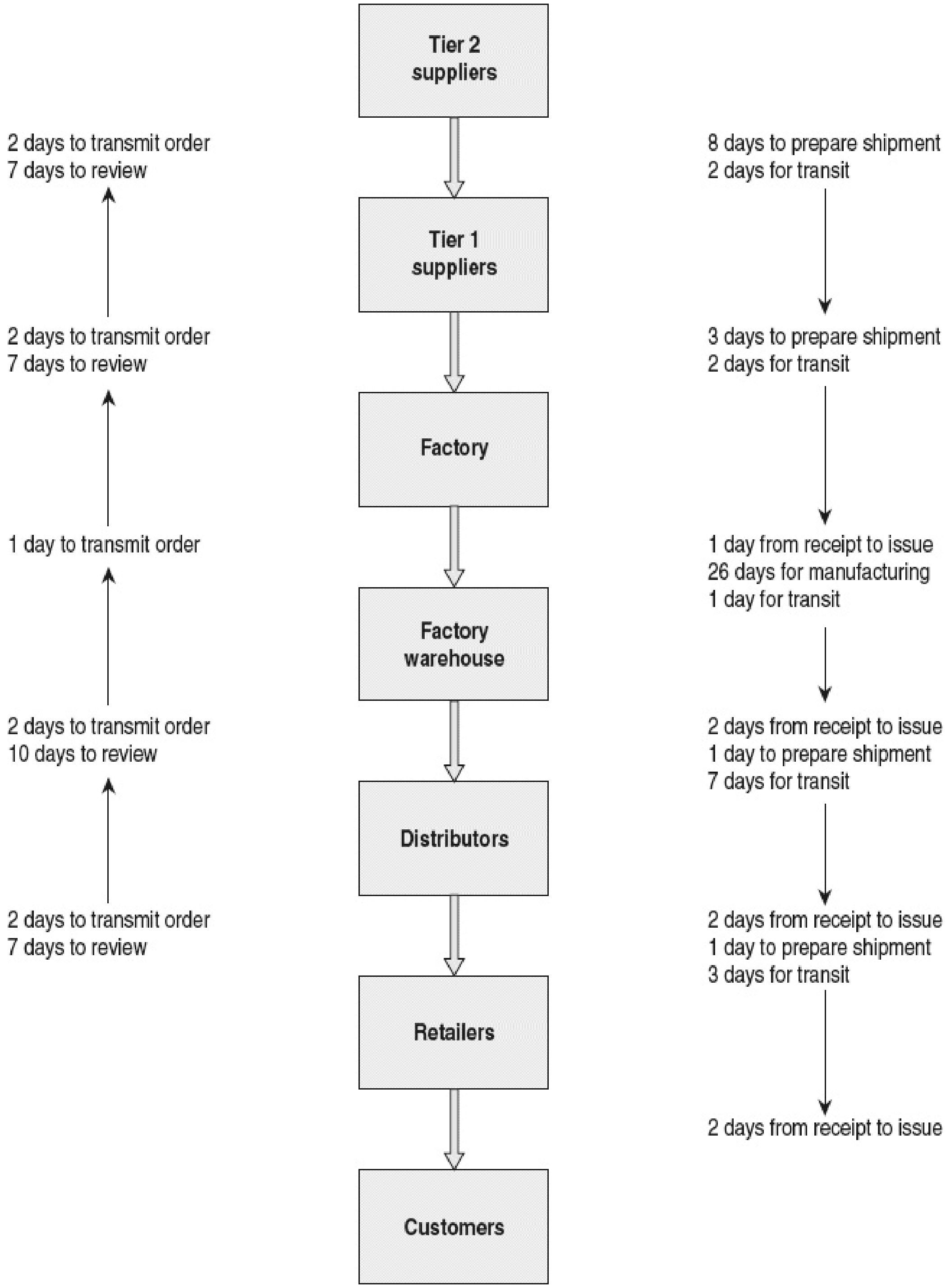


Figure 5.8 illustrates the supply chain structure. In this example, there are six layers in the supply chain. Each level is an independent profit-maximizing entity and manages its portion of the supply chain through a set of administrative controls. For instance, the retailer reviews the inventory position and the impending demand once a week and places an order with the distributor. At every level in the supply chain structure there are finite time delays. For instance,

after receiving the inventory, it takes two days to account for them and shelve them for sales. Similar administrative controls and procedures are followed at every level. The factory takes 26 days to convert raw materials and components into saleable goods. A study of the supply chain structure is very important to understand the various implications for the supply chain performance. The supply chain structure affects performance on account of several factors:

- *The number of layers*: The supply chain structure always involves several layers. However, one of the key issues in the supply chain structure is the impact of the number of layers on the overall system performance. When the number of layers increase, the delay in information and material flow also increases. The degree of coordination that needs to be achieved in order to manage a smooth flow of materials also increases. Further, an increase in the delay will result in higher investment in inventory in the supply chain.
- *Delays in the chain:* There are finite delays between a pair of layers to send and receive information and goods. For instance, the factory takes two days to transmit the order information. The delay could be primarily on account of the business processes involved in the purchase ordering process. Similarly, a Tier-1 supplier takes two days to send the material to the factory. On account of these delays in information and material flows in the supply chain, sufficient levels of inventory are maintained at every level. Moreover, delays in information flow often result in mismatch between actual demand in the market and the demand perceived by a supply chain member in the chain.
- *Decision-making patterns:* In Figure 5.8, we see that decisions on “how much to order” and “when to order” are taken independently of other supply chain members. Thus, while the distributors may choose to review these aspects every ten days, retailers may have a review every seven days. Even if all the retailers have a review once in seven days, some may be reviewing every Monday while some others may be reviewing every Friday. This can confuse the supply chain members at other levels. The cumulative orders placed with any supply chain member may not truly reflect the current realities in the market place. Hence, making decisions using such information may sometimes be misleading.
- *Independence of each member of the supply chain:* Since each layer consists of organizationally separate units with its own ownership structure, there is considerable independence in their mode of operation and the policy decisions taken. This can significantly affect overall supply chain performance. Let us return to the example of FMCG goods such as toilet soaps. Consider a situation when some distributors launch a trade discount programme to clear any excess inventory of soap that they may have. Ironically, at the same time, the factory might have taken a decision to step up the production of soaps and retailers might have chosen to aggressively promote a competitor’s brand in response to an incentive scheme that was introduced. Such examples abound in practice. It is extremely difficult to predict the performance of the supply chain but research studies show that more often these efforts have an adverse impact on the supply chain.

5.5 THE BULLWHIP EFFECT

The various aspects of supply chain structure that we just discussed culminate in the **bullwhip effect** in supply chains. In our example, each layer will employ its own practices in updating the demand forecasts. For instance, when the retailer may be revising its forecasts on the second Wednesday of every month, the distributor at the next level may be doing it on the first Saturday of every month. This introduces avoidable confusions into the system and may result in misleading signals in the system. While the retailer may be estimating a rising demand, the distributor may estimate falling demand due to alternative time periods of estimation.

> The **bullwhip effect** denotes the increasing severity of distortions in demand information and ordering patterns as the information travels from one layer of the supply chain to the next layer.

The problem may get more complicated if ordering patterns differ across the layers. Since at each layer the review of demand is done at different times, one would expect orders also to arrive at different times. Continuing our example, while distributors estimate lesser demand and place orders for fewer quantities, they may in fact receive larger orders from retailers. This will cause further problems in the supply chain and each supply chain layer will begin to respond to these confusing signals by revising the order either upwards or downwards. Moreover, the severity of these distortions in demand information and the subsequent ordering pattern increases as the information travels from one layer of the supply chain to the next layer.

Very soon, it will lead to a situation where the ordering pattern and magnitude will not be representative of the reality. This phenomenon eventually leads to a **bullwhip effect** in the supply chain.[4] The bullwhip effect often creates unnecessary strain in the entire supply chain and is responsible for sudden surges in inventory or severe shortages. Recent studies have shown the existence of the bullwhip effect in several supply chains and the possible causes for the same.

Minimizing the bullwhip effect calls for several decisions cutting across the supply chain and greater collaboration among supply chain partners. Reducing the number of layers could minimize the bullwhip effect. Very recently, several global firms have resorted to this approach. They try to directly reach a vast number of customers from just one or two strategically located distribution centres with the help of third-party logistics, provided by well-known players such as FedEx.

The other strategy is to reduce the delay of information flow in the supply chain. The use of point-of-sales data-capturing systems, Electronic data interchange (EDI), and the Web helps organizations to cut delay in information flow. Organizations need to encourage supply chain partners to share sales, capacity, and inventory data with other supply chain members. This task is easier said than done as it requires behavioural changes among the supply chain members. Suitably modifying the incentive structure could be one method to achieve this objective. During 1998, when Bangalore-based colour-TV manufacturer BPL electronically linked the top distributors and retail outlets with the factory planning system, the finished goods inventory level fell dramatically almost immediately.

Supply chain members can reduce the bullwhip effect further by reducing the lead time of their business processes. From Figure 5.8, one can see that from the time the retailer decides to place an order with the distributor, it takes eight days (two days to transmit the order to the distributor, one day to prepare shipment, three days to transport goods, and another two days to account the receipt and shelve it). This lead time could be reduced using better business processes, information technology, and closer working arrangements with logistics providers and distributors. The bullwhip effect can also be minimized through a reduction in fixed costs of ordering.

5.6 MEASURES OF SUPPLY CHAIN PERFORMANCE

Supply chain performance measures seek to provide a quantitative basis for understanding the performance of the supply chain and indicate potential areas for taking corrective measures. Since improvement projects have a certain time lag, current period results may indicate the effect of previous time periods' efforts in managing the supply chain efficiently. Hence, measures could also help the manager understand the nature of improvement efforts currently undertaken during the measurement period. Supply chain performance measures could be both post-process and process indices.

> Supply chain performance measures could be both postprocess and process indices.

Post-process Indices

Post-process indices are those that rely on past data to assess the performance of the supply chain function during the relevant period of time. These measures typically use information available in annual reports of companies to compute indices. Since inventory is the most representative item in the annual report, post-process indices for supply chain performance compute inventory measures. The following measures for supply chain performance could be computed from annual reports:

$$\text{Inventory turnover ratio (TO) percentage} = \frac{\text{Total investment in inventory (₹)}}{\text{Annual sales (₹)}} \times 100$$

$$\text{Number of inventory turns (TN)} = \frac{\text{Annual sales (₹)}}{\text{Total investment in inventory (₹)}}$$

$$\text{Total inventory (days) (TID)} = \frac{\text{Total investment in inventory (₹)}}{\text{Annual sales (₹)}} \times 365$$

$$\text{Days of sales outstanding (DSO)} = \frac{\text{Accounts receivable (₹)}}{\text{Annual sales (₹)}} \times 365$$

$$\text{Days of payables outstanding (DPO)} = \frac{\text{Accounts payable (₹)}}{\text{Value of raw materials consumed (₹)}} \times 365$$

$$\text{Cash-to-cash cycle time (days) (CCD)} = \text{TID} + \text{DSO} - \text{DPO}$$

Traditionally, the inventory turnover ratio and the number of inventory turns are employed to assess the performance of the supply chain. While these measures are quite useful for accounting and control functions, they do not offer substantial help to the operations function. On the other hand, the number of days of inventory is a useful measure for operations. It enables the operating personnel to relate the numbers to ground realities and helps them make improvements.

For example, consider a company having sales of ₹300 million and a total inventory investment of ₹50 million. The inventory turnover ratio is 16.67 per cent and the number of turns of inventory is six. Alternatively, one can express inventory in number of days, which is two months in this case. An investment of two months of inventory clearly indicates that the lead time of various activities in the company pertaining to procurement, manufacturing, and distribution is in the range of two months. Reducing inventory in this case requires that the lead time is cut proportionally, and clarifies to the operating personnel the nature of the activities to be undertaken to reduce the lead time and the relationship of these to the overall investment in inventory. Similarly, to the operational personnel, the DSO, DPO, and CCD indicate the credit terms enjoyed by the company and offered to the customers, and their impact on the overall working capital needs.

One can obtain a sharper focus by computing the number of days of inventory for each class of inventory, that is, raw material (RM), work in progress (WIP), and finished goods (FG) and relating them to specific activities in the supply chain. The formulae for computing each category of inventory is as follows:

$$\text{RM inventory (days) (RMD)} = \frac{\text{Raw material inventory (₹)}}{\text{Value of raw material consumed (₹)}} \times 365$$

$$\text{WIP inventory (days) (WIPD)} = \frac{\text{WIP inventory (₹)}}{\text{Value of production (₹)}} \times 365$$

$$\text{FG inventory (days) (FGD)} = \frac{\text{FG inventory}}{\text{Annual sales (₹)}} \times 365$$

EXAMPLE 5.1

Extracts from the annual reports for the years ended March 2010 and March 2011 of an auto-component manufacturer in Tamil Nadu are given in Table 5.1. Compute the relevant post-process indices of the supply chain performance. Are there any significant inferences that one can make based on the computation?

TABLE 5.1 Extracts from Annual Reports (Values in ₹Million, Unless Otherwise Specified)

	For the Year Ended	
	Mar 2011	**Mar 2010**
Sales	1605.7	1519.5
Value of production	1091.1	1053.5
RM consumed	742.3	740.6
Accounts receivable	265.6	203.5
Accounts payable	95.6	102.3
Inventory status		
Raw materials	69.3	42.7
WIP	9.7	08.5
FG	29.2	33.8
Others	22.6	16.3
Total inventory	130.8	101.3

Solution

Calculation of number of days of inventory for the year ended March 2011:

Inventory turnover (TO)

$$= \frac{\text{Total investment in inventory (₹)}}{\text{Annual sales (₹)}} \times 100$$

$$= \frac{130.8}{1605.7} \times 100 = 8.15\%$$

Inventory turns (TN)

$$= \frac{\text{Annual sales (₹)}}{\text{Total investment in inventory (₹)}}$$

$$= \frac{1605.7}{130.8} = 12.28$$

Total inventory (TID)

$$= \frac{\text{Total inventory}}{\text{Sales}} \times 365$$

$$= \frac{130.8}{1605.7} \times 365 = 29.73 \text{ days}$$

Sales outstanding (DSO)

$$= \frac{\text{Accounts receivable (₹)}}{\text{Annual sales (₹)}} \times 365$$

$$= \frac{265.6}{1605.7} \times 365 = 60.37 \text{ days}$$

Payable outstanding (DPO)

$$= \frac{\text{Accounts payable (₹)}}{\text{Value of raw materials consumed (₹)}} \times 365$$

$$= \frac{95.6}{742.3} \times 365 = 47 \text{ days}$$

Cash-to-cash cycle time (days) (CCD)

$$= \text{TID} + \text{DSO} - \text{DPO} = 29.73 + 60.37 - 47 = 38.56 \text{ days}$$

Calculation for sub-classes of inventory

RM inventory (RMD)

$$= \frac{\text{Raw material inventory}}{\text{Value of raw material consumed}} \times 365$$

$$= \frac{69.3}{742.3} \times 365 = 34.08 \text{ days}$$

WIP inventory (WIPD)

$$= \frac{\text{WIP inventory}}{\text{Value of production}} \times 365$$

$$= \frac{9.7}{1091.1} \times 365 = 3.24 \text{ days}$$

FG inventory (FGD)*

$$= \frac{\text{FG inventory}}{\text{Sales}} \times 365$$

$$= \frac{29.2}{1065.7} \times 365 = 6.64 \text{ days}$$

Table 5.2 presents the post-process indices for supply chain performance.

TABLE 5.2 Post-process Indices for Supply Chain Performance

	2011	**2010**
Inventory turnover ratio (TO) (%)	8.15	6.67
Number of inventory turns (TN)	12.28	15.00
Total inventory (TID)	29.73	24.33
Sales outstanding (DSO)	60.37	48.88
Payables outstanding (DPO)	47.00	50.42

Cash-to-cash cycle time (CCD)	43.10	22.79
Sub-classes of inventory		
Raw material inventory (RMD)	34.08	21.04
WIP inventory (WIPD)	3.24	2.94
FG inventory (FGD)	6.64	8.12

Some Inferences

During the year, there is an increase in TID, DSO and CCD. Clearly, the company is under the pressure of a high inventory and has apparently given generous credit terms to its customers. Therefore, although the finished goods inventory has come down, there is a significant increase in DSO, and correspondingly in CCD. Due to this increase, the working capital requirement has gone up.

The number of days of inventory in the case of raw material has significantly gone up during the year. Interestingly, during the same time, the credit term extended to the suppliers (indicated by DPO) has come down. This could be attributed to any of the several causes, including an increase in procurement lead time, mismatch between planning and production, poor performance by suppliers leading to increase in safety stock, and hedging inventory to protect against impending price increases. It could also point to the need for studying the inbound supply chain for possible performance deterioration during the year.

*An alternative base for computation of this measure could be cost of goods sold.

Process Indices

Improvements in supply chain performance occur only when the processes related to the supply chain are studied and corrective measures taken. Therefore, a set of measures is needed to understand the nature of improvement activities pursued in the supply chain. Process indices serve this purpose for an organization. By virtue of the improvements in the process, the supply chain may improve its responsiveness, cost, quality, or reliability.

For instance, when an organization develops superior suppliers with a high degree of delivery reliability and quality performance, the investment in raw material inventory may come down on account of reduced safety stock and lead time for procurement. Similarly, the component may also cost less in the long run. Some of the process indices used for assessing the performance of the supply chain are discussed here.

ideas at Work 5.3

Project Shakti of HUL: A Unique Distribution Chain for Rural Markets

One of the biggest challenges in configuring the out bound supply chain in a country like India is the difficulty in reaching the rural markets. A vast number of people live in villages and by not reaching out to them, firms can significantly lose on the opportunities to increase their market share. This is especially true for FMCG companies. In the last few years, Hindustan Unilever Limited (HUL) and ITC Limited have taken alternative initiatives to tap the rural market. ITC chose to deploy the internet infrastructure in villages and integrated it with the rural social system through what is known as ITC eChoupal.

On the other hand, HUL adopted a model of involving underprivileged rural women and created livelihood opportunities for them through what is known as Project Shakti. The project initially started in a few pilot villages in Andhra Pradesh in 2000. By the end of 2004 it grew to 13,000 Shakti Ammas in 12 states. By 2012 there were 45,000 Shakti Ammas in 15 states. In 2010, HUL rolled out the Shaktiman initiative that complemented the original project Shakti.

Through the Shaktiman initiative, men in Shakti villages distribute HUL products to five or six adjoining villages allotted by HUL. 26,000 Shaktimans have been added to the existing Shakti network. A bicycle is given to the Shaktimans so that it is easy for them to reach the villages. Earlier consumers had to travel to the nearest village. A typical Shaktiman is able to sell products worth ₹25,000 per month and retain 10% for himself. This model works as a trade-off between the cost of distribution and revenue for HUL.

Through project Shakti and Shaktiman, HUL is able to reach 3 million households in over 100,000 villages. On an average, a Shakti entrepreneur is able to earn about ₹1,800 – 2,400 per month, which is significant considering alternative earning opportunities available for them in the villages. HUL plans to use this format of out bound supply chain and increase its rural reach three-fold.

Source: Subramanian, A. (2011), 'Bicycle Chief', *Business Today*, June 12, 2011, pp 72; 'Project Shakti: It is all about empowerment', Indian Management, February 2012, pp 87 – 89.

On-time delivery index (OTD)

The on-time delivery index indicates how responsive and reliable a supply chain is. It provides a quantitative basis to understand how well and how often the supply chain partners have kept up to the promised delivery. Typically, some weighing scheme is used to judge the consistency of performance. Suppose:

Delivery committed to customer = A

Actual date of delivery = B

Weighing scheme for OTD:

Delivered on time: $(B-A) \leq 0$: 5 points

Delivered within a week: $0<(B-A) \leq 1$ week: 3 points

Delivered within 2 weeks: 1 week $< (B-A) \leq 2$ weeks: 2 points

Delivered after 2 weeks: $(B-A) > 2$ weeks: 0 points

$$\text{On-time delivery index (OTD) percentage} = \frac{\text{Cumulative points for orders}}{\text{Total number of orders} \times 5} \times 100$$

OTD could be used in any part of the value chain. In the inbound supply chain it could be used to measure the performance of the suppliers. Similarly, in the outbound supply chain, it could be used to measure the performance of the logistics and distribution system.

EXAMPLE 5.2

Eastern Castings is a crucial supplier to a machine tool manufacturing company. Since the delivery reliability of the castings has a direct bearing on the scheduling of the production system and the ability of the machine tool manufacturer to commit to the customers, they have instituted OTD as a measure of performance. Table 5.3 shows the performance of Eastern in the last 10 deliveries. Compute OTD index for Eastern Castings.

Solution

The number of points for each delivery is tabulated in Table 5.4.

On-time delivery index (OTD) percentage = $= \frac{34}{(10 \times 5)} \times 100 = 68\%$

TABLE 5.3 Performance of Eastern Castings: Last 10 Deliveries

Delivery No.	Committed Date	Delivered Date
1	25 July, 2002	23 July, 2002
2	11 August, 2002	16 August, 2002
3	28 August, 2002	02 September, 2002
4	10 September, 2002	10 September, 2002
5	25 September, 2002	30 September, 2002
6	04 October, 2002	19 October, 2002
7	22 October, 2002	25 October, 2002
8	09 November, 2002	17 November, 2002
9	30 November, 2002	30 November, 2002
10	14 December, 2002	13 December, 2002

TABLE 5.4 Data for Computation of OTD

Delivery No.	Committed Date (A)	Delivered Date (B)	(A2B)	Points
1	25 July, 2002	23 July, 2002	≤0 Week	5
2	11 August, 2002	16 August, 2002	<1 Week	3
3	28 August, 2002	02 September, 2002	<1 Week	3
4	10 S September, 2002	10 September, 2002	≤0 Week	5
5	25 September, 2002	30 September, 2002	<1 Week	3
6	04 October, 2002	19 October, 2002	>2 Weeks	0
7	22 October, 2002	25 October, 2002	<1 Week	3
8	09 November, 2002	17 November, 2002	<2 Weeks	2
9	30 November, 2002	30 November, 2002	≤0 Week	5
10	14 December, 2002	13 December, 2002	≤0 Week	5
Total				**34**

Supply chain lead time

Supply chain lead time indicates the responsiveness and flexibility of the supply chain members. The business processes related to planning, procuring, producing, and distributing could be measured in order to obtain the supply chain lead time. The overall measure will indicate the order-to-order[5] lead time for an organization. In the case of made-to-order situations, this could be an important measure of supply chain performance.

Other process indices

There are several processes in a supply chain and it is possible to incorporate specific indices to each of these processes. Organizations need to identify the relative importance of these processes and incorporate relevant indices. For example, if the inbound supply chain is crucial to an organization, then additional measures could be included in the list of process indices. Examples include the number of certified deliveries, the value of joint cost-reduction exercises, and import substitution value.

5.7 DESIGN OF SUPPLY CHAINS

Designing an appropriate supply chain calls for a good understanding of the product profile for which the supply chain is configured. Let us compare two product categories: one an FMCG item, such as toothpaste, and the other a trendy sportswear, such as World Cup cricket T-shirts conforming to specifications of the official design. Toothpaste is a *functional product*, or a product that is primarily intended to serve a function and is independent of the time of marketing the product. These products are stable, satisfy a basic need, and therefore will have a predictable demand over a longer time. Because of these features, there is more competition in such products, leaving very little profit margins for companies operating in this product.

The World Cup T-shirt, on the other hand, is an *innovative product*. Other examples include Tanishq jewellery by Titan and other fashion goods such as shoes. Liberty claims to introduce 1,000 new styles every year and withdraw several old styles. An innovative product is novel, very sensitive to the time frame within which it is being marketed, and may often have a short life cycle as opposed to a functional product. Because of its innovative nature, competitors may try to imitate it. Moreover, the innovation may also involve creating a large variety of offerings. All these may ensure greater profit margin, but may also introduce additional problems for an organization. As mentioned at the beginning of this chapter, increased variety results in demand volatility and greater need to predict demand accurately. Otherwise, the cost of operating the system may be very high. Other examples of innovative products include fashion goods, computers and high-tech gadgets.

The key differences between a functional product and an innovative product are as follows:[6]

- Innovative products command a higher contribution margin (20%–60%) than functional products (5%–20%) and have much more product variety.
- Due to variety, forecast errors in the case of innovative products will be higher (40%–100%) than functional products (10%), leading to product markdown at the end of the product lifecycle. Usually, there are no forced end-of-season markdowns for functional products. Innovative products, on the other hand, may have markdowns between 10 per cent and 25 per cent.
- Further, short product life cycles of 3 months to 1 year in the case of innovative products also imply that these products require shorter lead times (1 day to 2 weeks) in the supply chain.
- Because of the shorter lead times in the case of innovative products, *responsiveness* is the most important requirement. A responsive supply chain will be able to curb the demand–supply mismatch and significantly reduce the end-of-period markdowns. In the case of functional products, *efficiency* issues are important while configuring the supply chain due to their narrow profit margins.

VIDEO INSIGHTS 5.2

Retailing in India has certain restrictions, which prevents large multi-national retailers from directly reaching out to the ultimate customers. Therefore, they adopt a wholesale, cash and carry format to retailing. To know more about Walmart’s Indian operations and future plans, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Designing Efficient Supply Chains

Efficient supply chains are designed with the central objective of overall supply chain cost minimization and better asset utilization. Organizations need to incorporate several features in their supply chain to achieve this objective. Investing in supply chain partnership programmes on both the inbound and outbound supply chain is an important requirement. For instance, long-term relationships need to be developed with the suppliers. Suppliers need to be engaged in joint cost-reduction exercises, value engineering efforts, and process improvement. Similarly, it is important to invest in long-term relationships with the entities in the outbound supply chain and realize efficiency gains in the long run.

Efficient supply chains are designed with the central objective of overall cost minimization and better asset utilization in the supply chain.

Since demand is likely to exist for a longer time, the continuous replenishment of products in a cost-effective manner will require efficient information sharing across the supply chain. Developing robust inventory control mechanisms to accurately fix the reorder point and order levels are important to ensure efficient supply chains.[7] Integrating material planning and control systems with other related systems in the in-house supply chain using corporate-wide information systems such as enterprise resource planning (ERP) is yet another requirement for efficient supply chains.

Designing Responsive Supply Chains

The design of a responsive supply chain begins with the basic premise that uncertainty in demand and large forecast errors are often the reality. Therefore, the supply chain requires certain strategies for addressing these. Moreover, developing systems to improve responsiveness is another objective of the design. Capturing point-of-sale data and immediately updating the centralized planning system using EDI and Web linkages is an important operational feature of responsive supply chains. Cutting down the lead time by drastically redesigning business processes pertaining to various components of the supply chain is also a key requirement. Recently, newer strategies related to postponement have been devised to address the twin problems of increased variety and longer lead time. In a postponement strategy, variety creation is postponed as much as possible to the point of consumption. This alleviates the need for accurate forecasts for each variety and pre-stocking of finished goods.

The design of a responsive supply chain begins with the basic premise that uncertainty in demand and large forecast errors are often the reality.

Firms selling innovative products practice three types of postponement.

- In *packaging postponement*, the company delays the final packaging until the point of consumption of the product. Hewlett-Packard handles the multilingual requirements of its customers through packaging postponement by including an instruction manual relevant to the language of the customer at the point of sale.
- In *assembly postponement*, standardized subcomponents are kept ready and the product is assembled to order. A typical example of assembly postponement is Dell Computers.
- In the case of *manufacturing postponement*, the final stage of manufacturing is delayed until the point of consumption. Benetton started the practice of dyeing its fabrics after completing the stitching process. In this manner, they are able to quickly react and ship products with greater variety.

TABLE 5.5 Postponement Strategies for Responsive Supply Chain Design

Type of Postponement	Implications
Packaging postponement	

	• Savings in transportation (bulk containers) • I Handle multilingual requirements (Example: HP printers)
Assembly postponement	• Low levels of investment in FG • Ability to handle a large variety through modular design (Example: Dell computers)
Manufacturing postponement	• Final stages of manufacturing delayed until firm orders are received (Example: Benetton's dyeing of fabrics) • Reduced lead time

Other strategies employed in configuring an efficient supply chain include changes in product design. Deploying standardization, use of modular design and product platforms are some examples. The computer and automotive industries provide several examples of these. Table 5.5 lists postponement strategies and their implications to organizations.

> Firms selling innovative products practice three types of postponement: packaging postponement, assembly postponement, and manufacturing postponement.

5.8 THIRD-PARTY LOGISTICS IN WEB-BASED FIRMS

Firms selling through the Web reach out to the customer directly. They engage in a variety of direct selling techniques. For instance, they may display a catalogue and request the customers to select a product or service of their choice and pay for it using a digital payment system. For example, Indian Railways allows prospective travellers to book tickets through their Web site www.irctc.co.in. Similarly, LG Electronics encourages its customers to order directly through their Web site www.lgezbuy.com. Web-based firms may alternatively put up an auction and encourage customers to bid for their offerings online. A very good example of this is the well-known auction site www.ebay.com. In all these examples, once the customer makes his/her selection of product through a Web site and place an order, the firm reaches the product to the customer at the delivery address provided during order booking using a third-party logistics provider.

> The advent of Web-based e-commerce has projected a crucial role for third-party logistics providers.

In all these cases, the customer exercises his/her choice on the Web site and makes a payment. Order fulfilment is a crucial requirement in Web-based e-commerce. During the Christmas festival season in 1999–2000, Web-based firms took online payments from several customers and failed to make delivery of gifts before Christmas. In lieu of this, they offered to pay back the money and also gave gift cheques for USD 20–USD 50. Widespread protests by unhappy customers eventually led to the downfall of several Web-based firms. Therefore, the advent of Web-based e-commerce has projected a crucial role for third-party logistics providers.

SUMMARY

- Planning, procurement of input material and services, production of goods and services, and distribution to the end customers are the major activities in any supply chain.
- The components of a supply chain include *inbound, in-house* and *outbound*. While the inbound supply chain addresses issues relate to raw materials and component suppliers, the outbound supply chain pertains to the distribution network.
- *Supply chain structure* refers to the manner in which various entities pertaining to a supply chain are configured. It includes the number of layers that make up a supply chain, the composition of each layer and the nature of integration among the layers.
- The *bullwhip effect* occurs in a supply chain due to several reasons. These include:
    - The number of layers in the supply chain
    - Delays in information flow across these layers
    - Variations in decision making patterns at each layer
    - The independence of each member in the supply chain
- Several measures are available to assess the performance of supply chains. These can broadly be classified into *process indices* and *post-process indices*.
- The design of a supply chain must take into consideration the nature of products. Innovative products require responsive supply chains and functional products require efficient supply chains.
- Due to an increase in the use of the Web and IT infrastructure, third-party logistics providers play an important role in the outbound supply chain of many firms.

REVIEW QUESTIONS

1. Identify the key supply chain elements in the following cases:

    a. A major multi-specialty hospital
    b. An airline operator
    c. A manufacturer of semi-conductor devices
    d. A premier educational institute
    e. An automotive repair shop
    f. A newspaper business
    g. A pure-play Web-based firm offering travel bookings
    h. A manufacturer of shampoo sachets
    i. A machine tool manufacturer
    j. A law consulting firm

2. Consider Asian Paints and Berger Paints, the two close competitors in the paint industry. Which are the elements of supply chain management that would create differences among their competitive offerings in the market?
3. How should an organization manage an inbound supply chain that is organized into tiers? What are the benefits of organizing suppliers into these tiers?
4. What do you mean by supply chain structure? What is the relationship between the supply chain structure and supply chain performance?
5. Which sectors of industry will have a pronounced bull-whip effect? Why?
6. Why is the bullwhip effect undesirable for organizations? What are the various alternatives that organizations have to minimize the bullwhip effect?
7. What are the key aspects of managing a global supply chain? Can you give some examples of global supply chain management?

8. Identify an appropriate type of supply chain for each of the following product categories:

a. Jewellery watches
b. Toothpaste and brushes
c. Earth-moving equipment
d. Designer clothes
e. Mobile telephony services
f. Executive education programmes
g. Bicycles
h. Passenger cars
i. Heavy commercial vehicles

FORMULA REVIEW

Inventory turnover ratio,(TO)%

$$= \frac{\text{Total investment in inventory (₹)}}{\text{Annual sales (₹)}} \times 100$$

Number of inventory turns, (TN)

$$= \frac{\text{Annual sales (₹)}}{\text{Total investment in inventory (₹)}}$$

Total inventory (days), (TID)

$$= \frac{\text{Total investment in inventory (₹)}}{\text{Annual sales(₹)}} \times 365$$

Days of sales outstanding, (DSO)

$$= \frac{\text{Accounts receivable(₹)}}{\text{Annual sales (₹)}} \times 365$$

Days of payables outstanding, (DPO)

$$= \frac{\text{Accounts payable (₹)}}{\text{Value of raw material consumed (₹)}} \times 365$$

Cash-to-Cash cycle time (days), CCD

$$= \text{TID} + \text{DSO} - \text{DPO}$$

RM Inventory (days), (RMD)

$$= \frac{\text{Raw material inventory (₹)}}{\text{Value of raw material consumed (₹)}} \times 365$$

WIP Inventory (days), (WIPD)

$$= \frac{\text{WIP inventory (₹)}}{\text{Value of production (₹)}} \times 365$$

FC Inventory (days), (FGD)

$$= \frac{\text{FG inventory}}{\text{Annual sales (₹)}} \times 365$$

NET-WISE EXERCISES

1. Visit the URL: http://www.hul.co.in/sustainable-living-2014/casestudies/Casecategory/Project-shakti.aspx and browse through the page. Answer the following questions:

   a. What are the supply chain management issues pertaining to accessing rural markets? What are the opportunities that organizations can tap while addressing these issues?
   b. How does i-Shakti address the rural markets? List the strengths and limitations of their offerings.
   c. Google for the e-Choupal initiative of ITC and draw a comparative study of i-Shakti and e-Choupal.

2. Asian Paints is India’s largest and Asia’s third largest paint company, with a turnover of ₹109.70 billion. Asian Paints operates in 17 countries and has 23 paint manufacturing facilities in the world, servicing consumers in over 65 countries. Visit the URL http://asianpaints.com/index.aspx. From the main menus, click on the pull-down menus on the top and pursue the links there.

   Answer the following questions:

   a. Based on your understanding of the products and services offered, enumerate the supply chain management challenges that Asian Paints is likely to face.
   b. Can you relate the concepts discussed in the chapter to the Asian Paints situation? Identify some strategies that Asian Paints can utilize to manage their supply chain better.
   c. How have they addressed some of the SCM challenges?

MINI-PROJECTS

1. Select two close competitors in any sector of industry and study their annual reports for the last three years.

   a. Compute relevant measures of supply chain performance for both of them for these three years and report your significant observations from the study.
   b. Do you see any significant change in the performance in these companies during this period? If so, collect additional data and list down the possible reasons for such change(s).
   c. According to you, who is practicing supply chain management better? Can you support your claim by additional facts and figures?

2. Select one company from each of the following sectors of the industry: petrochemical, automobile, machine tools, fast-moving consumer goods (FMCG), and turnkey project management. Study their annual reports.

   a. Compute relevant measure of supply chain performance for all the four companies and prepare a comparative table.
   b. What are your significant observations? Do you see any pattern in these computations?
   c. Relate the significant differences in the performance measures to the operating characteristics of each company.
   d. Do you have any recommendations to each of these companies?
   e. If these companies have to improve their supply chain performance, what are the likely areas of primary focus for each company?

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CHAPTER 6

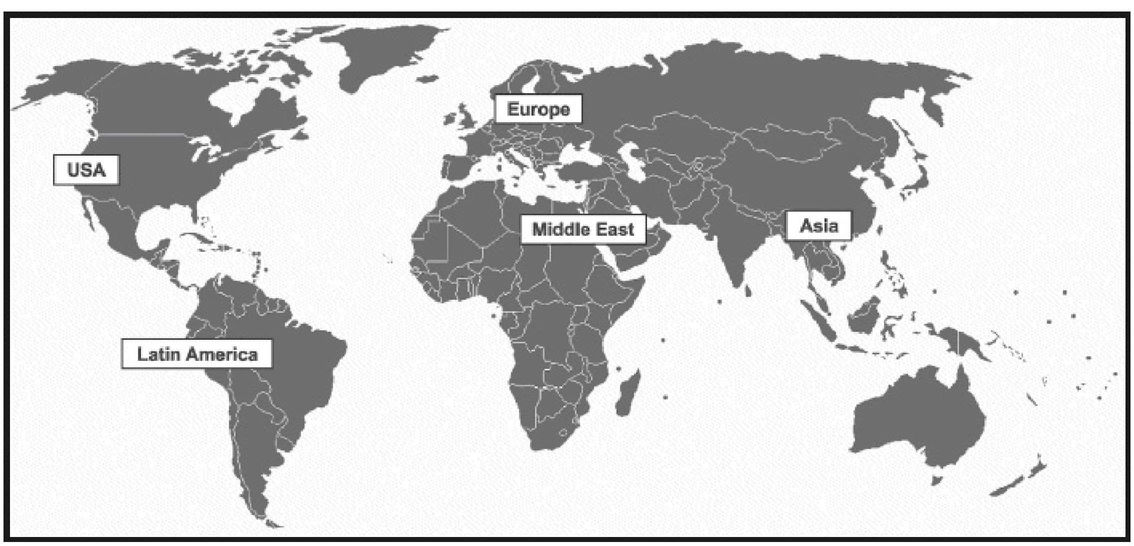
Facilities Location

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What role does globalization play in the facilities location problem that a firm faces?
- What are the factors that influence the facilities location problem?
- How is the facilities location problem solved?
- What are the qualitative and quantitative methods available for choosing one location from multiple possible locations?
- How does one use the transportation model for solving the location problem?

Many facilities are located in multiple markets so that it becomes easy to access customers. HSBC, for instance, has locations at many places all over the world.



Source: Wikimedia

ideas at Work 6.1

Akshaya Patra: The Nation-wide Mid-day Meal Scheme of ISKCON

Mid-day meal scheme (MDMS) is a mechanism to address the socio-economic objectives of boosting enrolment, retention, participation, and nutritional status of children at schools. The Akshaya Patra Foundation (TAPF) is a non-profit organization that operates a MDMS program for about 1.3 million children in over 9,000 schools across nine states in India. The vision of TAPF is ‘no child in India shall be deprived of education because of hunger’. From a humble beginning of delivering lunch to 23,000 children in 2003, it has grown to delivering lunch to nearly 1.3 million children by 2013.

Amongst many problems to be solved by TAPF, one of the fundamental problems is the location of the kitchens. A centralized kitchen may reduce the capital investments and help them benefit from economies of scale. On the other hand, it may increase the distribution cost as well as the time to reach the schools, which are the demand points. Loading food into vans must start at about 8 am each day, and the vans must complete their delivery schedule before 12.30 pm. Since schools break for lunch at 1 pm, any delay in delivery could result in students going back to their afternoon sessions with an empty stomach. Therefore, maintaining a strict cooking to consumption time is critical for TAPF logistics. This will put realistic limits to centralizing the kitchen.

The other option is to decentralize the kitchen. While this may improve the responsiveness of the delivery network and bring down the distribution cost, food preparation costs may go up as too much of capacity need to be built. These factors determine the location decision for TAPF.

The TAPF operating model involves setting up cooking infrastructure in a city that can cater to the demands of a number of rural schools in the surrounding areas using delivery vans. The capacity of the kitchen and the size of the delivery fleet are determined based on the estimated demand in a region. The maximum available time window for ‘cooking to consumption’ is about 6 hours. In the city of Bangalore there are two kitchens, one in Vasanthapura and the other in Hare Krishna Hills, Rajaji Nagar. The Vasanthapura kitchen caters to about 630 schools in the surrounding areas. TAPF’s has located 19 kitchens spread across 9 states in India. These kitchens have a daily cooking capacity ranging from 50,000 to 185,000 meals.

As is evident from the above example, location planning calls for a systematic approach to collect data on demand points, quantum of demand, transportation costs, etc., and uses this for solving the location problem. Other factors such as strict window for delivery also need to be included in the analysis of the location problem. We shall look at these issues in some detail in this chapter.

Source: Mahadevan, B., Sivakumar, S., Dinesh Kumar, D. and Ganeshram, K. (2013). 'Redesigning Mid-day meal logistics of AkshayaPatra Foundation: OR at work in feeding hungry school children', Interfaces, 43 (6), pp 530 – 546.

The controversy surrounding the Tata Nano project in the Singur special economic zone (SEZ) in West Bengal highlights the importance of location decisions for an organization. Ratan Tata's ambitious objective of building the world's cheapest car became a victim of a tussle between the CPI(M) leadership and the Trinamool Congress. For the CPI(M), the Nano project could have been a symbol of the new spirit of industrialization in the state. This was important because, over the years, West Bengal had been losing out to new hubs of corporate excellence such as Bangalore and Hyderabad. For Trinamool Congress leader Mamata Banerjee, however, it was an opportunity for gaining the goodwill of the farmers as she felt that they had been given a raw deal when their farmland had been acquired. Thus, location decisions seem to have a political dimension in a country like India due to its growing population and the paucity of land.

Location decisions are an integral part of designing a supply chain for an organization as it determines the flow of materials from the raw material suppliers to the factories, and finally to the customers. Location decisions affect the overall profitability of a firm. This is because the cost of manufacturing and the total cost of logistics and distribution are direct fallouts of location decisions. For instance, locating manufacturing facilities far away from the market could raise the logistics and distribution costs. On the other hand, locating manufacturing facilities in regions with high factor costs may make the firm unattractive as the cost of manufacturing may turn out to be high. Moreover, once location decisions are made, they are likely to stay longer as huge investments are made. Therefore, location decisions are strategic in nature.

Location decisions pertain to the choice of appropriate geographical sites for locating various manufacturing and/or service facilities of an organization. In reality, a firm may have to locate several operating units to cater to the requirements of the market. At one extreme, it is possible to have a single location in which all facilities could be located. Products are manufactured in this facility and sent to the markets using a distribution system. Companies in the aerospace and defence sectors, such as Boeing and Airbus, are examples of this category. Another example is the printer-manufacturing facility of Hewlett-Packard. At the other extreme, many facilities are located in multiple markets so that it becomes easy to access customers. Automobile manufacturers such as Ford and Toyota are examples of this category. Essel Propack, the Indian manufacturer of tubes for toothpastes, creams, etc., has factories in all continents except Australia. Both the extremes may prove inappropriate in most situations. However, they highlight the basic trade-off involved in solving the location puzzle.

Location decisions pertain to the choice of appropriate geographical sites for locating the various manufacturing and service facilities of an organization.

Locating facilities in regions that offer attractive cost advantages is one aspect of the trade-off. It may be expensive to set up a distribution system that is both efficient and responsive (it leads to an increase in transportation costs and the costs of coordinating and communicating with the supplier about products and availability). On the other hand, locating facilities very close to the markets provides the advantages of quicker responses and better customer service.

Operations managers need to evaluate intermediate solutions to arrive at an optimal location of facilities. Location planning essentially addresses this issue and provides the operations manager the needed tools and techniques to study the location problem. Location decisions affect other functional areas of business as well. Choice of locations is an important input to marketing as the management needs to plan their marketing strategy in relation to the location of facilities vis-àvis the customers. In this chapter, we shall look at these issues in some detail and understand how operations managers could make decisions with respect to location of the organization facilities.

6.1 GLOBALIZATION OF OPERATIONS

Location issues have become more prominent in recent years due to the increased pace of economic reforms in several countries and the consequent globalization of markets. The globalization of markets opens up new opportunities to multinational corporations on issues related to location, which they have not faced before. For instance, ABB decided to identify factories that could produce world-class products at internationally competitive prices. Moreover, the factories needed to have high levels of technical capability and domain expertise. This exercise resulted in selecting plants at Vadodara and Nasik for circuit breakers of ranges above 72.5 kV.[1] Similarly, their motor division in Faridabad, the only one available east of the Suez Canal, is capable of making variable drive motors for global markets.

These examples amplify the close relationship between globalizing operations and new dimensions to the location of manufacturing facilities. Therefore, we shall examine in detail the factors that have caused globalization of operations and how these influence the location decisions of firms. Figure 6.1 presents a schematic representation of the impact of globalization on the location decisions of organizations.

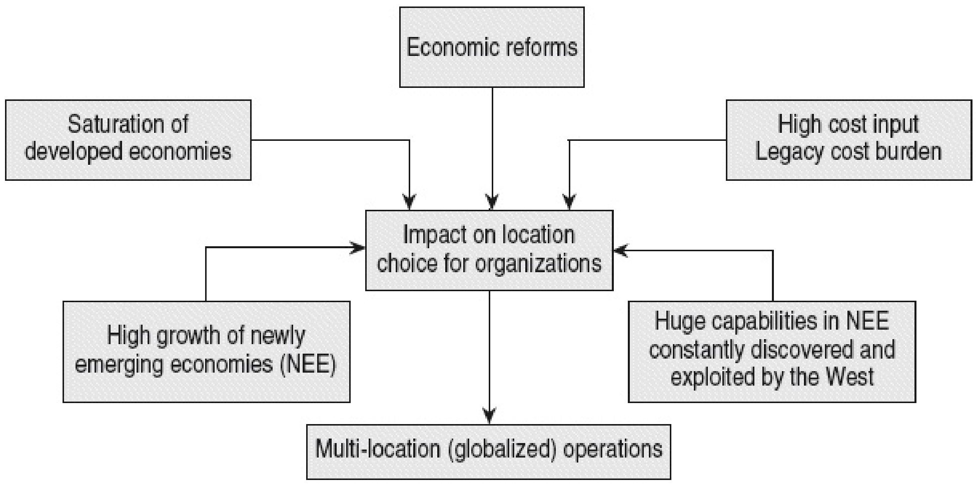
Regulatory Issues

The most significant factor that drives globalization is the ongoing economic and regulatory reforms in several developing countries. Beginning from 1991, we embarked on a set of regulatory changes that made India much more attractive in terms of locating a manufacturing facility. Two events have been broadly responsible for this. First is the reduction in customs and excise tariffs and a move towards the single-point value-added tax (VAT) regime. The other is the delicencing of several sectors of industry and the progressive removal of the cap on foreign direct investment (FDI). Further, there has been a progressive simplification of the procedural aspects of setting up operations here and running them on a day-to-day basis.

> The removal of entry barriers and reduction in the cost of manufacturing due to tariff reductions will make India an attractive destination to which manufacturing bases can be shifted.

These changes have several implications for the location choices of multinational firms. The removal of entry barriers and reduction in the cost of manufacturing due to tariff reductions will make India an attractive destination to which manufacturing bases can be shifted. In the case of multinational firms with manufacturing facilities already located in India, these facilities will be attractive candidates for further development and growth.

FIGURE 6.1 Impact of globalization on location decisions of organizations



Another relevant point for location planning with respect to regulatory issues is the emergence of regional trading blocs. A trading bloc is essentially a group of geographically separated nations that provide advantageous access to markets, manufacturing facilities, and technologies within the member countries. If required, it could also have a common currency, as in the case of the European Union. Such an arrangement provides multiple options for locations for an organization operating in such markets. India is a member of two trading blocs, the South Asian Association for Regional Cooperation (SAARC) and the Association of Southeast Asian Nations (ASEAN).

Factor Advantages

The globalization of manufacturing is also triggered by factor advantages that an organization can enjoy by operating in specific locations. Generally, developed countries in Europe and in the United States are characterized by the high cost of labour. On the other hand, developing countries offer significant advantages to a firm due to the availability of cheap labour. Therefore, in location planning, these advantages are likely to be considered. The recent shifting of manufacturing bases to China and India and the large-scale shifting of BPO activities to India are primarily related to the factor cost advantages that these countries offer to firms in the western world. For a similar reason, the bulk of semiconductor and electronic appliances manufacturing has been shifting to countries such as South Korea, Taiwan and Malaysia.

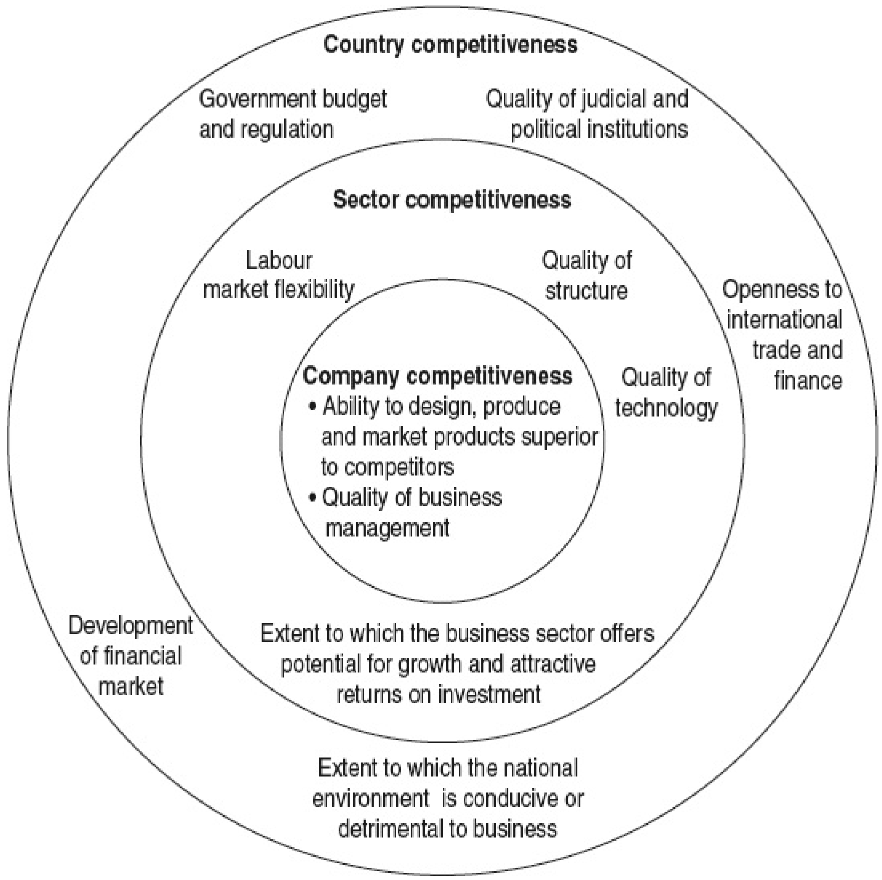
> Factor advantages may encourage a firm to globalize its operations.

Factor advantages also accrue to a firm on account of the availability of skilled labour and other resources required in plenty for manufacturing. The other resources may be power and water (as in the case of the chemical processing industry) or the availability of technical infrastructure in the form of well-developed ancillary industries. Essentially, when these resources are available in plenty, firms develop confidence that the location of their facilities will benefit them in the long run and enable them to make further enhancements in the product offering without much difficulty.[2] Moreover, the plentiful availability of these resources will introduce a healthy competition among them, paving the way for cost reduction and the overall improvement of quality and delivery reliability. These factors may significantly influence the location decisions of a firm and encourage the firm to globalize its operations.

Expanding Markets in Developing Countries

Another phenomenon that promotes the globalization of operations and provides more alternatives for location decisions is the growth rate of the economy in developed and developing countries. Developing countries such as India and China are growing at an annual rate of six per cent and above. In contrast, most developed countries witness very little growth, amounting to less than two per cent. Let us consider the automobile industry. In the United States, for every 1000 individuals, nearly 797 own a car. On the other hand, in India, only 41 out of 1000 own a car. This merely illustrates the untapped potential for market growth in developing countries. Moreover, developing countries (primarily in Asia) have very high populations. In several of these countries, the middle-income group is larger than the entire population of most developed countries. Clearly, such a scenario means that there are expanding markets in developing countries, and the desire of multinational firms has been to capture a significant market share in these regions. Therefore, several firms have been considering new locations in these markets for their manufacturing facilities in recent years.

FIGURE 6.2 A three-tier model for assessing the competitiveness of a location



The factors that drive the globalization of operations are aptly summarized by the study on world competitiveness rating by the Geneva-based World Economic Forum. Figure 6.2 illustrates the various factors that make a country (location) attractive for firms.[3] The model proposes three tiers of competitiveness. At the topmost level, there are certain factors that make a country attractive. These include the quality of judicial, economic, and financial institutions, openness to international trade and finance, and the role of its government in creating an environment conducive for business. At the second level, the sectoral competitiveness determines how attractive a location is. This level broadly covers issues of quality and the availability of manpower and associated infrastructure for the sector. At the lowest level, firm-level issues contribute to the attractiveness of the location. This basically pertains to the ability of the firm to compete effectively in the market by operating in a particular location.

Location planning in a globalized scenario also introduces additional complexities that managers had not faced earlier. Foremost is the multilingual and multicultural setting of the various locations. Managing an operating system in these introduces costs that are unknown a *priori* and therefore difficult to factor into a location decision-making framework. There are cultural dimensions and regional practices that account for productivity differences between locations. Complexities in communication and coordination arising out of a multilingual set-up also contribute to additional costs and loss of productivity. Moreover, unknown laws, regulations, and unfamiliar trade practices result in further differences between what is assumed about a location and the reality.

Despite these complexities, more and more organizations see merit in considering alternative locations. Developing and third-world countries are seen to be increasingly attractive options and more and more organizations have been making an effort to shift their manufacturing bases to these locations. The underlying logic behind this appears to be that of identifying the most significant factors from a large number of potential ones and using a methodology for studying the impact of these factors on the overall attractiveness of these locations.

6.2 FACTORS AFFECTING LOCATION DECISIONS

From the previous discussion, it is clear that there are several factors that affect the location decision. Therefore, a location planning exercise requires three steps:

1. Identify the set of factors that could influence the location decision.
2. Establish the relative importance of these measures for the location decision.
3. Develop a methodology to assess the impact of these factors.

We shall dwell on these three issues in some detail.

We frequently hear that multinationals seem to be investing more in China compared to India. We also know that huge manufacturing bases are set up in China to manufacture a variety of consumer goods such as toys and textiles and intermediary low-value-added engineering goods and components. Does that mean that China is a more attractive location compared to India? If so, why is it so? In order to understand this, let us look at some results from the study conducted by the World Bank on doing business in 2005. Table 6.1 presents a comparative study of India and China on some chosen parameters.

TABLE 6.1 Doing Business in 2014: A Comparison of India and China

Parameters	China	India
Starting a business		
Procedures (number)	13	12
Time (days)	33	27
Cost (% of per capita income)	2%	47.3%
Enforcing contracts		
Procedures (number)	19	46
Time (days)	406	1420
Cost (% of debt)	11.1%	39.6%
Closing a business		
Time (years)	1.7	4.3
Cost (% of estate)	22%	9%
Recovery rate	36%	25.6%

Source: World Bank. 2013. Doing Business 2014: Understanding Regulations for Small and MediumSize Enterprises. Washington, DC: World Bank Group. DOI: 10.1596/978-0-8213-9984-2. License: Creative Commons Attribution CC BY 3.0.

From a cursory analysis of the table, one may come to the conclusion that it is relatively easier to do business in China compared to India. This is because there are fewer procedures related to starting or closing business in China. Furthermore, it is easier to enforce contracts. We also notice that the costs associated with running the business, closing, or enforcing the contracts are much lesser in China. It is evident from this example that one can develop a set of factors that affect the location decisions of organizations and use it as a basis for the site selection.

In order to study the factors that affect a location decision in an organization, it is useful to categorize them and understand how each of these are relevant to the location problem. Table 6.2 shows a four-part classification of the various factors that affect the location decision.

Market-related Issues

The first set of factors in Table 6.2 comprise *market-related* issues. The existence of a market for the firm's products and services significantly influences the location decision. In general, it is very desirable to locate the operating system close to either the market or the source of raw material and other critical inputs for the system. Locating systems far away from these will often make the system unviable due to large transportation and distribution costs arising out of bringing the product to the market where it is ultimately consumed. Availability of raw material and other inputs also significantly affect the overall cost of the system, and hence the profitability. In India, successive governments have been trying to woo investors to backward and underdeveloped regions by providing tax rebates and other sops. In spite of that, firms have not been attracted to these places. This is due to the market-related issues of location planning and the absence of infrastructure facilities. The importance of market-related issues is much more in the case of a service organization.

The other related issue is the size of the market. A large market provides several advantages to an organization. It has higher demand for products and services. It also assures ample supply of key human resources for the operating system. Large markets are very attractive locations, as we currently see in the case of countries such as China and India. Furthermore, the nature of competition also determines the suitability of a location. If a market is already saturated and there are already several established firms competing for the market share, it requires considerable effort to successfully establish operations in such a market.

TABLE 6.2 Factors Affecting Location Decisions

Market-related Issues	**Cost-related Issues**
Market for products and services	Factor costs of inputs
Raw material availability	Transportation costs
Number and proximity of suppliers	Taxes and other tariff issues
Availability of skilled labour	Cost of manufacture/service
Quality of infrastructure	Currency and exchange rate fluctuations
Demand-supply gap	

Nature of competition	
Regulatory and Policy issues	**Other Issues**
Government and economic stability	Culture
Quality of legal and other institutions	Climate
Trading blocks and trading agreements	Quality of life

ideas at Work 6.2

Aravind Eye Hospital's Approach to Location of Healthcare Delivery Systems

Research shows that permanent eye care facilities in rural areas motivate people to seek earlier treatment for vision problems, allowing them to reintegrate back into the workforce instead of becoming visually impaired. In order to address the needs of the rural population, the location of healthcare delivery services requires a well thought out strategy so that the target segment is reached in the most effective manner. Being a service system, reach is an important aspect of location planning. Aravind Eye Hospital has a three tier approach for location planning.

At the first level, it has full-fledged hospitals in 10 locations in Tamil Nadu. The hospitals provide high quality and affordable services to the rich and poor alike, yet are financially self-supporting. They have well equipped specialty clinics with comprehensive support facilities. In the year ending March 2013, 3.1 million outpatients were treated and over 370,000 surgeries were performed in these hospitals.

At the second level, Aravind Eye Care has setup vision centres to provide eye care for the needy population located at the primary level. The vision centres offer innovative Internet-based Information Technology (IT) that allows patients in rural areas to be remotely diagnosed by ophthalmologists at the base hospital. Via high-speed wireless video-conferencing, doctors can consult with hundreds of rural patients per day, providing high quality eye care while eliminating the need for patients to travel to hospital (unless more advanced treatment is needed). Aravind has established more than 40 IT enabled vision centres providing telemedicine facility in various districts of Tamil Nadu. Each vision centre will cover a population of about 45,000–50,000.

Community eye clinics offer a permanent access point for comprehensive primary (non-surgical) eye care, in an underserviced suburban or semi-urban setting less than one hour drive (30 to 60 kilometres) from the base hospital. The community eye centre model is intended to replace regional eye camps and to manage primary eye care in order to enable the base hospital to focus on secondary and tertiary care. The main difference between a community eye centre and vision centre (besides its bigger size of about 1000 square feet) is the presence of a full-time ophthalmologist in the former set up. The staff consists of one doctor, five paramedics (2 senior ophthalmic assistants, and 3 junior), and one paramedically trained receptionist. The services offered include lab services (urine, blood sugar), optical shop, medical shop, and treatment follow-up.

Source: http://www.aravind.org/ClinicalServices.aspx. Last accessed on 20 May 2014.

Cost-related Issues

Cost-related issues capture the desirability or otherwise of competing locations on the basis of the cost of operating the system in alternative locations. Typically, logistics and distribution costs are often considered for the analysis simply because these costs are direct, tangible, and easy to measure and analyse. However, depending on the availability of data and sophistication of the analysis, other costs, such as wages or input factor costs and tax and other tariff benefits could also be included. Our earlier discussion on the hesitation of firms to locate their operating systems in far-off and underdeveloped regions could be easily justified by taking a cost-oriented approach to location planning.

> Typically, logistics and distribution costs are often considered for location analysis because these costs are direct, tangible, and easy to measure and analyse.

Regulatory and Policy Issues

So far, we have looked at factors that apply to a limited geographical reach (such as a country). However, when we analyse the feasibility of locations cutting across countries, other factors enter into the analysis. First among them is the *regulatory and policy climate* of local governments. The quality of the legal and judicial institutions in that area is one major element in decision making. For example, countries that offer very little or no protectionfor intellectual property will be least attractive for firms. In such a setting, the imitation of original research and interesting ideas will be rampant and a vibrant gray market will thrive. On the other hand, good-quality governance, availability of free markets, public finances, robust financial institutions and free access to markets will increase the attractiveness of the location.

Other Issues

Finally, *other issues* that influence a location decision include cultural, linguistic, and climatic aspects, along with the overall quality of life. These factors provide a certain assurance to firms that operating systems can work without much difficulty, as the key input for the system, in the form of human resources, will be readily available.

Any location planning decision needs to take these factors into consideration. Depending on the scope of the location planning and the type of modelling of the problem, location planners can judiciously make use of these factors for selection from among competing candidates.

6.3 LOCATION PLANNING METHODS

Generally, location decisions could be one of the two: *one facility–multiple candidates* and *multiple facilities–multiple candidates*. In the former, the decision boils down to selecting one location out of a group for a single facility. For example, a firm may want to choose one location out of several alternatives to build its factory. In the process of selecting the ideal location, one can suitably incorporate any of the factors discussed so far and assess the attractiveness of each location on their basis. We shall discuss two methods used to perform this exercise.

> Generally, location decisions could be one of the two: one facility–multiple candidates and multiple facilities–multiple candidates.

The second type is one of selecting *k* locations out of the *n* alternatives available. A typical example could be a firm wanting to locate four regional warehouses to serve the demand throughout the country. Therefore, it may have to choose four locations out of the 10 alternatives available to it. Some sort of network flow modelling is involved in this case to decide on an appropriate set of locations. In addition to choosing *k* locations, the location planner must also decide how these locations will serve multiple markets that are spread out geographically. One of the popular network models is the transportation method, which could address this issue.

Location Factor Rating

One of the simplest methods to compare alternative sites using the factors identified to be relevant is to use a factor rating method. **Factor rating** is a simple methodology to assess the attractiveness of each potential location. This method involves four steps in which the relevant factors are identified, their relative importance established, the performance of each location in each factor assessed, and, finally, all this information is combined to rank the locations.

> **Factor rating** is a simple methodology to assess the attractiveness of each potential location.

The advantage of this method is its ability to incorporate any factor into the analysis as long as the decision maker can assess its relative importance. It is also simple to compute and comprehend. However, the limitation of this method is that it can be used only for initial screening and broad-level ranking. A detailed cost-based analysis may be desirable to assess the quantum of benefit or impact of each candidate location before a final decision is made on the location.

The four-step process of identifying an appropriate location is as follows:

1. Identify and list all the relevant factors for the location decision. We have already discussed some of the factors to be considered. One can choose several factors from the list and add a few more that are specific to the context.
2. Establish the relative importance of each factor in the final decision. The easiest method to establish the relative importance of each factor is to rate each factor on a scale of 0 to 100. Once all the factors are rated, these ratings can be

normalized to obtain the relative weights. A simple example of normalization is provided in Table 6.3 for a hypothetical case of six factors.

3. Rate the performance of each candidate location using a rating mechanism.
4. Compute a total score for each location, based on its performance against each factor, and rank them in the decreasing order of the score.

ideas at work 6.3

Special Economic Zones: A Policy Angle to Location Planning

India was one of the first in Asia to recognize the effectiveness of the export processing zone (EPZ) model in promoting exports, with Asia's first EPZ set-up in Kandla in 1965. With a view to overcome the shortcomings experienced on account of the multiplicity of controls and clearances, the absence of world-class infrastructure and an unstable fiscal regime, and also to attract larger foreign investments in India, the Special Economic Zones Policy was announced in April 2000. This policy intended to make SEZs an engine for economic growth, supported by quality infrastructure complemented by an attractive fiscal package with the minimum possible regulations at both central and state levels. The Special Economic Zones Act, 2005, was passed by the parliament in May 2005 and presidential assent was given on 23 June, 2005.

The SEZ rules provide for different minimum land requirements for different classes of SEZs. Every SEZ is divided into a processing area where the SEZ units alone would come up and the non-processing area where the supporting infrastructure was to be created. The total land requirement for SEZs for which formal approvals have already been granted until May 2009 is approximately 67,680 hectares. The land for the 270 notified SEZs where operations have since commenced is approximately over 31,405 hectares. Units located in SEZs get several incentives and benefits. These range from income tax concessions, service tax and sales tax exemptions, and duty free import.

Out of the 531 formal approvals given till date, 174 approvals are for sector-specific and multi-product SEZs for manufacture of textiles and apparels, leather footwear, automobile components, engineering, etc., which would involve labour-intensive manufacturing. SEZs are going to lead to the creation of employment for a large number of unemployed rural youth.

The Nokia and Flextronics electronics and hardware SEZs in Sriperumbudur are already providing employment to 14,577 and 1,058 people respectively. The Hyderabad Gems SEZ for jewellery manufacturing in Hyderabad has already employed 2,145 people, a majority of whom are from landless families, after providing training to them. They have a projected direct employment for about 2,267 people. The Apache SEZ being set up in Andhra Pradesh will employ 20,000 people to manufacture 1,000,000 pairs of shoes every month. They currently employ 5,536 people. Brandix Apparels, a Sri Lankan FDI project would provide employment to 60,000 workers over a period of 3 years. Even in the services sector, 12.5 million m2 of space is expected in the IT/ ITES SEZs, which, as per the NASSCOM standards, translates into 1.25 million jobs. Therefore, it is expected that the establishment of SEZs would lead to faster growth of labour-intensive manufacturing and services in the country.

From these statistics, one can conclude that the benefits derived from SEZs include employment generation, increased exports, and the development of quality infrastructure. The benefits derived from the multiplier effect of the investments and additional economic activity in the SEZs and the employment generated could far outweigh the tax exemptions and the losses on account of land acquisition.

Source: http://sezindia.nic.in/HTMLS/about.htm, last accessed on 20 May, 2014.

TABLE 6.3 An Example of Normalization

Factor	Rating	Normalized
1	30	30/300 = 0.10
2	60	60/300 = 0.20
3	35	35/300 = 0.12
4	80	80/300 = 0.27
5	45	45/300 = 0.15
6	50	50/300 = 0.17
Total	300	

EXAMPLE 6.1

A manufacturer of garments is actively considering five alternative locations for setting up its factory. The locations vary in terms of their advantages to the firm. Hence, the firm requires a method of identifying the most appropriate location. Based on a survey of its senior executives, the firm has arrived at six factors to be considered for final site selection. The ratings of each factor on a scale of 1 to 100 provide this information. Furthermore, based on the detailed analysis of both the qualitative and quantitative data available for each of the locations, the ratings of the locations against each factor have also been arrived at (on a scale of 0 to 100). Using this information (see Tables 6.4 and 6.5), obtain a ranking of the alternative locations.

Solution

Establishing the Relative Importance Through Normalization

The first step in the solution is to establish the relative importance of each factor using a normalization procedure. The sum of all ratings is 325. Therefore, by dividing each factor rating by 325 one can obtain the relative weight of the factors. The workings are presented in Table 6.6.

TABLE 6.4 Factor Ratings

Factors	Rating
Availability of infrastructure	90
Size of the market	60
Industrial relations climate	50
Tax benefits and concessions	30
Availability of cheap labour	30
Nearness to port	65

TABLE 6.5 Rating of Each Location Against Each Factor

Factors	Location 1	Location 2	Location 3	Location 4	Location 5
Availability of infrastructure	20	40	60	35	55
Size of the market	30	30	40	60	80
Industrial relations climate	80	30	50	60	50
Tax benefits and concessions	80	20	10	20	20
Availability of cheap labour	70	70	45	50	50
Nearness to port	20	40	90	50	60

TABLE 6.6 Relative Weight of Each Factor

Factors	Rating	Relative Weights
Availability of infrastructure	90	0.28
Size of the market	60	0.18
Industrial relations climate	50	0.15
Tax benefits and concessions	30	0.09
Availability of cheap labour	30	0.09
Nearness to port	65	0.20
Sum of all factor ratings	325	1.00

Computing the Performance of Each Location

Since the normalized weight of each factor is available, one can compute how each location fares by weighing the rating of the location against each factor with the weight for the factor. The computation for Location 3 is as follows:

Overall rating for Location 3 = $(60 \times 0.28) + (40 \times 0.18) + (50 \times 0.15) + (10 \times 0.09) + (45 \times 0.09) + (90 \times 0.20) = 54.45$

The computation for all the other locations is done in the same manner. Based on these overall scores, the locations are finally ranked. Table 6.7 has all the relevant computations.

On the basis of this computation, we find that Location 5 is the best, followed by Location 3. It will be useful to shortlist these two locations and perform additional analysis by collecting more information, such as costs and distances, in order to finally select the most appropriate location. Therefore, it is evident that the location factor analysis method provides a mechanism for a rough-cut and quick evaluation of several sites before identifying two or three probable sites for detailed analysis and final selection.

TABLE 6.7 Ranking of the Five Locations

__Note__: The overall scores computed in the table are more accurate as the relative importance of the factors are not rounded to two decimals, as shown in the sample computation for Location 3.

The Centre-of-gravity Method

In the location factor rating method, we utilized a simple weighted scheme to assess the attractiveness of each location. However, it is possible to utilize more direct measures for evaluating each location. Sometimes, location planners tend to use a distance measure to evaluate the impact of a proposed location. Such an approach has merit when the dominant requirement is proximity to the market for products (or for raw materials). By locating itself too far away, an organization may end up spending considerably on logistics and distribution. Therefore, assessing the distance of a site vis-à-vis the reference market could be a better method for selecting appropriate locations.

In the **centre-of-gravity method**, all the demand points (or the supply points, if the raw material is supplied from several locations) are represented in a Cartesian coordinate system. Each demand (or supply) point will also have weights, which indicates the quantum of the demand (or the supply) per unit time. In this context, it is possible to identify the centre of gravity of the various demand (or supply) points. Locating the new facility at this point will be most appropriate.

> The **centre-of-gravity method** merely indicates the ideal location in the grid map that would ensure that the weighted distances travelled on the whole is minimum.

The centre-of-gravity method merely indicates the ideal location on the grid map that would ensure that the weighted distance travelled on the whole is minimal. However, location planners may have to include other practical considerations before making a final decision. For instance, the coordinates indicated by the centre-of-gravity method may point to an infeasible site to set up a plant. In some cases, it may be very expensive to acquire the land and develop the site. There could be regulatory constraints in locating a factory (as in the case of having a factory in a residential area). Therefore, one method to solve this problem could be to evaluate multiple sites in the area and select one among them.

EXAMPLE 6.2

A manufacturer of a certain industrial component is interested in locating a new facility in a target market and would like to know the most appropriate place in the target market to locate the proposed facility. The manufacturer feels that there are no location constraints in the target market (that is, any point in the target market is good enough). There are four supply points in the locality that will provide key inputs to the new facility—A, B, C, and D. A two-dimensional grid map of the target market in which we would like to locate a new facility, along with the distance coordinates of the four supply points, is available (see Figure 6.3). The annual supply from these four points to the proposed facility is 200, 450, 175 and 150 tonnes respectively. The situation is graphically shown in a two-dimensional plot in the figure. While the coordinates within parentheses show the distance from the origin of the target map to each of the supply points, the number that follows is the annual shipment (in tonnes) from these points to the proposed facility. Identify the most appropriate point in the grid map to locate the new facility.

Solution

Let us represent the given information using the following notations:

Number of existing demand (or supply) points in the grid map = n

Coordinates of Location i in the grid map = (x_i, y_i)

Quantum of shipment between existing demand (or supply) point i and proposed facility = W_i

Coordinates of the centre of gravity in the grid map = (X_C, Y_C)

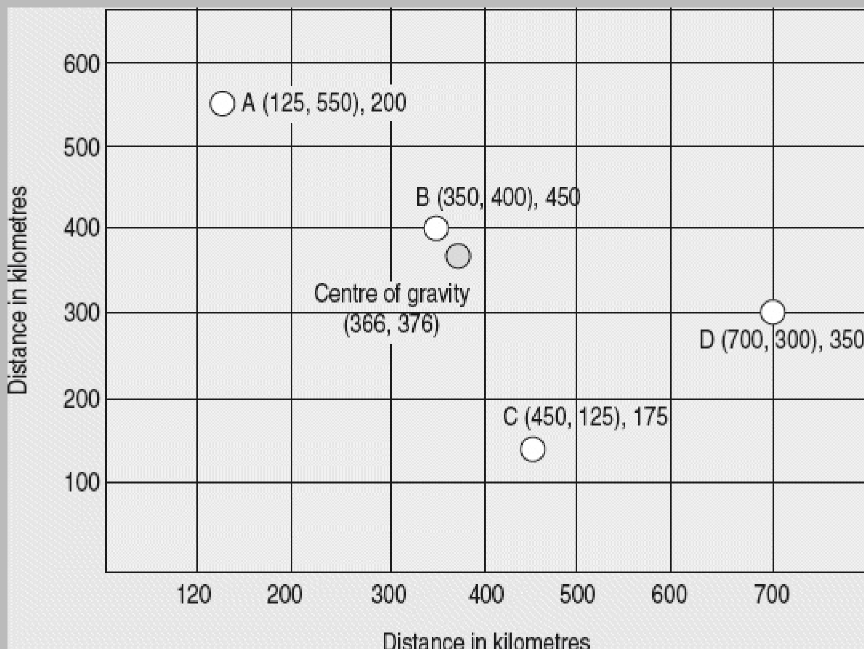
In our example, the location of supply point B is represented as $(x_B, y_B) = (350, 400)$.

The coordinates of the centre of gravity are given by:

$$X_C = \frac{\sum_{i=1}^{n} (x_i) \times W_i}{\sum_{i=1}^{n} W_i} \text{ and } Y_C = \frac{\sum_{i=1}^{n} (y_i) \times W_i}{\sum_{i=1}^{n} W_i} \qquad (6.1)$$

Using the information available in Figure 6.3 for Locations A to D and Eq. 6.1 one can compute the centre of gravity for the above example to be (366,376). The figure also has the plot of the centre of gravity. Therefore, the manufacturer might want to locate the new facility at this point.

FIGURE 6.3 Grid map of the target market



The Load–Distance Method

As opposed to the centre-of-gravity method, the load–distance method enables a location planner to evaluate two or more potential candidates for locating a proposed facility vis-à-vis the demand (or supply) points. The **load–distance method** provides an objective measure of the total load distance for each of the potential candidates. Choosing the location with best load distance among these will satisfy the objective of identifying an appropriate location for the proposed facility. Distance is measured using a Cartesian measure.

> The **load–distance method** enables a location planner to evaluate two or more potential candidates for locating a proposed facility visà-vis the demand (or supply) points.

Let us use the following notations for the load–distance method:

Number of existing demand (or supply) points in the grip map = n

Index used for existing demand (or supply) points = i

Coordinates of existing demand (or supply) points i in the grid map = (x_i, y_i)

Quantum of shipment between existing demand (or supply) point i and proposed facility = W_i

Number of candidates for the proposed facility = m

Index used for the candidates for the proposed facility = j

Coordinates of candidate j in the grip map = (X_j, Y_j)

The distance measure for the Cartesian coordinates between an existing demand (or supply) point i and a candidate j for the proposed facility (D_{ij}) is given by:

$$D_{ij} = \sqrt{(x_i - X_j)^2 + (y_i - Y_j)^2} \tag{6.2}$$

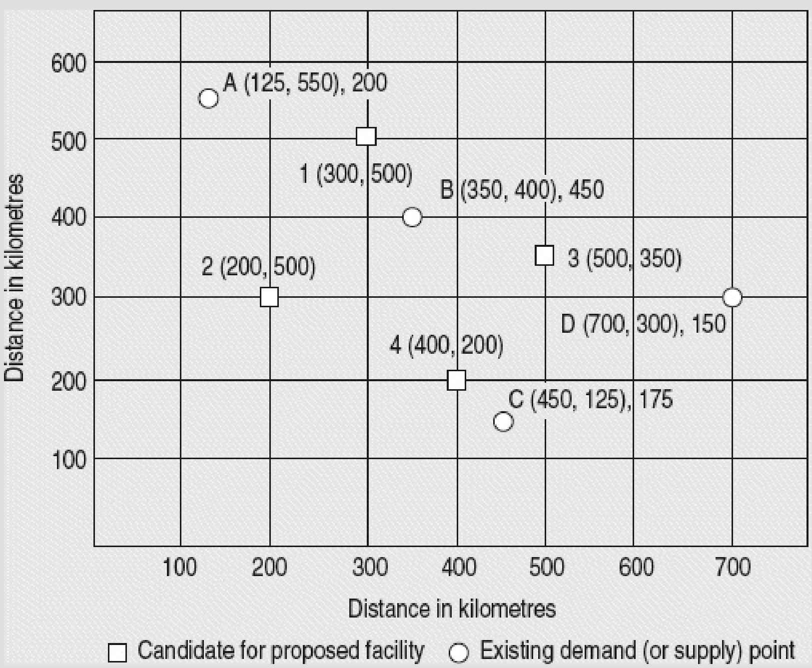
The load–distance for a candidate *j* for the proposed facility LD_j is nothing but the product of the distance between the candidate and all existing demand (or supply) points. It is computed as follows:

$$LD_j = \sum_{i=1}^{n} D_{ij} \times W_i \tag{6.3}$$

EXAMPLE 6.3

Consider Example 6.2. Assume that the manufacturer came to know that there are constraints in locating the new facility. Based on an initial survey of possible sites for the proposed facility, the manufacturer identified four candidates. Figure 6.4 has the location coordinates of the four candidates (numbered 1 to 4). What is the best location for the proposed new facility?

FIGURE 6.4 Location coordinates of the four candidates



Solution

Let us first summarize the coordinates of the existing supply points and the candidates for the proposed facility by tabulating them from the grid map for the target market. Let us also tabulate the quantum of shipment from these supply points to the proposed facility. Table 6.8 presents this information.

Using the information available in Table 6.8 and Eq. 6.2, one can compute the D_{ij} values between every pair of supply point and candidate for locating the new facility. The computation for A-1 is as follows:

TABLE 6.8 Coordinates of Supply Points and Proposed Locations

	Existing Supply Points			Candidates for Proposed Facility		
	x_i	y_i	W_i		X_j	Y_j
A	125	550	200	1	300	500
B	350	400	450	2	200	500
C	450	125	175	3	500	350
D	700	300	150	4	400	200

$$\begin{aligned} D_{A1} &= \sqrt{(x_A - X_1)^2 + (y_A - T_1)^2} \\ &= \sqrt{(125-300)^2 + (552-500)^2} \\ &= \sqrt{(175)^2 + (50)^2} \\ &= 182.00 \end{aligned}$$

Computing for all the pairs in this manner, one can obtain a matrix of D_{ij}, as shown in Table 6.9.

TABLE 6.9 D_{ij} Values

	1	2	3	4
A	182.00	90.14	425.00	445.11
B	111.80	180.28	158.11	206.16
C	403.89	450.69	230.49	90.14
D	447.21	538.52	206.16	316.23

Using Eq. 6.3, one can obtain the LD_j values and select the candidate with the least value of LD. The computation of LD_j is available in Table 6.10.

TABLE 6.10 LD_j Values

1	2	3	4
2,24,474.41	2,58,801.57	2,27,410.05	2,45,000.8

The computation of LD_1 is as follows:

$LD_1 = 182 \times 200 + 111.8 \times 450 + 403.89 \times 175 + 447.21 \times 150. = 2,24,474.41$

As we see from the table, Candidate 1 has the least LD_j value and therefore, is the most appropriate place to locate the proposed new facility. It is interesting to note that Candidates 1 and 3 are very close to the centre of gravity that we computed in Example 6.2 and therefore, they have the minimum LD_j compared to the other two sites.

The Transportation Model

So far, we have confined ourselves to the issue of choosing one location for the proposed new facility out of several alternatives. However, in reality, there are several situations that prompt an organization to select multiple locations instead of just one. While the choice of these multiple locations could be on the basis of the factors described above, the multiple location problem introduces another dimension to location design. The location planner must also decide which of the demand points will be served by each of these locations and to what extent. Locating distribution centres for nationwide distribution of products is a typical example belonging to this category of decision making. Choosing multiple locations invariably requires that the combined set of locations will ensure minimum cost of transportation pertaining to flow to products in the distribution chain. Therefore, the problem is one of managing network flows to satisfy a set of demand points using a combination of supply points. The transportation model is ideally suited for solving this combinatorial optimization problem.

In the case of multiple plants and multiple demand points, the location problem can be solved using the standard transportation model.

The transportation model is an interesting variation of the basic linear programming (LP) model, which could be used to optimally identify a subset of supply points from a potential list that can satisfy the demand at various demand points. There is a unit transportation cost of shipping material from every supply point to every demand point, and by an optimal choice of supply points, the total cost of transportation is minimized. In the process of doing this, it is ensured that none of the capacity constraints in the supply point is violated. Similarly, it is also ensured that at every demand point the requirement is fully satisfied. Figure 6.5 shows the typical representation of a transportation problem.

FIGURE 6.5 Typical representation of a transportation problem

	Market 1	Market 2	Market 3	Market 4	Market 5	Supply
Factory A	100	70	50	30	40	600
Factory B	30	90	40	120	50	400
Factory C	80	20	70	40	30	700
Factory D	20	40	90	90	80	200
Demand	200	450	300	550	400	1900

In this example, there are four factories that could supply to five markets. The last column in the table shows the capacity available in each factory. For instance, Factory C has 700 units of capacity whereas Factory D has just 200 units of capacity. The last row shows the demand for the product in each of the five markets. The demand in Market 1 is 200 units and the demand in Market 5 is 400 units. Since the markets and the factories are physically separated, one could expect different costs of transportation between each pair of markets and factories. This information is available in the cells of the table. The numbers inthe cell (upper right hand side) denote the cost of transporting one unit from a factory to a market. In our example, it costs ₹100 to transport one unit from Factory A to Market 1.

An important decision in this problem is to decide which of the factories will serve the markets and how many units should be transported from a factory to a market. The transportation model provides the optimal combination of a factory with a particular market and also identifies how many units need to be shipped. Location problems in the case of multiple plants and multiple demand points follow exactly the same pattern; therefore, one can use the standard transportation model to solve the multi-location problem too. The transportation model is discussed in any standard and elementary level textbook on operations research. However, the application of the transportation model in a location problem is illustrated using an example.

EXAMPLE 6.4

A manufacturer of washing machines is in the process of locating regional warehouses in four geographical locations in south India to serve the markets. The markets are geographically and organizationally split into five segments. Based on the forecasting estimates by the marketing department, it has been found that the average monthly demand for the washing machine is 2000, 1500, 1200, 2800, and 2500 in each of the market segments. Based on this forecast and other costs including the fixed and variable costs of setting up warehouses, it has been decided to build four warehouses with a capacity to handle monthly requirements to the extent of 2900, 2300, 3700 and 1100 units, respectively. Due to the geographical spread of the warehouses and the markets, the transportation cost per unit is different between these pairs of warehouses and market segments. Figure 6.6 presents the cost of transporting one unit. Identify the most cost-effective way of serving the markets from these warehouses.

FIGURE 6.6 The cost of transporting one unit

	Market 1	Market 2	Market 3	Market 4	Market 5
Warehouse A	100	70	50	30	40
Warehouse B	30	95	40	125	50
Warehouse C	75	20	65	40	30
Warehouse D	20	40	95	85	80

Solution

Constructing the Transportation Table

Let us first construct the initial transportation table by adding the available demand and supply information. Figure 6.7 has the initial table. In this case, we find that the demand and supply are exactly balanced. If the supply and demand are unbalanced, the first step is to make the transportation problem anced, the first step is to make the transportation problem balanced by adding dummy supply (or demand) points. If the demand is greater than the supply, then we need to add a dummy supply point with zero cost of transportation. Similarly, if the supply is more than the demand, we need to add a dummy demand point with zero cost of transportation.

FIGURE 6.7 The initial transportation table

	Market 1	Market 2	Market 3	Market 4	Market 5	Supply
Warehouse A	100	70	50	30	40	2900
Warehouse B	30	95	40	125	50	2300
Warehouse C	75	20	65	40	30	3700
Warehouse D	20	40	95	85	80	1100
Demand	2000	1500	1200	2800	2500	10,000

There are several heuristic methods to solve the transportation problem. Optimal methods are also available. Typically, the heuristic methods are used as the starting solution for the optimal method. One heuristic, Vogal's approximation method (VAM) is known to provide close-to-optimal solutions to the transportation problem.[4]

Solution Using Vam

VAM is implemented with the following three simple steps:

- *Step 1*: For each row and column, compute the difference between the minimum cost cell and the second smallest cell.
- *Step 2*: Choose the row or column with the maximum difference. Assign as much as possible to the minimum cost cell in the chosen row or column (in case of zero assign e—denoting epsilon, an insignificantly small quantity—to the cell). Decrement the supply and demand values corresponding to the cell by the amount assigned. Delete either the row or the column—whichever has become zero, but not both.
- *Step 3*: If there is only one row or column left, allocate to each of the remaining cells in the row or column and stop. Otherwise, return to Step 1.

The first iteration of VAM is shown in Figure 6.8

Computing the Difference Between the Minimum Cost Cell and the Next Higher Cost Cell

The maximum value of the differences as computed in Figure 6.8 is 20. Since it occurs at two places, we break ties arbitrarily and choose Market 2. We shall assign the maximum to the least cost cell in the column. Using this logic, we assign 1500 to Warehouse C in that column and adjust the demand and supply values. Since the entire requirement of Market 2 is met with, we strike off the column. We also note that after this allocation, the balance capacity available with Warehouse C is 2200. After making these adjustments, we return to Step 1 of the algorithm and recompute the differences and proceed with the allocation in the same way as mentioned above.

FIGURE 6.8 The first iteration of VAM

	Market 1	Market 2	Market 3	Market 4	Market 5	Supply	Diffe-rence
Warehouse A	100	70	50	30	40	2900	10
Warehouse B	30	95	40	125	50	2300	10
Warehouse C	75	20	65	40	30	3700	10
Warehouse D	20	40	95	85	80	1100	20
Demand	2000	1500	1200	2800	2500	10,000	
Difference	10	20	10	10	10		

The final allocation table obtained in this manner is shown in Figure 6.9. The final solution and the cost of the plan is as shown in Table 6.11.

FIGURE 6.9 The final allocation table

	Market 1	Market 2	Market 3	Market 4	Market 5	Supply
Warehouse A	100	70	50	30 2800	40 100	2900
Warehouse B	30 900	95	40 1200	125	50 200	2300
Warehouse C	75	20 1500	65	40	30 2200	3700
Warehouse D	20 1100	40	95	85	80	1100
Demand	2000	1500	1200	2800	2500	10,000

TABLE 6.11 The Final Solution and the Cost of the Plan

6.4 OTHER ISSUES IN LOCATION PLANNING

Recent trends in international markets point to a shift towards fewer facilities that could serve markets worldwide. For example, the HP DeskJet printer manufacturing facilities are available only at two places, Vancouver in Washington State in the United States, and Singapore. Several other appliance manufacturers are gravitating towards fewer and fewer distribution centres.

These developments point to the fact that there are two aspects that could affect the location planning problem significantly. One is the availability of good transportation infrastructure and the other is the use of the Internet and IT infrastructure. Today's operations managers must know how these two tools affect location design.

> The availability of good transportation infrastructure enables firms to invest in fewer and larger facilities and provide a good level of service to the customers.

The availability of good transportation infrastructure enables firms to invest in fewer and larger facilities and provide a good level of service to customers. Infrastructure includes availability of an all-weather high-speed road network, good railway infrastructure that is capable of transporting bulk cargo, availability of ports that have faster turnaround times and good connectivity to the ports. The recent attempts by the Central Government pertaining to the Golden Quadrilateral Projects seek to address this issue. Once the project is complete, one can expect significant changes in the approach to location planning.

In the era of the Internet and IT, providing useful interfaces for customers may offset some of the shortcomings of location decisions. In recent years, the advent of the Internet has resulted in significant reductions in the cost of communication and coordination among trading partners. This has great relevance for the location planning problem that operations managers face. Due to the reduced cost of communication and coordination, it is possible to have fewer locations and still provide better customer service. Developing home pages that provide for high levels of customer interfacing and interaction may enable an organization to directly deal with the customers and provide good service even without a physical facility within close proximity of the customer.

> In a service-intensive industry, nearness to the market will be more important than the cost of the site.

Another issue pertaining to location is the supply management practice of leading Japanese manufacturers such as Toyota. Japanese manufacturing management techniques lay an emphasis on location planning in the overall context of the just-in-time manufacturing philosophy. In Japan, it is often the practice to locate a good number of suppliers in the vicinity (20–40km radius) of the manufacturer. Locating suppliers who are close by provides several advantages to the firm. It enables them carry almost zero inventory. Typically, a milk-van-type routine is followed, in which a truck goes round and collects hourly or half-day requirements of material from each of these suppliers and delivers them at the factory premises. Several Indian automobile manufacturers have similar practices with respect to locating their suppliers. The Ambattur and Guindy industrial estates in Chennai cater to the requirements of all major automobile manufacturers in Chennai. Similarly, Maruti has several suppliers located in the Gurgaon–Faridabad belt on the outskirts of Delhi. Locating suppliers close by helps, especially when the quality of the infrastructure is not good. Further, it helps minimize disruptions arising out of *bandhs*, strikes and natural calamities.

Finally, location issues in a service-intensive industry are different from those in a manufacturing industry. Since service quality is largely determined by the responsiveness of the service delivery system, locating service outlets as close to the demand point as possible is an important requirement in a service system. Therefore, nearness to the market will be more important than the cost of the site, as opposed to a manufacturing system, where the cost of the site would take precedence over location.

SUMMARY

- Location issues have become more prominent in recent years on account of the globalization of markets. Multinational corporations have more opportunities to identify candidate locations for their manufacturing facilities.
- Factor cost advantages and expanding markets in developing countries have made these nations attractive for locating new facilities.
- Simple qualitative methods are useful for quickly screening an initial set of candidates and narrowing down the choice to one or two.
- The *load–distance and centre-of-gravity methods* help evaluate the suitability of candidate solutions from a perspective of distance and the quantum of items to be transported between a location and the demand points.
- The *transportation method* helps in optimally identifying a set of *k* locations out of *n* candidate solutions.
- The availability of good transport infrastructure and recent developments in Internet technology suggest that it is possible to have fewer locations and still provide better customer service.
- Location decisions in service systems must address the requirement of speed of responsiveness. Therefore, locating service outlets as close as possible to the demand points may be highly desirable in service systems.

FORMULA REVIEW QUESTIONS

1. The coordinates of the centre of gravity

$$X_C = \frac{\sum_{i=1}^{n} (x_i) * W_i}{\sum_{i=1}^{n} W_i} \quad \text{and} \quad Y_C = \frac{\sum_{i=1}^{n} (y_i) * W_i}{\sum_{i=1}^{n} W_i}$$

2. Distance between demand point *i* and the proposed facility $j \;\; D_{ij} = \sqrt{(x_i - X_j)^2 + (y_i - Y_j)^2}$

3. The load-distance for a candidate *j* for the proposed facility $LD_j = \sum_{i=1}^{n} D_{ij} * W_i$

REVIEW QUESTIONS

1. How important are location decisions in operations management? What are the consequences of a bad location decision?

2. What factors drive the globalization of operations? Do these have any bearing on the location decision that an operations manager makes?
3. Will the choice of factors for selecting an appropriate location vary with the geographical spread of the potential candidates for location? Why?
4. Identify three important factors that a location planner may consider with respect to each of the following:

    a. A super-specialty intensive care unit
    b. A thermal power plant operating with coal as its fuel
    c. A state-of-the-art design centre for automobile manufacturing
    d. A multi-cuisine restaurant
    e. An agro-based handicrafts manufacturing unit

5. What are the pros and cons of using the location factor analysis method for location planning? Do you have any recommendations on how to use this method for location planning?
6. A manager intending to use the location planning model for analysis is not sure about which of the two models, the centre-of-gravity method and the load–distance method, should be used for his analysis. Prepare a one-page note that will help him identify an appropriate model for his consideration.
7. What are the key differences between using a transportation model and a load–distance method for solving a location problem?

PROBLEMS

1. A firm is considering three alternative locations for setting up its new factory. Each of these locations provides some advantages and some limitations. Therefore, it is necessary that some method of assessing the attractiveness of each site be arrived at. Based on a survey of its top management, the company has identified seven factors that will determine the appropriateness of a site for setting up the new factory. These factors and the score out of 100 for each of them are shown in Table 6.12.

TABLE 6.12 The Factors and the Score Out of 100

Sl. No.	Factor for Consideration	Score (Out of 100)
1	Nearness to port	80
2	Existence of supplier infrastructure	70
3	Availability of skilled labour	90
4	Government policies and local taxes	50
5	Projected cost of operations	60
6	Quality of road infrastructure	70
7	Availability of educational infrastructure	40

The company collected some data pertaining to each site that it is considering, and, based on some criteria, was able to arrive at how each site rates against a score of 100 against each factor. In some cases, actual data was estimated on the basis of some projections. Table 6.13 has details pertaining to these:

TABLE 6.13 The Ratings for Each Site Against Each Factor

Sl. No.	Factor for Consideration	Site 1	Site 2	Site 3	Basis
1	Nearness to port	70 km	130 km	95 km	Actual data
2	Existence of supplier infrastructure	60	80	85	Score out of 100
3	Availability of skilled labour	50	70	85	Score out of 100
4	Government policies and local taxes	70	45	60	Score out of 100
5	Projected cost of operations	₹20,000,000	₹18,000,000	₹17,000,000	Actual data
6	Quality of road infrastructure	80	90	70	Score out of 100
7	Availability of educational infrastructure	60	80	80	Score out of 100

Identify the most appropriate site for locating the new factory on the basis of the above information.

(Hint: Suitably convert the actual data into scores out of 100 and then analyse)

2. A chain of stores trading in a host of retail goods for urban customers is planning to set up operations in one of the metropolitan cities in the country. The exact location for the new outlet is to be decided. In order to do that, the company conducted a market survey and found five pockets of consumption in the city. The distance coordinates of these five pockets from a reference point in the grid map pertaining to the city are as follows: Zone 1 (15, 22), Zone 2 (10, 40), Zone 3 (35, 15), Zone 4 (50, 5), and Zone 5 (40, 35). The annual demand for the goods (in tonnes) in the five zones is 200, 130, 80, 170, and 120, respectively.

   a. What is the centre of gravity for setting up the operation in the city?
   b. If the cost of transporting the goods is ₹300 per tonne, what is the cost implication of locating the stores at the centre of gravity?

3. The chain store officials found that locating the operations in the centre of gravity point, as obtained in the above problem, would cost them a lot. The operational costs of renting and maintaining the site will be ₹2,500,000 per annum. In view of this, they are now considering other options. They have identified three other candidate locations whose cost of operations will be less than the centre of gravity location by 10 per cent, 25 per cent and 18 per cent, respectively. The locational coordinates for these three are (20, 40), (40, 25), and (35, 45), respectively. What should the chain store do in this case? Does it make sense to set up operations in any of these three alternatives locations?
4. A manufacturer of certain household goods caters primarily to the south Indian market. At present, the manufacturer has located six stock points in the major south Indian cities of Hyderabad, Mysore, Chennai, Kochi, Pune, and Vizag to cater to the demand. There are four warehouses from which the components are distributed. In order to save on the cost of operations, the warehouses are typically located away from these cities in different locations. The unit cost of transporting the items from each of these warehouses to the cities (₹tonne), the capacity of the warehouses, and the demand at the city stock points per unit time (in tonnes) are all summarized in Figure 6.10. Identify the least cost schedule for deciding which warehouse will send the items to the cities.
5. Suppose, in the above problem, the company has decided to shut down its Kochi operations and to serve the requirements of Kochi from Mysore. Will the decision change? What will the cost impact of this decision be?
6. Consider Problem 4. Suppose the company has received a proposal for setting up another warehouse (Warehouse E) with a capacity of 900 units. The location of the warehouse is such that the unit costs of transporting to the six cities are as follows: Hyderabad–45, Mysore–75, Chennai–30, Kochi–65, Pune–90 and Vizag–80. The company would like to know how the allocation will change if the warehouse is made operational and the likely cost impact on the operation of the system.

   (Hint: Its introduction of will result in an unbalanced transportation problem. Convert it into a balanced transportation problem and solve.)

FIGURE 6.10 Demand–supply and cost data for the problem

	Hyderabad	Mysore	Madras	Kochi	Pune	Vizag	Supply
Warehouse A	60	70	10	30	90	90	1900
Warehouse B	70	25	40	55	80	100	1800
Warehouse C	50	80	45	75	85	30	3300
Warehouse D	80	40	50	45	90	60	1300
Demand	1750	750	2000	1800	1200	800	8300

NET-WISE EXERCISES

1. The BMW Group is the only manufacturer of automobiles which concentrates entirely on premium standards and outstanding quality for all its brands, and across all relevant segments. Click on the 'Production' icon on the top right side of the webpage (http://www.bmwgroup.com/e/0_0_www_bmwgroup_com/home/home.html), then you can click on 'Production worldwide' on the slide menu. To view the facilities and location click on 'Manufacturing facilities'. In addition, find a location in the map by clicking on the 'Place markers' in the map to know what is happening in each of these locations.
    1. BMW being a global company, do you think they might have had a bearing on the location of their facilities?
    2. Why do you think BMW setup an assembly plant in Chennai rather than a manufacturing plant?
2. Blue Star is one of India's largest central air-conditioning and commercial refrigeration companies. It has 4 state-of-the art manufacturing facilities. To view these facilities, go to the webpage (http:// www.bluestarindia.com) and click on **Manufacturing** on the top menu bar. You can then click on **Manufacturing Facilities**, and choose the facilities you want to view.
   After going through the Web site, answer the following questions:
    a. Location issues play a very important role in setting up a manufacturing plant. Can you analyse why the plants have been set up at these places on account of the availability of electricity, water, transport facilities, etc?
    b. Do you think that the spread of potential customers plays an important role in selecting the location?

MINI PROJECT

1. Several cities now have chain stores that sell a variety of goods. These chain stores may be like Vivek's (selling household appliances and white goods), Garment manufacturers (such as Raymonds), supermarkets (such as Food World and Big Bazaar), high-end malls (such as Shoppers Stop and Life Style), and eating outlets and joints (such as Café Coffee Day). Select two such categories of chain stores for the study. Visit the chosen chain stores, interview the operations manager and the owner of the franchisee and elicit information on the various factors that are important for choosing an appropriate site for locating their retail outlet. For the important factors identified, obtain the relative importance of the factors as perceived by the companies.

Based on this exercise, prepare a final report that covers the following aspects of the location decision-making framework

a. What are the important factors that drive the choice of location in each of the two examples that you have studied? How important are they to these examples?

b. Are there significant differences between the importance of the factors in the two examples that you have studied? Explain why these differences occur.
c. If a new player wants to set up an operation in the same area as the one that you have looked at, explain how you will advise the new player on its choice of an appropriate location for their operation.

CASE STUDY

INDCOSERVE—AN INDUSTRIAL COOPERATIVE OF TEA FACTORIES IN THE NILGIRIS

The Tamil Nadu Small Tea Growers Industrial Cooperative Tea Factories Federation Limited, usually called Indcoserve, was established in the year 1965 and is functioning under the administrative control of the Department of Industries and Commerce, Government of Tamil Nadu. With the establishment of the first Industrial Cooperative Tea Factory at Kundah in 1962, the small growers in the Nilgiris region in Tamil Nadu were able to realize a better price for their green leaf. In the four decades of its existence, Indcoserve has enabled its 15 member industrial cooperative tea factories to command 17 per cent of the total production of tea in the Nilgiris District by offering its expertise in technical, managerial, and commercial competence. The 15 factories are functioning in the Nilgiris district with an aggregate installed capacity to produce over 27.3 million kg of tea per annum. Nearly 20,000 small growers supply green leaf to these factories that are geographically spread out in the region. Table 6.14 presents some basic details on these factories. The table has data for 17 factories. However, two factories—Kotagiri and Kilkotagiri—have discontinued their operations. At the outset, it is evident from the table that the 15 factories vary considerably on several parameters. For instance, Salisbury has the highest value in all the parameters. Nearly 20,000 small growers supply green leaf to these factories that are geographically spread out in the region.
Indcoserve factories have a serious problem of price realization. Except for the period 1997–1999, the price realized is much lower. The cost of production has gone up to 300 per cent of the 1989–1990 levels. This disparity between price and cost trends is highly undesirable and may threaten the viability of Indcoserve. Therefore, the management would like to assess the performance of these factories in order to make certain choices with respect to location of the factories and their future plans.

Data on the Performance of the 15 Factories

Data is available from all the factories for the period April 2004 to March 2006 (24 months). The data pertain to input material (green leaf) in terms of the quantity procured and the cost, production of tea in the factories, various elements that make up the production cost, data pertaining to cost of production excluding the green leaf cost, and price fetched by the tea in the market.

Green Leaf Purchased

The total green leaf procured during 2004–2005 and 2005– 2006 were respectively 55.302 million kg and 48.027 million kg. The combined installed capacity for production of tea in all the 15 factories is 27.3 million kg. As per the existing norm, 4 kg of green leaf is required to produce 1 kg of tea. Therefore, the amount of green leaf procured is much lower than the productive capacity of the plants. The data pertaining to the quantity of green leaf (GL) purchased is available in Table 6.15.

TABLE 6.14 Basic Data on the 15 Factories of Indcoserve

Number	Factory Name	Installed Capacity (in Million Kg)	Number of People Employed	Acreage Covered
1	Kundah	2.81	65	2294
2	Kotagiri		Operations discontinued	
3	Karumbalam	1.00	34	1441
4	Kilkotagiri		Operations discontinued	
5	Mercunad	1.56	77	2268
6	Mahalinga	1.40	57	2641
7	Manjoor	2.81	87	2124
8	Ithalar	2.81	71	2362
9	Pandalur	2.01	98	2934
10	Kaikatty	1.25	57	2343
11	Kattabettu	1.56	45	1705
12	Salisbury	2.81	108	2931
13	Frontier	2.01	72	2872
14	Kinnakorai	1.25	30	1303
15	Bikkatty	1.56	49	1151
16	Ebbanad	1.09	18	1685
17	Bitherkad	1.40	52	1794

The quantity procured across factories fluctuates wildly in every period. During all the 29 months, Salisbury procured the highest quantity of leaves (at an average of 0.824 million kg per month as opposed to the overall average of 0.309 million kg per month). For nine out of 15 factories, the maximum-to-minimum ratio was in excess of 300%). Such marked variations between Salisbury and other factories cannot be explained in any manner other than the acceptance that there were significantly varying procurement practices among the 15 factories. All the 15 factories exhibited significant price differences for the green leaf that they procured. These differences existed in each factory throughout the 29-month period of observation. Salisbury not only paid higher rates, but also procured the maximum quantity during the observed period.

Production of Tea

The data on production-related details are available in Table 6.16. Based on the data available, it was found that Salisbury was the highest producer in 28 out of 29 months of data that was analysed at an average production of 0.207 million kg per month (as opposed to an overall average of 0.08 million kg per month). Ebbanadu (0.027 million kg per month), Karumbalam (0.032 million kg per month) and Kinnakorai (0.035 million kg per month) are the lowest producers of tea during the observed period.

The level of technology used in tea manufacturing continues to be low in Indcoserve factories. Therefore, a useful measure for comparison is the labour productivity. Labour productivity is measured using “the number of kg of tea produced per person employed in the factory”. The relevant data is available in Table 6.16. It is evident from the table that productivity differences across the factories are very significant and that Salisbury scores higher than all others in the group. Salisbury employs the maximum number of peoples among the 15 factories.

All factories seem to have very similar, albeit high cost of production (excluding the cost of GL) close to the average of ₹18.68 per kg (Table 6.17). The only exceptions to this are Salisbury (₹12.93 per kg), Pandalur (₹14.97 per kg) and Frontier (₹15.27 per kg). A comparison of the maximum and minimum values observed during the 29 months of observation also shows that these factories had better cost control (evidenced by a narrower range).

Components of Cost of Production

The overall scenario points to significant differences among the factories with respect to the cost of production. In order to gain some more understanding of this aspect, data pertaining to one calendar year (2005–2006) on the various components of the cost of production is available in Table 6.17.

Packing material, and excise duty are very similar in all the factories. Perhaps it does not make sense to look at these aspects for cost cutting. Salisbury shows an interesting trend in the cost components of tea production. While it has the highest input cost, it has the lowest cost of other factors and overall has the lowest cost per kg of tea.

Average Sale Price Fetched

Tea is primarily sold through auctions in India. In the case of Indcoserve factories, they have three options to sell the tea; through their own auction centre (Teaserve), through other auction centres (such as Coonoor, Coimbatore, and Cochin in South India), and direct sales. However, a vast majority of the Indcoserve produce is sold only through Teaserve. The data-pertaining to the price fetched though auctions (Teaserve) have been tabulated in Table 6.18. As in the case of other items of data, we observe fluctuations in the price fetched by Tea from the 15 factories. Salisbury continues to be a good performer in this dimension also. Salisbury tea fetches on an average a much higher price compared to other factories.

QUESTIONS FOR DISCUSSION

1. Develop a set of measures for assessing the performance of Indcoserve factories. Which are the best performing factories among them?
2. Advise Indcoserve on the location choices of the factories. Do you recommend the closure of any of these factories?
3. Based on your recommendations for location of the factories also list out the changes in operations that Indcoserve needs to do for the revised plan.

TABLE 6.15 Green Leaf Purchased in the 15 Factories During April 2004–March 2006

Particulars	Kundah	Karumbalam	Mercunad	Mahalinga	Manjoor	Ithalar	Pandalur	Kaikatty	Kattabettu	Salisbury	Frontier	Kinnakorai	Bikkatty	Ebbanad	Bitherkad
Green leaf purchased (in lakh kg)															
Average	4.06	1.16	2.96	2.84	2.71	3.87	4.88	2.09	2.03	8.24	3.61	1.31	2.13	1.32	2.75
Maximum	6.97	2.37	4.67	4.95	5.69	5.85	6.67	3.74	3.25	10.37	6.16	2.44	3.76	2.87	4.09
Minimum	2.04	0.32	1.56	1.37	1.58	1.79	3.57	1.05	1.13	5.67	2.47	0.70	1.02	0.30	1.69
Max/Min (%)	341%	733%	300%	361%	361%	326%	187%	355%	289%	183%	250%	347%	369%	958%	242%
Max/Avg (%)	172%	204%	158%	174%	210%	151%	137%	179%	161%	126%	171%	186%	176%	219%	148%
Green leaf rate paid (₹/kg)															
Average	6.72	6.87	6.64	6.69	6.71	6.72	6.81	6.74	6.79	7.29	6.42	6.55	6.65	6.50	6.70
Maximum	9.17	9.17	9.17	9.17	9.17	9.17	8.83	9.17	8.48	9.88	8.58	9.00	9.17	8.65	8.58
Minimum	5.00	4.92	4.92	5.00	5.00	5.28	5.08	4.93	5.15	5.61	4.85	4.95	4.68	5.27	5.67
(Max–Min)	4.17	4.25	4.25	4.17	4.17	3.88	3.75	4.23	3.33	4.27	3.73	4.05	4.48	3.38	2.92
Acreage covered	2294	1441	2268	2641	2124	2362	2934	2343	1705	2931	2872	1303	1151	1685	1794
Average kg of green leaf procured per acre	176.79	80.78	130.69	107.71	127.59	163.74	166.26	89.25	118.87	281.27	125.64	100.61	185.12	78.04	153.52

TABLE 6.16 Tea (Production) in the 15 Factories During April 2004–March 2006

Particulars	Kundah	Karumbalam	Mercunad	Mahalinga	Manjoor	Ithalar	Pandalur	Kaikatty	Kattabettu	Salisbury	Frontier	Kinnakorai	Bikkatty	Ebbanad	Bitherkad
Tea produced (in lakh kg)															
Average	1.07	0.32	0.81	0.76	0.73	1.01	1.19	0.56	0.54	2.07	0.90	0.35	0.66	0.27	0.68
Maximum	1.58	0.56	1.07	1.08	1.24	1.35	1.47	0.77	0.72	2.40	1.25	0.53	0.96	0.37	0.91
Minimum	1.02	0.24	0.78	0.79	0.87	0.81	1.15	0.58	0.56	1.79	1.04	0.34	0.64	0.32	0.63
Max/Min (%)	155%	231%	137%	137%	143%	167%	127%	134%	128%	134%	121%	155%	151%	118%	145%
Max/Avg (%)	147%	178%	133%	142%	169%	133%	123%	139%	134%	116%	139%	150%	145%	140%	133%
Labour productivity of the 15 factories															
Total employed	65	34	77	57	87	71	98	57	45	108	72	30	49	18	52
Avg. production per employee (kg)	1651	929	1046	1340	843	1427	1216	981	1194	1916	1250	1172	1351	1482	1314
Capacity utilization of the 15 factories															
Production of tea (2005–2006)	1.10	0.43	0.76	0.72	0.80	1.00	1.28	0.48	0.57	0.90	0.90	0.33	0.66	0.20	0.70
Capacity utilization	39%	43%	49%	51%	28%	36%	64%	38%	37%	32%	45%	26%	42%	18%	50%

*Installed capacity and production of tea are in million-kilograms per year.

TABLE 6.17 Production Cost Excluding Green Leaf Cost in the 15 Factories During April 2005–March 2006

Particulars	Kundah	Karumbalam	Mercunad	Mahalinga	Manjoor	Ithalar	Pandalur	Kaikatty	Kattabettu	Salisbury	Frontier	Kinnakorai	Bikkatty	Ebbanad	Bitherkad
Cost of production (2005–2006) (₹per kg)															
Total RM expenses	**18.20**	**18.56**	**17.65**	**17.28**	**17.76**	**18.50**	**23.70**	**20.18**	**23.85**	**29.20**	**20.70**	**18.15**	**16.84**	**18.56**	**21.05**
Variable costs															
Fuel charges	6.06	5.78	6.79	6.89	7.69	6.50	6.80	6.61	7.73	5.66	6.51	7.88	6.39	7.83	7.14
Other variable costs															
Wages	1.82	2.36	2.87	2.67	2.23	2.29	1.87	2.59	2.29	1.46	2.04	2.48	2.03	1.76	1.56
Packing material	0.89	1.02	0.90	0.73	1.01	0.84	0.78	1.10	0.93	0.87	0.84	0.85	0.79	0.87	0.93
Transport	0.42	0.10	0.29	0.33	0.18	0.21	0.21	0.27	0.12	0.08	0.09	0.35	0.08	0.32	0.07
Total other variable costs	**3.13**	**3.48**	**4.06**	**3.73**	**3.42**	**3.34**	**2.86**	**3.96**	**3.34**	**2.41**	**2.97**	**3.68**	**2.90**	**2.95**	**2.56**
Total variable costs	**9.19**	**9.26**	**10.85**	**10.62**	**11.11**	**9.84**	**9.66**	**10.57**	**11.07**	**8.07**	**9.48**	**11.56**	**9.29**	**10.78**	**9.70**
Overheads															
Factory overheads	2.37	1.56	2.04	2.57	2.11	2.25	2.24	3.71	2.90	2.23	1.99	2.47	2.27	7.97	3.79
General overheads	2.94	2.36	3.50	2.04	2.26	2.61	2.14	4.82	2.68	1.14	3.00	4.87	2.64	5.77	2.82
Total overheads	**5.31**	**3.92**	**5.54**	**4.61**	**4.37**	**4.86**	**4.38**	**8.53**	**5.58**	**3.37**	**4.99**	**7.34**	**4.91**	**13.74**	**6.61**
Other expenses															
Excise duty	0.31	0.30	0.30	0.30	0.30	0.32	0.33	0.31	0.30	0.30	0.31	0.30	0.31	0.30	0.31
Total	33.01	32.04	34.34	32.81	33.54	33.52	38.07	39.59	40.80	40.94	35.48	37.35	31.35	43.38	37.67
Cost excluding G.L.	**15.75**	**15.38**	**18.04**	**16.52**	**16.90**	**15.99**	**15.83**	**21.35**	**18.36**	**13.14**	**16.43**	**19.75**	**15.02**	**26.52**	**18.46**

*Installed capacity and production of tea are in million-kilograms per year.

TABLE 6.18 Average Sale Price in the 15 Factories During April 2004–March 2006

N

Particulars	Kundah	Karumbalam	Mercunad	Mahalinga	Manjoor	Ithalar	Pandalur	Kaikatty	Kattabettu	Salisbury	Frontier	Kinnakorai	Bikkatty	Ebbanad	Bitherkad
Sale average fetched (₹/kg)															
2004–05															
Average	41.18	42.45	38.12	38.89	39.88	40.11	45.22	39.53	42.63	46.68	41.47	38.56	40.38	34.76	44.15
Maximum	45.42	46.32	41.47	44.01	44.48	45.14	51.14	43.28	54.84	53.98	46.91	43.46	44.94	40.56	50.70
Minimum	33.51	38.60	33.18	32.66	34.13	34.32	40.07	34.13	33.49	40.90	36.41	32.16	34.93	29.40	38.29
(Max–Min)	11.91	7.72	8.29	11.35	10.35	10.82	11.07	9.15	21.35	13.08	10.50	11.30	10.01	11.16	12.41
2005–06															
Average	33.76	33.80	31.68	32.16	32.92	33.93	39.20	33.74	39.39	41.93	34.21	23.77	32.92	32.47	38.34
Maximum	48.11	41.73	45.90	44.61	49.60	47.18	47.95	45.18	47.99	48.79	44.36	43.02	45.58	43.13	51.20
Minimum	24.97	26.30	22.72	24.38	23.26	26.86	35.30	25.45	30.86	38.14	26.45	0.00	24.41	23.23	31.48
(Max–Min)	23.14	15.43	23.18	20.23	26.34	20.32	12.65	19.73	17.13	10.65	17.91	43.02	21.17	19.90	19.72

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CHAPTER 7

Sourcing and Supply Management

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What is the importance of sourcing and supply management in operations management?
- What are the elements of a procurement process? What do you mean by “procurement lead time”?
- What are the traditional and current approaches to supply management? How are they different from one another?
- What are the steps involved in developing reliable vendors? How is vendor rating done?
- How can we assess the performance of the purchasing and supply management functions in an organization?
- How is the make-or-buy decision made?
- What do you understand by the term e-procurement?

Good sourcing and supply management practices enable an organization to obtain good-quality products and services at competitive prices. They also help organizations build relationships with trading partners.

Source: Faraways.Shutterstock

ideas at Work 7.1

EID Parry: Supplier as a Stakeholder in Business

When a cyclonic storm hit the east coast of Tamil Nadu on 30 December 2011, it inflicted major damages on the Nellikuppam sugar mill of EID Parry. About 4,000 acres of sugarcane was uprooted by the cyclonic storm. This meant that about 100,000 tonnes of sugarcane had to be crushed within ten days in a plant which was already damaged. If this was not done, it would have meant major losses to the farmers who are the suppliers of EID Parry. The company took an extraordinary decision and steps to crush the sugarcane. This decision reflects the importance EID Parry gives to over 70,000 farmers in its command area.

Contrary to the thinking in the sugar industry, EID Parry sees the farmers as not mere suppliers of raw material but in a much larger role. The company launched a call centre operated by a third party to answer the queries of the farmers. Each query should be answered in a specific time and it gets escalated if there is delay or if the farmer is not satisfied. The company also commissioned a farmer satisfaction survey to understand the gaps in the service.

Sugarcane growers can register with the cane management system of EID Parry. The support services offered include advice on various farming activities such as soil testing, land preparation, and weeding. Besides this, the company has also setup retail outlets to make agricultural inputs available to the farmers. The company also assists the farmers for obtaining crop loans, term funding for drip irrigation, and digging bore wells. The company enters into an agreement with the bankers and the farmers and agrees to repay the loan from the cane proceeds. The company also has brought about 25,000 labourers, whom the farmers can deploy to prepare the land or harvest. This is a significant step considering the labour shortages that prevail in the country in the agricultural sector.

This approach to supplier development by EID has provided several advantages to them. Better supplier management always helps in mitigating supply side uncertainties in the agro-sector. Average cane productivity in the company's command area was 32 tonnes per acre as against the national average of 27 tonnes. The company has been able to run its crushing plants for more than 300 days in 2011–2012 thereby enabling it to improve its operating margin. The concept of command area requiring farmers to supply only to certain sugar mills in the area will be dismantled. Companies that treated farmers as captive suppliers will be affected and companies such as EID Parry will be greatly benefitted.

This case highlights the importance of sourcing and supplier development in an era characterized by global competition and profit margin squeeze. We shall see several aspects pertaining to sourcing and supply management in this chapter.

Source: Madhavan, N. (2013), "Ryot Act", *Business Today*, March 3, 2013, pp 98 – 104.

Sourcing and supply management raise several issues of importance to an organization. Every organization is engaged in procuring goods and services and therefore faces certain important questions. Did the organization fetch a good price for the procurement? Are the suppliers reliable? Will they deliver good-quality products/services at the right time? How efficient is the procurement process? How can an organization benefit from its suppliers? Should it develop new sources? The search for the right answers to these questions requires a systematic approach. In this chapter, we shall address several of these questions and try to understand how organizations can address them.

The onslaught of the Web has enabled organizations to broad-base their search for newer sources of supply that promise greater cost saving potential. The recent rise of business process outsourcing (BPO) and shifting businesses from developed countries such as the United States and the United Kingdom to places like India and China are fallouts of this phenomenon. This has further amplified the need for a greater understanding of sourcing and supply management practices. However, before dealing with the various aspects of sourcing and supply management, let us first understand the changing business practices that have a direct impact on supply management practices.

7.1 THE IMPORTANCE OF SOURCING AND SUPPLY MANAGEMENT

Sourcing and supply management are important functions in any organization. In recent years, the focus on supply management has increased significantly on account of several developments in the market and the competition. Some of the salient aspects of these developments are discussed in this section.

Quality Management Issues

Quality management practices in the last two decades have gone through a basic change in their underlying philosophy. We discussed this aspect in Chapter 12 of the book. In the past, quality management was achieved through the "detection and correction mode". In this approach to quality management, the processes employed to produce the goods and services in an organization were allowed to be defective. This meant that sophisticated detection mechanisms were required to identify the defects after they occurred and segregate them "as far as possible". As opposed to this, the current mechanism employed for quality management is one of prevention and elimination. Such a philosophy demands that all inputs to an operating system be defect-free. Clearly, a defect-free input is not achieved merely by rock-bottom price negotiations with suppliers but also by looking at other aspects of doing business with them. Therefore, alternative methods are required for the procurement process.

> A defect-free input is not achieved merely by rock-bottom price negotiations with suppliers.

Changing Cost Structure

There has been a dramatic change over the last thirty years in the components of the cost of goods sold by an organization. Organizations were buying raw materials and were deploying simple technology to manufacture everything in-house. Consequently, about 40–50 per cent of the cost of manufactured goods was due to bought-out raw materials and components, 20 per cent due to overheads and over 30 per cent due to direct labour. However, today close to 65–70 per cent of the cost is due to bought-out assembled components and sub-systems. Another 20–25 per cent contributes to overheads on account of use of automation. The labour component is less than 10 per cent in most situations. After taking into account the profit margins, the cost of materials would account to over 70 per cent of the cost of the goods manufactured. Over the years, the proportion of the cost of materials to the overall cost is increasing. Such a change in cost structure clearly indicates that much of cost control lies upstream of the manufacturing system and a good sourcing and supply management is inevitable. Clearly, when the bulk of the cost incidence of the product is fixed *a priori* by input costs, emphasis on input cost reduction becomes important.

> When the bulk of the cost incidence of a product is fixed *a priori* by input costs, emphasis on input cost reduction becomes important.

Quick-response Requirements

As competition increases in markets, customers become more demanding. Firms are required to respond to the market requirements much more rapidly. Good supply management practices are central to any quick-response system. Organizations need to have less lead time and greater flexibility to respond to the changes in the marketplace. This calls for closer ties with the suppliers and the ability of the suppliers to match the requirements placed by the buyers. It also calls for alternative methods for cutting down the procurement lead time.

> Good supply management practices are central to any quick-response system.

Creating a Lean Organization

One of the foundation blocks of a lean organization is the network of supply organizations that co-partner with the manufacturing organization in creating a value stream for efficient delivery of goods and services. Traditional procurement practices do not address the issue of building such a network of organizations. It calls for mutual trust and long-term relationships among the participating organizations. It also requires patience. Furthermore, it involves a considerable amount of give-and-take on the part of the organizations engaging themselves in such exercises. Procurement and supply management practices need to accommodate these requirements.

The Importance of New-product Development

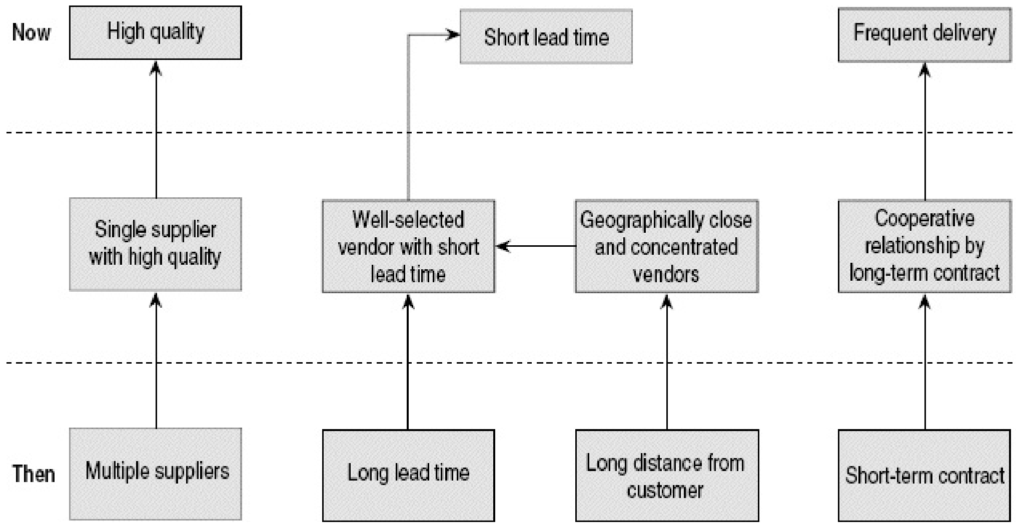
A study by the Massachusetts Institute of Technology showed that Japanese automobile firms were rapidly expanding their product range, even as they were renewing existing products. Between 1982 and 1990, they nearly doubled their product portfolio from 47 to 84 models.[1] The study also showed that during that period, Japanese cars were in production for a period ranging from 1.5 and 2.0 years on average, compared to a range of 2.7 to 4.7 years for a car in the U.S. manufacturers. Other sectors of the industry began to understand the strategic advantages of shrinking product life cycles and cutting short the new-product introduction time. Quantum's cross-functional design teams reduced development cycles for new disk drives by 15 per cent and cut the bill of materials costs for the drives by as much as 30 per cent. Similarly, at IBM, co-locating purchasing in the design lab has helped halve product development cycles for computer hardware, software and related peripherals in less than two years.[2]

Organizations cannot hope to design products and deliver them at an efficient cost and time on their own. Faster new-product introduction requires the active support of suppliers. In this process, the inherent strengths of each part of the value chain are exploited to deliver the best product within a shorter time. Cutting down the new-product introduction time, therefore, calls for good supply management practices.

> Faster new-product introduction requires the active support of suppliers.

The requirements of faster new-product introduction and good supply management practices have placed several new demands on the purchasing and supply management practices in every organization. Figure 7.1 briefly captures the important changes that have taken place in this process in response to these requirements. Organizations have moved from multiple suppliers to fewer (and often one supplier) for an item. Typically, cooperative and long-term relationships are established with these suppliers. Due to these new arrangements, suppliers are able to deliver quick-response capabilities to an organization through short lead time and frequent deliveries. Moreover, the quality level is also found to increase significantly. Before we analyse the nature of activities undertaken to implement the transitions indicated in Figure 7.1, let us understand the notion of *strategic sourcing* and the various steps involved in a typical procurement process. A good understanding of the procurement process is crucial to appreciate the impact of the new procurement methods and the supply management practices, which will be discussed in a later section.

FIGURE 7.1 Transitions in purchasing and supply management practices



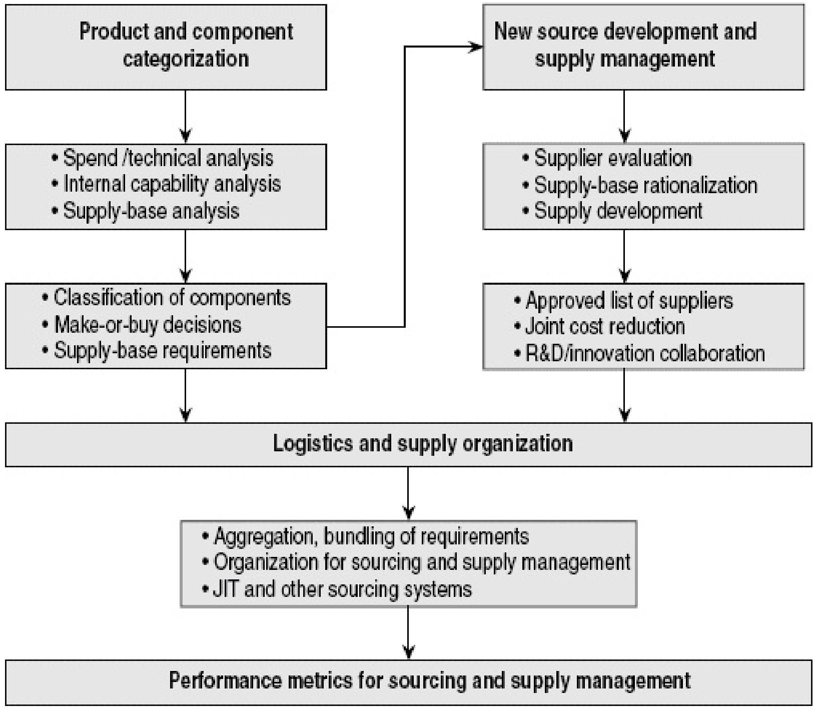
7.2 STRATEGIC SOURCING

Globalization of economies worldwide is driven by the basic premises of cost-effectiveness of operations, access to new markets, and economies of scale. Over the years, this has caused organizations to organize manufacturing and services using globally located suppliers and production/distribution facilities. These business characteristics have increased the pursuit of low-cost country arrangements and the business notion that offshore outsourcing to developing countries is an inevitable trend. Firms in developing countries are becoming important links in global sourcing and production networks. The amount of goods and services sourced from low-cost country suppliers are increasing. Low-cost country sourcing has ranked as one of the most challenging topics for procurement professionals in the period 2004–2006.[3]

Global sourcing is a concept that focuses on the integration and coordination of common items, materials, processes, designs, technologies, and suppliers across the world. According to the World Trade Organization, 55 per cent of all raw materials for U.S. manufacturing are sourced outside the United States. For industries such as apparel and footwear, consumer packaged goods, and high-tech electronics, the numbers are even higher.[4] On the other hand, the value of purchased input as a percentage of cost of goods sold has continued to rise. Further to these developments, sourcing is no longer considered as a tactical issue in organizations. It is increasingly viewed as a proactive strategy capable of creating competitive advantage. Sourcing is considered *strategic* because cost reduction and lead time reduction opportunities are closely linked to the manner in which the sourcing and supply management decisions are made in an organization. Consequently, sourcing managers must integrate their companies' strategic priorities into the sourcing strategies of each sourced part, system, product, or services and decide about the relevance and detailed implementation of a sourcing strategy.

Figure 7.2 illustrates the major activities of a strategic sourcing function. As shown in the figure, it consists of four aspects.

FIGURE 7.2 Strategic sourcing—a framework



- *Product and component categorization*: Sourcing strategies often focus on a specific part, component, service, or product. A one-size-fits-all sourcing strategy makes little sense across a company's category portfolio. Suppliers might be plentiful and eager to compete in some categories, while for other categories, supply options might be limited. Some categories requested by internal customers may have a larger impact on business in terms of total expenditure or on a company's strategic position, while the impact of other categories might be relatively small. In many cases, very specific characteristics of the parts, services, or products requested by internal customers will drive the sourcing strategy, while the supplier perspective or supply-market perspective will be primarily driven by those requirements. In some cases, products or services might only be sourced from a specific supplier due to worldwide intellectual property rights or unique access to resources, giving the relationship with this supplier a more prominent role in the sourcing strategy. Finally, factor cost advantages or local content requirements might lead to the decision to source a specific spend volume from a single supply market.
  Often, an analysis of the components that need to be procured will lead the efforts in strategic sourcing into two directions:

  - Focus on components that are critical to the product and the company is good at making.
  - Outsource all other components where suppliers have a distinct competitive advantage, greater scale, lower cost, or greater performance incentives.

  In a large multi-product multi-division organization such as Bosch Limited, the approach to supply management depends on the classification of parts and suppliers. The suppliers are classified as *preferred suppliers* (P), *technology specialists* (T), *customer-specified suppliers* (D), *new suppliers* (N), *Bosch Limited approved essential suppliers* (E), *suppliers for elimination* (X), and *suppliers without new business* (W). After an initial classification of suppliers as P, T or D, the other classifications are arrived at using a structured supplier evaluation methodology.
- *New source development and supply management*: Supply management considerations include all the activities necessary to develop and implement sourcing objectives with the overall supply base and individual suppliers. Key strategy elements are the number of suppliers and the kind of relationship, such as arm's-length transactions or collaborative partnerships. Furthermore, the number of suppliers for a specific product or service in the form of sole sourcing, single sourcing, dual sourcing or multiple sourcing is important. A good supply management programme will endeavour to constantly identifying reliable and capable sources that provide good-quality inputs at lower costs. Further,

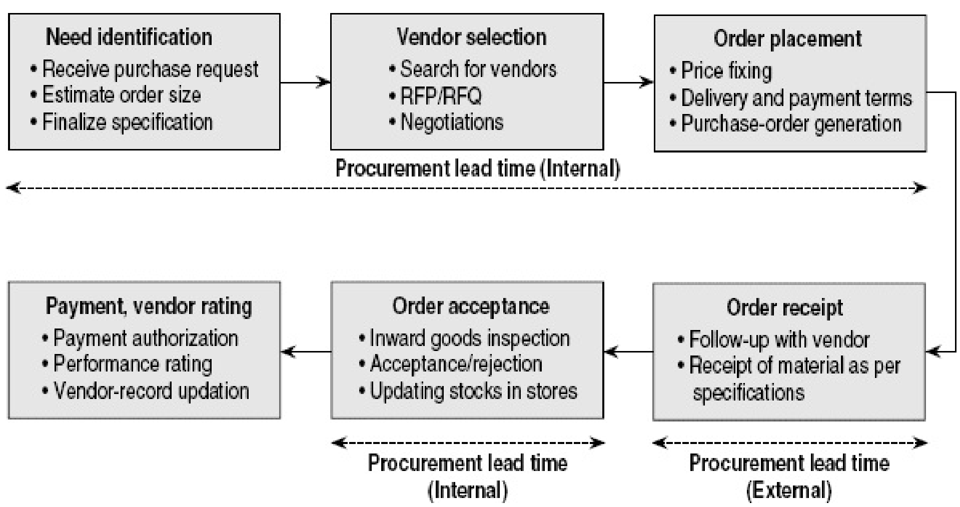
continuous efforts will be invested in developing the existing vendor base in terms of technology, quality, and process upgradation. Shrinking the vendor base in order to reduce the transaction costs arising out of the procurement process will also be another aspect of the supply management process.

- *Logistics and supply organization*: The sourcing function will enable all activities necessary for developing and implementing the sourcing objectives of the organization, as well as the other functions involved in the sourcing process. The sourcing function requires an organizational set-up that helps in the alignment of requirements and specifications across multiple product categories and geographical locations. Relevant activities are standardization and bundling. *Standardization* aims to find or increase similarities between products and services which need to be sourced in order to improve performance measures such as cost reduction or process improvements. *Bundling* efforts will increase the sourcing volume for specific categories across different business units or companies in order to improve the negotiation power towards suppliers and realize economies of scale.
  From a logistics perspective, requirements such as stock delivery, just-in-time delivery or just-in-time purchasing need to be addressed.
- *Performance metrics for sourcing and supply management*: Traditional measure such as purchase price is grossly inadequate to measure the performance of the sourcing and supply management function. Several organizations have realized that while price is a major component in the sourcing decision, other attributes are equally important. Furthermore, the performance of the sourcing function should not be merely judged by tactical parameters. Measures indicating the capability of the suppliers, the competitive advantage that they bring to the business, and the rate at which they improve on certain key parameters are important. New metrics such as *total cost of ownership* are useful to measure the sourcing and supply management function in an organization. We discuss the metrics in a later section of the chapter.

7.3 THE PROCUREMENT PROCESS

Irrespective of the type of organization, the ownership pattern, and the nature of items procured, the procurement process consists of a standard set of activities that needs to be performed in a chronological order. Figure 7.3 outlines the steps in the procurement process.

FIGURE 7.3 Steps in the procurement process



- *Step 1: Need identification.* The first step in the process is need identification. Unless the users of the material express a desire to consume more than what they have during a time or the inventory records show the potential depletion of inventory, a procurement process never gets initiated. In the case of regular production items, inventory control policies that are in vogue will trigger a procurement process. In the case of non-routine requirements such as the manufacturing of a customized order, maintenance, and R&D requirements, users will usually raise a purchase request. The purchase request will be the basis for procurement. The purchase request will have detailed specifications of the material required.

Based on the inventory control policy, appropriate order sizes are established.

> The first step in the procurement process is *need identification*.

- *Step 2: Vendor selection.* Once the exact requirements are identified, the procurement process focuses on identifying an appropriate source for supply. This usually begins with a search for potential vendors.[5] The existing set of vendors dealing with the organization is the usual starting point. However, additional sources could be identified thorough professional contacts, trade directories, and B2B portals. The sources are contacted and are subjected to a request for proposal (RFP) and request for quotation (RFQ) processes. Several alternatives are available for an organization to place the order. These include placing a repeat order with an established vendor, selection through a tendering process, post-tender negotiations for price and use of very recent methods such as reverse auctions through an electronic market. These procedures vary markedly between government organizations and private-sector organizations.
- *Step 3: Order placement.* After source selection and negotiations, the vendor is selected and certain administrative steps are taken to place an order with the selected vendor. This includes fixing all the terms of the contract, such as price, payment, and delivery terms, along with other engineering specifications, and obtaining the required authorizations for spending. Purchase-order generation is inextricably linked to the authorization procedures in vogue in the organization. For orders with very high monetary value, the decision making is done at the highest level in the organization. Therefore, the purchase order is generated only after the competent authority has approved the purchase.
- *Step 4: Order receipt.* Once the order is placed with the selected vendor, follow-up of the order is done to ensure that the order is received as per the specifications and on time. Traditionally, organizations have spent much time on this step if its suppliers are not reliable enough. Multiple communication channels such as phone, e-mails, faxes, personal visits, and face-to-face meetings are held to follow up the purchase order. However, due to better sourcing and supply management practices, many organizations have been able to cut time, cost, and deployment of organizational resources in this stage of the procurement process. The reasons for this transition and the systems put in place in order to ensure this constitute the modern supply management knowledge. We shall understand this in some detail in a later section in the chapter.
- *Step 5: Order acceptance.* The received material is subjected to some inward-goods inspection and a decision is taken to either accept or reject it. Once a lot is accepted after inspection, the relevant inventory records are updated in the stores and the material becomes available to the user. Therefore, this signifies the end of the procurement process for a purchase request initiated at the beginning of the procurement process. In recent times, due to modern sourcing and supply management practices, the inspection of incoming material is either eliminated altogether or minimized to a large extent.

Although the steps in the procurement process are standard, there are several procedural variations with respect to purchasing in every organization. These are largely dictated by the purchasing policies in vogue in the organization. The simplest purchasing procedures pertain to off-the-shelf buying, oral orders over phone, and placing repeat orders with an existing supplier. In all these cases, the crucial steps of identifying an appropriate source of supply and price negotiation are skipped. This results in large reductions in lead time and simplicity in operation. Typically, low-value items are procured in this manner.

> Although the steps in the procurement process are standard, there are several procedural variations with respect to purchasing in every organization.

However, in a vast majority of public-sector and government procurements, a detailed tendering process in adopted. Each interested supplier is asked to submit a technical bid and a commercial bid. Once the technical bids are screened and shortlisted, the commercial bids are opened and detailed negotiations follow. Moreover, detailed guidelines are spelt out to split the final order between L1, L2, and L3 suppliers. L1, L2, and L3 are nothing but the first three lowest-quoted vendors (L1 is the lowest among the three). There are guidelines to the extent of split between the three and firms need to justify and obtain authorization if these guidelines are not followed.

Another characteristic aspect of these organizations is the stores and purchase committees (SPCs). Typically, there are four levels of SPCs and depending on the value of the procurement, the decision to place the order is taken by the appropriate SPC. At the highest level, executive directors will be part of the SPC. All these procedural issues result in enormous paperwork, the commitment of managerial time for decision making, and long lead time for purchase in public-sector and government procurements. Several private-sector firms also follow similar purchasing procedures, but are generally quicker in decision making with regard to order placement.

Of late, two other methods have been adopted for procurement. These include the use of electronic markets for reverse auctions and just-in-time (JIT) purchasing. In JIT purchasing, long-term and collaborative relationships are established with a single vendor on the basis of mutual trust and cooperation and in return the purchasing procedures are highly simplified. Several of the steps mentioned in the procurement process are skipped and the supplier is encouraged to make direct “online” delivery of items at frequent intervals. In the case of reverse auctions, suppliers are invited to participate in an auction hosted on a Web site and asked to compete for a contract. Appropriate screening mechanisms are put in place before suppliers are selected for participating in the auction. Within a matter of three hours, an appropriate supplier and price are discovered efficiently and the order placed thereafter.[6]

> Electronic markets for reverse auctions and JIT purchasing are two recent methods adopted for procurement.

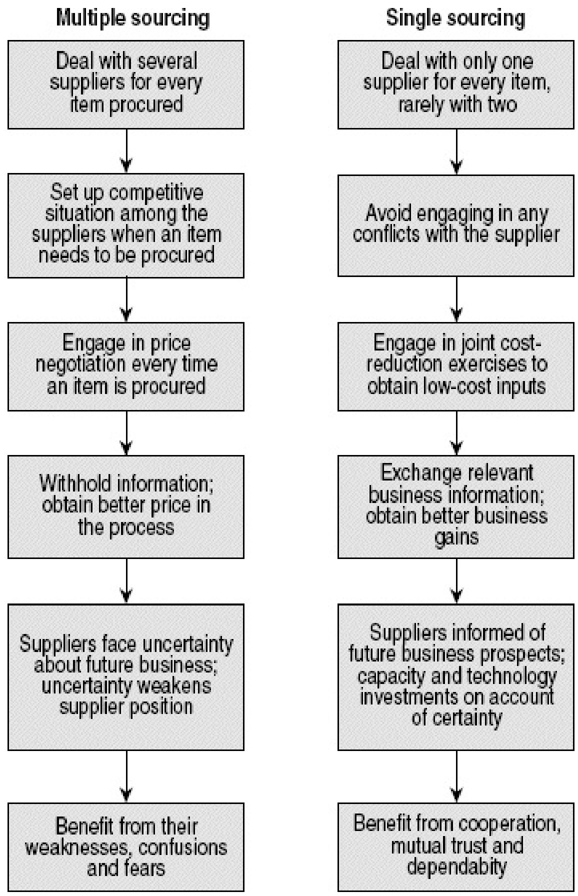
Procurement lead time is made up of three components, as shown in Figure 7.3. First, there is an *internal* lead time due to the various administrative processes involved in selecting a vendor and placing an order with the vendor. Once the order is placed, the lead time taken by the supplier constitutes the *external* component of the procurement lead time. Finally, a set of administrative activities is performed within an organization to accept the order, which relates to the third component of procurement lead time. Although not evident from the figure and the description, process complexities can significantly influence the lead time. If an organization has a very complex process for order placement, then one could expect a very high procurement lead time. Public-sector organizations sometimes suffer from such procedural complexities, leading to very high procurement lead time.[7]

7.4 APPROACHES TO SUPPLY MANAGEMENT

JIT purchasing philosophy suggests that by developing a good relationship with suppliers, it is possible to simplify the purchasing process in an organization and thereby reduce cost and lead time.[8] Traditional supply management philosophy will not help an organization develop suppliers who can deliver today’s requirements. On the contrary, there are several other advantages for an organization in developing exclusive sources. In order to appreciate this point, we shall first take a look at how traditional methods and the recent methods of supply management differ. The traditional approach to supply management is best described as *multiple sourcing*. On the other hand, the recent approach to supply management can be referred to as *single sourcing*. These approaches are based on fundamentally different assumptions. Figure 7.4 illustrates the important differences between the two approaches.

The multiple-sourcing model, as the name implies, deals with multiple suppliers every time an item is procured and enjoys some gains from the competitive scenario that a supplier faces in the process. Moreover, information about future business is not shared as there is no requirement for it. There is no guarantee that the same supplier will win the procurement contract in the future. In a nutshell, buying organizations hope to benefit from the weakened position of the suppliers and are confident of obtaining lower prices. It was true to a certain extent that the buyers did obtain lower prices for the items procured in this manner. However, the cost associated with obtaining the items as per specifications and in time was often high. Excessive follow-up was required. Moreover, suppliers performed miserably on other parameters such as quality, dependability during emergencies, quick response, and development of new technology and capabilities. These issues were simply not captured in the price-negotiation process, so the suppliers had no motivation to deliver on these parameters.

FIGURE 7.4 Multiple- and single-sourcing approaches to supply management



In contrast to the multiple-sourcing model, the single-sourcing model is based on the premise that by developing a long-term collaborative relationship based on mutual trust and dependability, it will be possible to obtain not only lower prices but also several other benefits that are missed out in a multiple-sourcing model. This cooperative relationship includes sharing vital business information pertaining to production plans, future contracts, and cost information so that both the supplier and the buyer can gain substantially from business certainties. Suppliers will be in a position to plan their capacity additions and technology and skill upgradation in anticipation of future business from buyers. Buyers, on the other hand, benefit from lower costs, better technology, quick-response capabilities, dependability in case of emergencies, and the long-term strategic engagement of the suppliers in matters such as new-product development.

> The traditional approach to supply management is known as *multiple sourcing*, and the modern approach to supply management can be referred to as *single sourcing*. The single-sourcing model is built over the premise of mutual trust.

Single sourcing, the Japanese prescription for supply management, has attracted considerable attention in recent years, both in practice and in theory. Japanese manufacturers claim that this new arrangement makes business sense. They report several benefits from single sourcing, including a substantial reduction in inventory, reduction in planning and procurement costs, continuous cost reduction, and faster new-product introduction. Manufacturing organizations in other Western countries such as the United States and the United Kingdom have followed suit and claimed similar benefits. In India, major automobile and component manufacturers have adopted the single-sourcing model successfully.

One of the concerns that managers have about single sourcing is that when there is no competition among suppliers, it is difficult to fetch a lower price. On the contrary, the price-fixing mechanism in single sourcing is more rational and is based on a “win–win” proposition. In a single-sourcing agreement, the focus actually shifts to cost. The buyer and the supplier will freely exchange information and arrive at the cost of making the item through negotiation. Once the cost structure is arrived at, the required margin for the supplier is added to it to arrive at the final price. Such an arrangement is in the interest of both parties. Suppliers show greater interest because their margins are built into the price. Buyers show interest because this new arrangement makes it easy to engage in cost-reduction exercises. For example, once the cost structure and the margin for the supplier are agreed upon, both parties can engage in cost-reduction exercises jointly. The reduced cost gets passed on to the buyer, while the margin that is required for the supplier to conduct business is preserved. The cost structure and the required margins could be reviewed once per annum. During the intervening period, both parties can engage in joint cost-reduction exercises.

> Single sourcing, the Japanese prescription for supply management, has attracted considerable attention in recent years, both in practice and in theory.

Another issue of concern in a single-sourcing model is the likelihood of poor delivery reliability on account of some larger issues. These include the poor state of the logistics infrastructure; incidence of strikes by transport operators, trade unions and political parties; and natural calamities arising out of floods, cyclones, etc. In practice, this issue has been addressed in many ways. Once the buyer and supplier get into a single-sourcing arrangement, they work together against all odds and ensure minimal disruption of business. The recent experiences of automobile component manufacturers in India during a prolonged truck operators’ strike seem to reinforce this viewpoint.[9]

ideas at Work 7.2

Alternative Procurement Processes Followed by Organizations

Procurement is done under varying conditions in organizations. Sometimes the procurement is routine as opposed to a very specialized one. At other times there is a severe time constraint in procuring the materials and services. Therefore in practice organizations deploy several methods of procurement. We shall see some of them.

Purchase on S*ingle tender* basis will be resorted to when there is an emergency to tide over. There are also other reasons for single tendering. Procurement from a single source may be resorted to when the goods and related services are available only from a particular supplier or a particular supplier has exclusive rights in respect to these items and no alternative exists. Alternatively, when the purchase is of a product or a service of specialized nature or of high technical specification, organizations go for a *single tender*. There are also occasions where the award of contract is of a very specialized nature and a single source will be the only alternative feasible under the circumstances.

A *Limited tender* method is followed in cases where the nature of service or product involved is highly technical and a few empanelled suppliers are available. In addition, when there is emphasis on the quality and specification, this method is adopted. *Repeat orders* are placed on an existing supplier at the same price, terms, and conditions of the previous order after satisfactory performance. This is usually done in the case of vendors who have entered into rate contract. *Repeat orders* are considered when there is no downward trend of the price of materials and services.

Annual rate contract is entered into for supply of stores and services at a specified rate during a period as per requirement at the agreed rate, terms, and conditions. The overall consumption is normally estimated for the items based on the purchase requisitions received during the previous year. *Emergency purchases* are made to meet any urgency such as repairs and for materials for operational usage. Normally, *emergency purchases* are made only for budgeted items. Organizations also resort to *petty purchases* for purchase of non-stock items of low value. No formal enquiries or quotations are obtained and the user departments are allowed to procure subject to some annual limit.

Source: Author’s own research

Another approach to solve this issue is factoring the geographical proximity of suppliers in prioritising single-sourcing initiatives. If the suppliers are geographically closer, many of the problems we have discussed could be easily sorted out. Perhaps, this explains why automobile manufacturers develop suppliers in a 50-km belt around their place of operation. Moreover, there are other benefits from the geographical proximity of suppliers. Earlier studies reported that as the distance between suppliers’ and automakers’ plants decreased, automakers’ inventories as a percentage of sales also decreased.[10]

Despite these benefits and success stories, adopting a single-sourcing model has not been easy for organizations. In some sense, it amounts to putting all one’s eggs in one basket, which is perceived to be risky. Jumping over to single-sourcing agreements overnight will create havoc in business. The single-sourcing model is built on the premise of mutual trust. Establishing trust between the two partners invariably takes time. However, organizations can approach the single-sourcing model using a two-pronged initiative. One is to reduce the number of suppliers from many to two immediately and the other is to set up the required mechanisms for developing reliable vendors. We shall focus on the latter aspect in some detail in the next csection.

> Despite several benefits and successful stories, adopting a single-sourcing model has not been easy for organizations. The single-sourcing model is built on the premise of mutual trust.

The examples in Ideas at Work 7.3 show that there are no hard and fast rules for developing an atmosphere of trust. It helps greatly if the buyers take the initial steps in this direction. The extent to which a buyer can develop trustworthiness in the minds of the suppliers is limited only by its corporate mandate and the commitment and creativity on the part of managers involved in this process.

ideas at Work 7.3

Trusting Suppliers?

The most difficult aspect of developing good suppliers is the building of trust between the buyer and the supplier. Unfortunately, there are no certification procedures for “trustworthiness”. Neither the buyer nor the supplier can begin to trust the other overnight. Trust-building takes time, but the essential question is—how do the two parties begin to develop trust? Unfortunately, this does not lend itself to a simple approach.

Organizations have taken recourse to a variety of means that might help the buyer and the supplier develop mutual trust over a period of time. Often, these include the buyer organization voluntarily taking steps to offer infrastructural and technical support to the suppliers and addressing the payment-related issues of the supplier. Maruti Udyog Ltd, has been continuously engaged in a variety of initiatives that would help the suppliers improve their quality, technology, and business. For instance, Maruti imported machine tools under the Export Promotion Capital Goods Scheme (EPCG), and gave them away to its suppliers. This actually meant upgrading the machining capabilities of the suppliers, providing infrastructural and technical support, and making an export commitment to the government on behalf of the suppliers.

A Chennai-based company took several measures during the 1990s to speed up payments to its suppliers. According to one executive, this alone was responsible for bringing down the inventory investment by one-third. A leading computer manufacturer invested in all the tooling required for the manufacture of tower cabinets. It went further and encouraged the supplier to increase the production and sell it to its competitors as well.

Ranbaxy Limited took several initiatives that were much beyond the traditional supplier–buyer relationship. These included improving the core competencies of the suppliers, sharing several benefits, equity participation, financial assistance, and joint ventures for their expansion. Some of their endeavours included conducting joint training programmes on "customer–supplier relations" using reputed consultants, and actively participating in quality improvement projects in vendor companies.

As a result of these initiatives, one supplier of the drug Alpha-D was able to increase the purity level from 97.2 per cent to 98.5 per cent, as well as his business with other customers. The company also helped another supplier of printed aluminium coils in changing its sealing machines. In another instance, while solving a quality control problem at a sugar plant belonging to one of its suppliers, Ranbaxy helped change certain piping sections by providing a loan. The suppliers were highly motivated by these efforts of Ranbaxy.

7.5 DEVELOPING RELIABLE VENDORS

All modern approaches to sourcing and supply management have a fundamental prerequisite, namely, developing reliable suppliers. Therefore, every organization should invest in supplier development and have methods by which it can assess the reliability of its suppliers.

Supplier Development

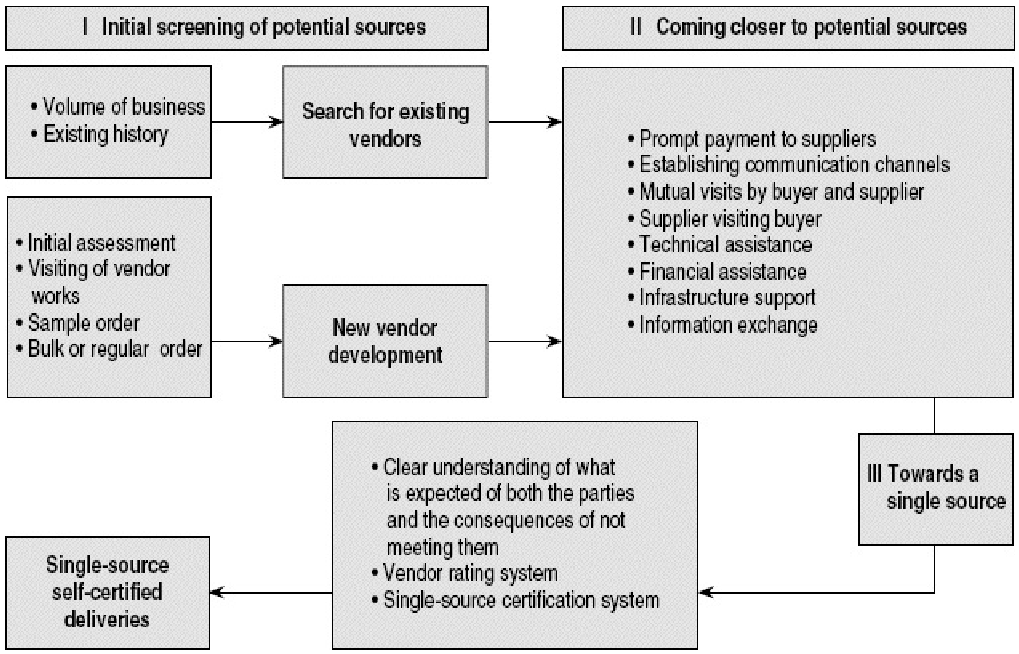
A good supplier development programme can be implemented in three stages. In each stage, a set of activities are undertaken to identify the most appropriate source for the organization. Figure 7.5 is an illustration of these steps. The first stage involves drawing up a list of potential sources that could be considered for developing long-term relationships. In several organizations, the search begins and ends with the existing set of suppliers with whom they have been dealing. Analysing the volume of business and past history will reveal the suitability of considering some of the suppliers. However, it is also not uncommon for organizations to enlist new vendors with whom they have not dealt with earlier. In such cases, detailed questionnaires are sent to them and some initial visits are made to assess the suitability of such suppliers. Trial orders are also given to assess their capabilities, technical and otherwise. Bosch Limited categorizes its suppliers to classify them and make various decisions with respect to their development. For instance, "X-category suppliers" are those identified for elimination while "N-category suppliers" are new ones who have been found to have the competitive capability to replace suppliers facing elimination.

> A good supplier development programme can be implemented in three stages: initial screening of potential sources, coming closer to potential sources, and working towards signle-source self-certified deliveries.

VIDEO INSIGHTS 7.1

Supplier development initiatives span across a number of areas. This includes technology support, guaranteed procurement, and assistance to put in place better quality systems and improved methods of operations. Nestle's efforts in the case of procurement of red chilies is a case in point. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

FIGURE 7.5 Stages in supplier development



During the second stage, the organization needs to take several steps to build trust and assess the suitability of having long-term contracts in realistic terms. This is achieved by a series of measures, as shown in Figure 7.5. Providing various types of assistance, encouraging mutual frequent visits, and information exchange are some of the crucial steps in the process. Frequent personal contacts and mutual visits by both suppliers and buyers will invariably result in faster product development cycles and more reliable products. After some years of working with a select set of suppliers, an organization would be reasonably confident of establishing much closer and long-term relationships. Therefore, in the third stage, several measures are taken to put checks and balances in place for the proposed single-sourcing arrangement. These include a robust certification mechanism and a good vendor rating system. Once these mechanisms are in place, it is possible for the organization to engage in a single-sourcing relationship with the supplier.

The steps outlined in this section are broad and suggestive. Several organizations have adopted a similar approach for vendor development. The differences are mainly in the time taken to develop self-certified deliveries. While in some cases it takes as little as nine months, in several other cases it could take two to three years to reach this stage. The time taken for vendor development also depends on the complexity of the item for which a vendor is being developed.

Supplier Certification Programmes

Developing long-term relationships essentially means putting all one's eggs in one basket, as we already pointed out. Therefore, organizations should exercise great care in doing so and institute checks and balances to accommodate unforeseen circumstances in the future. One way to minimize the risks in the process is to assess certain important aspects of doing business with the supplier. A supplier certification programme seeks to fulfil this objective. Figure 7.6 outlines the activities to be performed as part of the certification programme.

ideas at Work 7.3

The Cluster Approach to Supplier Development

Small and medium enterprises (SMEs) often grapple with the lack of high-quality human resources with technical and managerial know-how. In order to improve the quality and productivity of their organizations, they need to benefit from the best practices and knowledge of qualified experts. Large organizations are also interested in developing their vendors, who face similar challenges. In order to address these issues, the Confederation of Indian Industry (CII) devised a cluster approach to help organizations in this process. The cluster programme has been in operation since 1998. This approach focuses on helping manufacturing enterprises (particularly the SME sector) to become lean and helps them to absorb and implement these skills.

The cluster approach essentially provides a platform for business alliances and helps enterprises to specialize, attract suppliers and buyers, spread ideas and the capacity to innovate, and most important, to engender co-operative action through mutual sharing and learning. In this approach, 8–12 companies (mostly SMEs) come together to learn, share experiences, and solve problems. Traditionally, the approach has been applied to manufacturing enterprises from the same sector. Examples include the auto-component, light engineering, heavy engineering, education, and leather industries.

The companies in a cluster may come together at the request of a customer or an original equipment manufacturer (OEM), or a set of companies could group together and then approach CII for support. The CII cluster members network with institutions that provide adaptable technology and financing. Cluster members are provided with training inputs and handholding support/counselling. Inputs are based on manufacturing excellence, cost management, HR management, and energy management. Energy conservation has been a part of some clusters. Companies meet every month to share and learn from the implementation practices, and all members in the cluster progress together to achieve the common goal of enhancing their competitiveness.

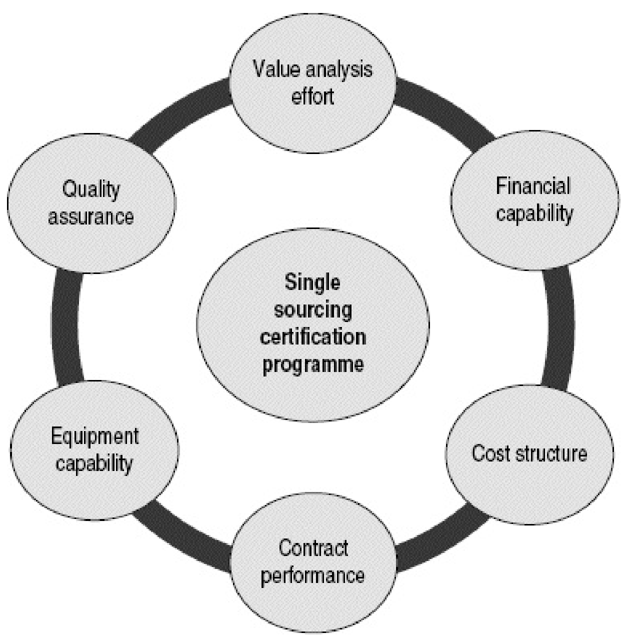
The cluster approach by the CII-LM Thapar Centre for Competitiveness for SMEs has all the elements of a typical supplier development programme that any organization might want to embark on. Further, it also promises to deliver benefits arising out of the synergy and networking of the participants.

Source: Based on information from the CII-LM Thapar Centre for Competitiveness for SMEs, accessed at www.ciicfc.org.

The certification programme assesses, amongst other things, the financial and equipment capabilities of the supplier under active consideration. Past balance sheets are analysed to realistically assess if there is a possibility of the supplier going bankrupt. Similarly, the supplier's equipment capabilities, quality assurance systems, and propensity to engage in value analysis efforts are also analysed. Other issues studied include understanding the cost structure and a detailed scrutiny and finalization of the contract performance. The contract performance is an elaborate exercise in which various contingencies likely to emerge are envisaged and the expected behaviour on the part of both parties is spelt out. This includes, for instance, expected performance in quality and delivery parameters and the time frame for corrective action to restore deteriorating performance.

The certification programme assesses the financial and equipment capabilities, the cost structure, the contract performance, the quality assurance system, and the value analysis effort of the supplier under active consideration.

FIGURE 7.6 The supplier certification programme



Once a supplier is subjected to the certification programme and is found to meet the requirements, there will be no need for an inward goods inspection and the supplier will be entirely responsible for quality and delivery performance. It is technically feasible to have direct “online” sourcing of the items procured from the supplier. This will provide enormous savings in procurement lead time and costs for the organization, which the multiple-sourcing model cannot deliver.

Vendor Rating

Selecting the right vendor is a difficult but important part of the sourcing and supply management process in any organization. Suppliers have varied strengths and weaknesses as much as organizations have varied emphasis on different parameters pertaining to procurement. For example, one organization may give greater importance to delivery reliability and another may place greater emphasis on quality. Therefore, a systematic and careful method of assessment of suppliers’ performance is required to enable an organization to monitor its suppliers’ performance and to align them with its requirements. Vendor rating systems are used for this purpose in every organization. As suppliers make repeated deliveries of items in response to the purchase orders that have been placed, they provide an opportunity for buyers to evaluate their performance using the **vendor rating system**.

> **Vendor rating** is a systematic method to evaluate suppliers’ performance using data from the delivery of items in response to the purchase orders placed.

The first step in developing a vendor rating system is to establish the criteria to be used for assessing the vendors. For example, an organization would be keen to understand if the suppliers performed well in quality, delivery reliability, and dependability parameters. Although several criteria could be used, the following criteria are used frequently: quality, price, service, technical capability, financial strength, geographical location, reputation, and reciprocal arrangements.[11] Further, when several criteria are used, it is also necessary to determine how far each criterion influences the vendor rating. The relative importance of the factors is established, typically by assigning weights to the factors such that the sum of all factor weights is 100, as illustrated in Table 7.1.

In a *weighted points plan*, vendor rating is done using a two-step procedure. The first step is to design the vendor rating system. As already discussed, it involves identifying the set of factors to be considered, establishing the relative importance of each of these factors and the development of yardsticks for each of these factors. Once the yardsticks are established, the performance of individual vendors could be rated using the yardsticks and the weights for each factor. If a vendor has excellent performance in all the factors, then it will score the maximum points in the vendor rating. In reality, vendors score very high on some factors and low on others. Therefore, one can compute the vendor rating as the ratio of the sum of the actual score that they have obtained for all the factors to the maximum possible score.

TABLE 7.1 A Sample Vendor Rating System

Criterion for Rating	Weights	Yardstick for Measuring Performance Against Each Factor				
		Excellent-5	Very Good-4	Good-3	Average-2	Below Average-1
Quality	28	<1000 ppm	1001–5000 ppm	5001–10,000 ppm	10,001–50,000	>50,001 ppm
Delivery reliability	24	100% schedule adherence	1 day after due date	2–4 days after due date	5–7 days after due date	>7 days after due date
Price	21	Base price	up to 1% above base price	2–3% above base price	4–5% above base price	>5% above base price
Delivery terms	14	Free delivery	FOB	Only collection free	Chargeable basis	Ex-terms works, Ex-godown
Payment terms	13	60 days	45 days	30 days	10–15 days	Immediate, advance
Total	**100**					

Criterion for Rating	Weights	Vendor 1			Vendor 2		
		Performance	Rating	Factor Score	Performance	Rating	Factor Score
Quality	28	792 ppm	5	140	5400 ppm	3	84
Delivery reliability	24	1 day after due date	4	96	2–4 days after due date	3	72
Price	21	2–3 %above base price	3	63	up to 1% above base price	4	84
Delivery terms	14	FOB	4	56	FOB	4	56
Payment terms	13	45 days	4	52	60 days	5	65
Total	**100**			407			361
Vendor rating				**81%**			**72%**

Note: FOB means free on board.

In Table 7.1, five factors have been considered for vendor rating and the relative importance of these manifests as weights for the factors. In this example, quality has 28 per cent weightage and delivery reliability has 24 per cent weightage. For each factor, there is a 5-point scale used to measure the performance of the vendors. Therefore, the maximum that a vendor can get is 500 points. In the lower part of the table, the actual performance of two vendors is compared. The factor scores are arrived at on the basis of the yardstick for each factor. Each factor rating is multiplied by the factor weight to get the factor score. For example, Vendor 1 gets an excellent rating for quality. Therefore, his factor score for quality is 140 (28 × 5). The sum of all the factor scores is given towards the end of the table and the ratio of this to 500 is the final vendor rating (in percentage). From the table, we find that Vendor 1 has a higher rating (81 per cent) compared to Vendor 2 (72 per cent).

7.6 MEASURES FOR SOURCING AND SUPPLY CHAIN MANAGEMENT

The traditional purchasing method and approach was that supply management did not require any measure other than the price of procurement for an item. The management accounting system measured price variances using a standard costing system and purchasing managers were evaluated on the basis of this information. This method of measuring performance based on just the price of procurement had a serious drawback. Even when managers were getting an apparently low price for the items that they procured, in reality the actual costs of eventually owning the material was significant. Unfortunately, existing measurement systems totally ignored this aspect. Moreover, as we have seen, the current approach to supply management requires several measures other than simply assessing the price for how well the procurement process is performing. These measures pertain to the actual procurement processes and the outcomes of these processes rather than mere financial numbers. Some of the measures worth considering are listed in Table 7.2.

TABLE 7.2 Measures of Performance for Purchase and Supply Management

Purchasing and Supply Performance Perspective	Applicable Measures
Basic supplier performance	• Total cost of ownership • Percentage of on-time deliveries (delivery schedule adherence) • Improvement rate in lead time, quality, and delivery performances • Vendor rating score • Raw material inventory (in days)
Long-term partnership	• Percentage of suppliers who have entered into long-term contracts • Percentage of value of purchase under long-term contracts • Rate of shrinkage of the supplier base • Number of certified deliveries • Total man-days spent in technical assistance for supplier problem solving • Quantum of financial assistance to suppliers
Joint cost reduction	• Number and value of value engineering assignments done • Average cost reduction achieved over the previous year
New capability-building initiatives	• Number of import substitution exercises and the value of savings • Number of new-product development exercises with supplier participation • Number of ongoing and completed target costing exercises with the suppliers

Basic Measures for Supplier Performance

The basic set of measures for supplier performance includes measures of cost and performance with respect to quality, delivery, and other important parameters. Inventory investment in raw material and bought-out components is also a good indicator of the effectiveness of the procurement function. A poorly managed procurement process will invariably result in carrying raw material and bought-out components for a number of days and vice versa. Of particular interest is the total cost of ownership measure. We have already seen that focusing on price alone may be misleading as suppliers may have missed out on other important parameters. The total cost of ownership is a comprehensive measure that factors, in addition to the price, other costs incurred in eventually owning the material.[12]

> The total cost of ownership is a comprehensive measure that factors, in addition to the price, other costs incurred in eventually owning the material.

Measures for Long-term Partnerships

The second set of measures pertains to the long-term relationship-building efforts undertaken by the purchasing department in an organization. These measures give an indication of how far the organization has progressed and what tangible benefits have accrued to the organization on account of these. A good supply management initiative helps an organization identify substantial cost-reduction opportunities and make progress in this aspect. Further, it also helps the organization build certain capabilities such as faster new-product development, target cost reduction and import substitution. The last two sets of measures capture these aspects of purchasing and supply management.

ideas at Work 7.5

Total Cost of Ownership in an Auto-component Manufacturing Unit

Pressurized by the competition in the market, an auto-component manufacturer was left with no choice but to reduce the cost of its components by 10 per cent initially and by 3–5 per cent annually thereafter to match inflation and the price reduction demanded by customers. Under such conditions, organizations need better methods of understanding how costs accrue in the procurement process. *Total cost of ownership* (TCO) is a concept in which all the costs associated with purchasing are included in addition to the purchase price. The manufacturer decided to estimate the TCO for a selected set of components that contributed to a considerable amount of the total spend.

For the purpose of computing the TCO, costs incurred were categorized into three groups: purchase costs; internal company costs; and joint supplier, company, and customer costs. The *purchase cost* is the price of the component as mentioned in the purchase order. *Internal company costs* include inventory-carrying costs, cost of incoming inspection, personnel and instrumentation costs, internal transportation cost, and cost of quality. On the other hand, *joint supplier, company, and customer costs* include the costs of order processing, monitoring, follow-up, R&D expenses, process improvements, transportation, handling, and joint inventory holding.

The results of the TCO computations for three major components are shown in Table 7.3.

The analysis in Table 7.3 clearly shows the areas in which the manufacturer can attempt cost reduction. Joint supplier, company, and customer costs was one major category that provided scope for cost reduction. On the basis of this information, specific areas for cost-cutting were identified. These included the following:

TABLE 7.3 Results of the TCO Computations

	Cost as a Percentage of TCO		
TCO Category	**Inserts**	**Bleed Screws**	**Adjuster Sleeves**
Purchase cost	77.0	79.4	88.7
Joint supplier, company, and customer costs	16.0	14.0	9.0
Internal company costs	0.6	1.1	0.5
Freight cost	6.4	5.5	1.8

- Involving suppliers in R&D efforts, reducing/ sharing of R&D costs, reducing processing costs, and co-developing proprietary materials
- Minimizing supplier costs by sharing long-term volume forecasts and jointly evaluating vendor capital expenditure plans

Based on further analysis and corrective decisions identified in the study, the company hoped to reduce the supply base from 68 to 10. The potential savings identified out of the proposals made was to the tune of ₹6.898 million.

Source: P. B. Suriyanarayanan and K. Sivakumar, "Supplier Management Strategies for Enhancing Manufacturing Competence," unpublished MPT project report submitted at IIM Bangalore.

7.7 THE MAKE-OR-BUY DECISION

One of the frequently encountered issues in purchasing is the "make-or-buy" decision. In the early period of the twentieth century, several firms were making all components in-house. The Ford Motor Company was extracting iron ore at its own plant and fabricating all the components required for assembling a passenger car all by itself. On the other hand, by 1980, Toyota was buying over three-fourths of its requirement from suppliers and was focusing only on assembling the components and integrating various sub-systems to produce a defect-free passenger car. Clearly, every item that an organization requires in its manufacturing or service set-up could be made either in-house or bought from a supplier. Therefore, the issue to resolve is what to make in-house and what to buy from an external source.

In recent years, we are seeing a greater trend towards buying from external vendors and focusing on certain core activities in-house. Several service businesses such as catering, event management, software maintenance, maintenance of machine tools, billing and collection, computer facilities management, fleet management, recruitment, front-office functions, and several aspects of customer relationship management have all been shifted from in-house to a third-party vendor. The growth of business process outsourcing (BPO) has been extremely rapid over the last few years. Companies across the world are not only outsourcing some of their peripheral and support business processes, but are also seriously looking at outsourcing possibilities across the entire value chain. As of 2012, the Indian IT outsourcing industry employed around 2.8 million people. Annual revenues were around USD 11 billion. The global outsourcing market has grown from USD 111 billion in 2002 to USD 234 billion in 2005 and USD 310 billion by 2008.[13]

> In recent years, we have seen a greater trend towards more and more buying from external vendors and focusing on certain core activities in-house.

The recent spurt in BPO signals the tendency of organizations (cutting across different sectors of industries and services) to buy rather than make their requirements in-house. In such a scenario, the importance of supply management further increases as suppliers' performance is likely to have an even greater impact on delivery and quality commitments made by an organization to its customers. The trend towards outsourcing in several organizations is driven primarily by four factors: *cost*, *core versus non-core activities*, *management of capacity expansion*, and *strategic restructuring*.

> The trend towards outsourcing in several organizations is driven primarily by four factors: *cost, core versus non-core activities*, *management of capacity expansion*, and *strategic restructuring*.

Cost

The primary reason for outsourcing is that the cost of the product or service is much less if procured from a third party. Several reasons are attributed to this. Some of them include the benefits of large capacity investments made by the third party, the low volume of in-house activity, and the need for continuous upgradation of the technology and process behind these activities to obtain cost and productivity benefits. Consider the transportation of finished goods to the market situated all over India. If an organization such as Voltas invested in its own fleet of trucks to transport its air conditioners and refrigerators, it would suffer from all the drawbacks that we identified. On the other hand, a trucking company will be ready to constantly invest in new technology and improved processes. It will also have justifiable volume of business to spread its cost over a wider set of activities. Another example is the emergence of software as a service (SaaS) and cloud based software services.

Core Versus Non-core Activities

In the Voltas example, even if there is sufficient volume for the company to maintain its own fleet of trucks, it may still not be interested in doing so. This is simply because it is not prudent to develop know-how and spend a considerable amount of managerial time in developing talents related to fleet maintenance. If the same effort is exerted on understanding newer technologies and skills related to heating and cooling applications, it will be much more beneficial. Therefore, another strong driver of outsourcing is the existence of non-core activities in every organization. By definition, a core activity is one that is critical to the product or service offered, that has the know-how for creating a competitive advantage, and is required to be kept out of reach of the competition. Such activities typically require specific investments in technology, production processes, skills, and knowledge.

Therefore, every non-core activity will be a potential candidate for a “buy” rather than a “make” decision. One can expect that a non-core activity can be better done by some other organization for which it forms the core. Therefore, there will be cost advantages to the firm choosing to buy it from another organization for which the activity is core. In the previous example, a fleet service provider such as Southern Roadways Limited will be better equipped to optimize its fleet management practices than Voltas engaging in a similar activity. Therefore, there is not only the benefit of offloading a non-core activity, but also cost benefits to Voltas.

Management of Capacity Expansion

During times of rapid capacity expansion, organizations try to avoid investing in non-core activities. Therefore, such opportunities are best utilized for shifting some of the in-house facilities to an outside vendor and making use of the released resources for capacity expansion in core activities. Several distribution-intensive companies, such as those operating in the FMCG sector, are likely to engage a third party logistics (3PL) provider for warehousing and transportation rather than going for leasing and building of new facilities during periods of rapid expansion.

Strategic Restructuring

Even when many of the opportunities do not exist for an organization, sometimes “make-or-buy” decisions are taken as a part of a strategic restructuring exercise. During such an exercise, the top management may contemplate some future expansions and market penetration strategies and in response to these it may take a fresh look at the nature of activities to be performed. Core and non-core activities are identified and plans drawn for outsourcing.

7.8 E-PROCUREMENT[14]

Local sourcing was a standard sourcing strategy for many years because the transaction costs of sourcing across long distances were high. Furthermore, potential suppliers were seldom known and contract enforcement was a problem. Transporting goods was costly and highly risky as well-developed global logistics and supply networks did not exist. With the advent of modern communications technologies and globally integrated markets as well as efficient transportation services, global sourcing is now a reality. Multinational companies in particular are using global sourcing strategies to overcome specific local factor shortages in their home countries and to benefit from the availability of specialized skills elsewhere. They also benefit from factor cost advantages.

All these have led to a new dimension in procurement—*e-procurement*. The growth of electronic markets has dwarfed historical growth patterns of other sectors of the industry. Over the years, several market mechanisms have sprung up in the electronic marketplace to tap new value creation opportunities. Free markets introduced the idea of conducting reverse auctions using the electronic media during 1995. Similarly, the big three auto players in the United States (GM, Ford, and Chrysler) created COVISINT, a consortia-based market structure, in February 2000. Many others such as Oracle, i2, SAP and Ariba developed a variety of supply chain collaboration tools. It is evident that there are several types of markets structures operating in the B2B electronic market domain. Each B2B site typically operates multiple market structures. The market structures fall under three distinctive categories: *collaborative mechanisms*, *quasi-market mechanisms*, and *neutral market mechanisms*.

> B2B market structures fall under three distinctive categories: *collaborative mechanisms*, *quasi-market mechanisms* and *neutral market mechanisms*.

VIDEO INSIGHTS 7.2

Agro-supply chains need a major transformation in order to unlock the inefficiencies in the supply chain. ITC’s e-Choupal is an arrangement that provides Internet access to the farmers. Using this infrastructure, farmers can access information for better methods of farming and can discover the prevailing prices for their produce. To know more about ITC e-Choupal, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Collaborative Market Mechanisms

Collaborative mechanisms consist of market structures that fundamentally enable market participants to gainfully exploit electronic integration. This includes Extranet, trading partner network (TPN) and Web-based electronic data interchange (Web EDI).

> **Collaborative mechanisms** eliminate duplication of resources, cut costs, and improve the responsiveness of the supply chain.

Quasi-market Mechanisms

In the second set of market structures, one or a small group of either the buyers or the sellers will initiate the marketplace, host, and monitor, enrol market participants, and moderate the market behaviour if required. In a buyer-centric marketplace, buyers take the initiative to host the market and appropriate greater benefits than other market participants, just as the suppliers do in a supplier-centric market. Two well-known variations of seller- and buyer-centric marketplaces are forward and reverse auction sites, respectively. In the case of a forward auction a seller auctions an item and several buyers will bid for the item. On the contrary, in a reverse auction, several sellers bid to win a procurement contract from a buyer. A host of industrial procurement contracts fall under reverse auctions.

> In a quasi-market mechanism, the market structures have an inherent bias towards one of the market participants, namely, the buyer or the supplier.

On the other hand, a few buyers or a few suppliers belonging to a sector of an industry could create a consortium marketplace. Examples include www.covisint.com (automobiles) and www.metaljunction.com (steel industry).

Neutral Market Mechanisms

The third set of market structures includes exchanges, catalogue aggregators, and an online community. Potentially, a large number of buyers and suppliers participate in these market structures. Therefore, these markets are characterized by neutrality.

E-procurement denotes the set of strategies that a purchase manager could employ to identify appropriate sources of supply, finalize the terms of the trade, and place the order (all electronically) with the help of any of the market structures identified earlier. E-procurement offers several unique advantages that were unavailable in a traditional purchasing scenario. These include dramatically increased reach and a substantial reduction in transaction costs. A registered member of alibaba.com gains access to a vast database of trade leads of companies pertaining to thousands of products worldwide as soon as he/ she logs into its homepage. The extensive reach attainable through electronic markets provides value to organizations in new ways. Fragmentation of the supply chain is no longer an issue in electronic markets. Buyers will be able to globally locate new and cost-effective sources of supply and reduce their input costs. On the other hand, suppliers will be able to compete on a level playing field for business with global customers, who previously may have been unreachable.

> **E-procurement** denotes the set of strategies that a purchase manager could employ to identify appropriate sources of supply, finalize the terms of the trade and place the order, all electronically.

Every organization engaged in procurement incurs transaction costs in several forms, including the cost of discovering products and prices, the cost of negotiating and concluding contracts and costs of monitoring and safeguarding the agreements entered into through contracts. These costs are far in excess in the case of paper-based and semi-automated transaction processing environments. In such traditional markets, organizations also incur heavy costs in tightly integrating with their supply chain partners. B2B sites help organizations cut these costs. Using the Web infrastructure, an organization can seamlessly integrate with its supply chain partners and exchange complex technical drawings, sensitive business documents, voluminous transaction data, and even cash in real time. Approvals for purchases and other complex business processes can be efficiently managed using software addressing workflow and business process management issues. Coordinated production planning and control among the supply chain partners will enable better demand management. Moreover, unwanted inventory will not be shipped across the supply chain.

> While e-procurement offers several new advantages, it also requires that organizations draw a blueprint on how they will derive value by exploiting e-procurement opportunities.

While e-procurement offers several new advantages, it also requires that organizations draw a blueprint of how they will derive value by exploiting the e-procurement opportunities thrown open by the various electronic market structures. For certain products and services, purchase managers will endeavour to build tighter integration through electronic market structures. For instance, key suppliers and dealers will be encouraged to participate in a TPN. Enlisting trading partners in the TPN will be a challenging task. Managers need to build incentives for participation in such markets. These may include sharing vital commercial and technical information, primarily through the network, sharing cost benefits accruing out of reduced transaction costs, and hosting private auctions of excess and obsolete items in such marketplaces even before tapping other traditional channels.

> E-procurement necessitates restructuring of the logistics and supply chain network of an organization.

In certain other cases, purchase managers will discover more value in engaging existing trading partners with whom they developed close relationships in more competitive mechanisms. For instance, a supplier of custom components with low or transferable tooling may be asked to participate in a reverse auction, where they will compete with a handful of other suppliers carefully pre-selected through a robust RFQ process. In yet another class of items, managers will see immediate value arising out of sourcing from competitive neutral markets. Some suppliers may be replaced with more competitive sourcing decisions involving neutral electronic markets. Electronic markets may also cause dis-intermediation of some traditional channels. For instance, neutral auction sites may replace channels for the disposal of second-hand capital goods, and surplus inventory. New opportunities will emerge in recasting the distribution network in several industries. Resellers may be eliminated and the role of distributors and other channel partners will be redefined.

Managers will find it necessary to look at procurement practices afresh. Restructuring the logistics and supply chain network of an organization will become inevitable. However, launching several pilot projects to tap these alternative market structures in the mid-term of about two years will be a valuable step in reconfiguring their value chain.

SUMMARY

- Important developments in operations management in the recent past have redefined the role of sourcing and supply management in organizations. These include new quality management initiatives, changing nature of cost structures, creating lean organizations, and quick-response requirements.
- A typical procurement process consists of six steps: (i) *need identification*, (ii) *vendor selection*, (iii) *order placement*, (iv) *order receipt*, (v) *order acceptance*, and (vi) *vendor rating*.
- Traditionally, organizations utilized a *multiple-sourcing model* for vendor selection. However, in recent times, organizations employ a *single-sourcing model*. The single-sourcing model provides several advantages over the traditional model.
- Supplier certification and vendor rating are important components of modern day supplier development and management initiatives.
- The "make-or-buy" decision is made on the basis of the criticality of the item under consideration, cost, capacity issues, and strategic restructuring initiatives in an organization.
- *E-procurement* offers several advantages to an organization such as reduced cost and lead time. However, it requires that organizations develop a new blueprint for dealing with the existing suppliers as well as the new suppliers likely to be discovered though the electronic markets.

REVIEW QUESTIONS

1. Why has sourcing and supply management assumed importance in today's organizations?
2. How is procurement lead time determined? What factors contribute to the procurement lead time in an organization?
3. An organization has high investment in inventory. Although it is not clear what factors contribute to this, the organization would like to know if the procurement lead time has any impact on inventory. Assume that you have been asked to conduct a study on this issue, and prepare a one-page proposal for the organization, detailing the various aspects that your study would cover.
4. What are the key differences between the traditional and contemporary approaches to supply management?
5. What benefits accrue to an organization through the single-sourcing model?
6. What are the steps involved in a supplier development programme?
7. What is a supplier certification programme? Why is it required?
8. Identify some measures of performance for the purchasing and supply management function. How would an organization benefit in the long run by performing better on these measures?
9. What do you mean by "make or buy"? Can you give some examples for how organizations utilize this concept?
10. How is business process outsourcing related to purchasing and supply management practices?
11. What do you understand by the term e-procurement? Identify three reasons for an organization to opt for e-procurement.

CASE STUDY

Bharat Controls Limited Mysore

Bharat Controls Limited Mysore (BCLM) was set up in 1981 to manufacture process control instrumentation. BCLM manufactures instruments that process industries use for remote control. From 1997, BCLM has been experiencing pile-up of inventory as well as high levels of non-moving inventory. By 2004, it was estimated that non-moving inventory could be around ₹7 million. Considering a total inventory of about ₹32 million, the non-moving stock represents a sizeable chunk of over 20 per cent.

BCLM operates in an environment characteristic to high-tech and electronics industries. The product life cycles continue to shrink as the rate of obsolescence increases due to rapid technological growth. A classic example is the evolution from analog instruments to discrete instruments and intelligent automation systems. Technology grows in the area of distributed control systems even for smaller scales of operation. While it is generally recognized that these factors have been responsible for the pile-up of non-moving inventory, it still calls for means for addressing this important issue. Although it is unrealistic to imagine a situation of zero non-moving stock, it is nevertheless possible to bring the rate at which non-moving inventory piles up well under controllable limits. This called for close scrutiny of certain systems and procedures. A detailed study of the existing non-moving inventory was carried out to understand the causes for the build-up.

Analysis of the Non-moving Items

The analysis of the non-moving items and the reasons for it were carried out using three different approaches. Firstly, the database of non-moving items was used for further analysis. The analysis included classifying them under various heads and ascertaining the quantum of stock that could be associated with various end products and sources. The second approach was to hold discussions with executives belonging to various functional areas such as marketing, planning, and materials and seek their opinion with respect to the buildup of inventory in the past and specific reasons and events responsible for this. Finally, the quantitative analysis and the discussions were mutually validated and some broad factors responsible for the build-up identified.

BCLM has classified items under non-moving items based on whether an item under consideration finds place in any of the bill-of-material (BOM) codes developed as on 1 July 1994. Stores 00 (items consumed for local sales) and Stores 03 (items consumed for export sales) were taken up for consideration. Table 7.4 gives the overall position of the non-moving inventory.

The average value of closing stock of raw materials for the period April 2003 to March 2004 was ₹29.194 million. Thus non-moving inventory represents nearly one-fourth of the total investments in raw material inventory (25.06%, Table 7.5). This is a considerably higher figure. The total non-moving inventory has been classified source-wise and compared with the average closing stock of the respective source. The results have been presented in Table 7.5. As it could be seen from the table, the FXB non-moving stock contributes to nearly 31.67 per cent of the average closing stock. The similar figures for the other two sources are 32.11 per cent and 9.28 per cent.

Stores 00 contribute to the bulk of the non-moving items (₹6.938 million). 287 items constitute nearly ₹5 million of non-moving inventory. The non-moving items lying in Stores 00 was further split and classified into product groups and the source of procurement. Table 7.6 has the details on the non-moving inventory with value of the stock more than ₹5000 in Stores 00. Some of the salient points are:

- 120 items belonging to SPEC200 family contribute to ₹2.317 million (46.40% of the total).
- 19 items belonging to BMOS (old/LCMS) amount to ₹493,000 (9.88% of the total).

TABLE 7.4 Details of Non-moving Items (Overall) as on 1 July 2004

Location and Stock value of Items	Number of Items	Value of the Items
Stores 00		
Stock value > ₹5,000	287	`4,994,047
Stock value < ₹5,000	1,235	₹1,943,833
Sub-total	1,522	₹6,937,880
Stores 03	82	₹378,242
Total	**1,604**	**₹7,316,122**

TABLE 7.5 Ratio of Non-Moving Stock to Average Closing Stock of the Respective Sources

Location and Stock Value of Items	FXB (₹)	Local (₹)	Non-FXB (₹)*	Total (₹)
Stores 00, stock value more than ₹5,000	3,283,370	1,048,182	662,695	4,994,047
Stores 00, stock value less than ₹5,000	1,048.411	840,918	54,504	1,943,833
Stores 03	173,852	109,982	94,408	378,242
Total	4,505,633	1,999,082	811,407	7,316,122
Average closing stock (April 2003 to March 2004)	14,229,000	6,226,000	8,739,000	29,194,000
Ratio of non-moving to average closing stock	31.67%	32.11%	9.28%	25.06%

Note: *The non-FXB column includes all imported items other than FXB.

TABLE 7.6 Classification of Non-moving Items (Stock Value > ₹5,000) in Stores 00

Sl. No.	Product Family	Number of Items	Value (₹)	Value (% of Total)
1	SPEC200	120	2,317,158	46.40
2	BMOS (OLD/LCMS)	19	493,226	9.88
3	760 (Obsolete, 4300, BMOS, etc.)	26	375,536	7.52
4	Panel	18	373,057	7.47
5	Plasma display	1	152,902	3.06
6	99UC	1	115,328	2.31
7	E2OS	11	113,441	2.27
8	E93/94	8	106,555	2.14
9	Others	35	371,623	7.43
10	Unidentified	48	575,221	11.52
	Total	**287**	**4,994,047**	**100.00**
Source-wise classification				
1	FXB	182	3,283,370	65.75
2	Local	92	1,048,182	20.99
3	Non-FXB	13	662,495	13.26
	Total	**287**	**4,994,047**	**100.00**

Since FXB components form the bulk of the purchase, they also contribute to a large percentage in the non-moving category. However, in the case of low-value items, i.e., items with stock value less than ₹5,000, the local items also form a larger proportion of the non-moving stock. In spite of being an imported category, in both the cases, the non-FXB components (source code K) do not contribute substantially to the non-moving stock. This phenomenon perhaps suggests that more attention need to be given to the nature of interaction with FXB.

Similar analysis has been carried out with respect to Stores 03. The product-wise and the source-wise classification of the inventory point to more or less the same situation as it exists for Stores 00. The FXB components contribute to about 46 per cent of the total non-moving inventory in Stores 03. The details are available in Table 7.7.

TABLE 7.7 Classification of Non-moving Items in Stores 03

Sl. No.	Product Family	No. of Items	Value of Items (₹)	Value (% of Total)
1	760 (Export)	28	212,847	
2	7500	1	76,412	
3	8000	1	22,600	
4	SPEC200	6	19,764	
5	Others	46	46,619	
	Total	**82**	**378,242**	
Source-wise classification				
1	FXB	34	173,852	45.96
2	Local	44	109,982	29.08
3	Non-FXB	4	94,408	24.96
	Total	**82**	**378,242**	**100.00**

Reasons for Non-Moving Inventory Build-Up

The analysis presented in the previous pages clearly shows certain patterns with respect to the build-up of non-moving inventory. When product-wise classification is done, it is obvious that excessive amount of inventory has piled up in only a few product families such as BMOS, SPEC200, display units and 760. In fact, these product families may probably cover up to 60–65 per cent of the total non-moving inventory. When the non-moving items are grouped source-wise, it is again clear that while FXB items contribute to a majority. Surprisingly, the local items also contribute to a large proportion of non-moving items in stock. These aspects call for further study with respect to the reasons. Some of the possible reasons could be:

TABLE 7.8 A list of Products Withdrawn by BCLM in the Recent Past

Sl. No.	Product Name	Year of Withdrawal	Remarks
1	BMOS	2001	BCLM product, product failure
2	Dual plasma indicator	2002	BCLM product, product failure
3	872, 874 monitors	Around 2003	FXB product; FXB withdrew it
4	FXB flow computer	Around 2003	BCLM flow computer introduced in lieu of FXB flow computer
5	Analytical instruments	2001	Sales down due to liberalization; customers directly approach FXB

- Relatively lesser lead times of procurement for the nonFXB imported items
- Ability to order variable (and sometimes smaller quantities) with non-FXB suppliers
- Better interaction and coordination possible with nonFXB suppliers
- Poor planning of procurement leading to excess ordering of all items and especially the indigenous items
- Restrictions on minimum order quantity

- Poor relationships with the local vendors leading to inability to reap the advantages that may accumulate due to relatively short lead times of procurement
- Sudden withdrawal of orders, sometimes, by the customers, leading to accumulation of non-moving inventory
- Changes in technology and product obsolescence. The instruments manufactured/assembled and sold by BCLM were initially analog. However, the changes in technology resulted in digital and Intelligent Automation (IA) systems. Such changes in technology have always resulted in pile-up of non-moving inventory.
- Wrong forecasting. Another source for non-moving inventory, according to a few executives, has been the overly optimistic assumptions about the product performance leading to gross overestimation of the demand. However, when the product failed to meet the expectations, the inventory piled up. The examples of the product BMOS seem to substantiate this phenomenon. At the time of introduction, it was felt that BMOS was a premium product. Initially, 25 units were supplied to the customers and orders were placed to manufacture/assemble about 300 sets. However, the high price and the inferior design of BMOS could not substitute the standard, universally known, low-priced and easy-to-sell FXB 760 models. It appears, in this case, that very little feedback has been obtained from the marketing and branch offices. Knowledge of these factors would have helped in avoiding the build-up of non-moving inventory.
- Product failure in the market. When new products were introduced, the performance of some of the components has not been satisfactory, leading to customer dissatisfaction. Changes made in such products have also contributed to pile-up of non-moving inventory of older designs and versions. The example of BMOS fits into this category. Similarly, when the plasma indicators were introduced, the customer feedback pointed out to the reliability problems. Hence, it was decided to changeover to fluorescent display in 2002–03. Such sudden changeover resulted in a non-moving inventory of about 100 sets. Currently, it is estimated that about 49 displays and about 60–65 kits may be in stock.
- Withdrawal of products either by BCLM or FXB. BCLM has been regularly withdrawing various product groups for several reasons. Some of them, such as change in technology and product failure in the market, have already been mentioned. In addition, BCLM withdraws products because FXB withdraws them from their product line. Withdrawal of products is not unusual to many manufacturing organizations. The frequency of withdrawals in industries such as BCLM may be high. Under such conditions, it is important to develop certain systems and procedures with respect to withdrawal of the products. At the time of the study, enough evidence of such systems and procedures was not found. For example, it was given to understand that FXB announces its withdrawal plans about six months in advance. At BCLM, information on such announcements and the action taken on these was not available. Table 7.8 has a list of products withdrawn by BCLM in the recent past.

The observations made by various executives during the discussions indeed confirmed the analysis and conclusions drawn based on the database of non-moving items. In addition, a few significant observations were made with respect to the build-up of non-moving inventory. All these point to the fact that a few areas need to be strengthened in order to prevent the build-up of non-moving inventory.

QUESTIONS FOR DISCUSSION

1. Make a salient list of observations of the non-moving inventory problem that BCLM is facing.
2. Can you identify three potential causes of this problem? Are these specific to the nature of the product that BCLM is manufacturing?
3. What are your recommendations to BCLM to prevent recurrence of the non-moving inventory problem in the future? Do you have any suggestions for addressing the problem immediately?
4. Can you suggest new ideas and methods in sourcing, procurement, and supply management to help BCLM tide over the non-moving inventory problem?

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Part III

Designing Operations

CHAPTER 8

Process and Capacity Analysis

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What do you understand by the terms “process” and “process analysis”?
- What is the relevance of measures such as throughput time, cycle time and bottleneck? How is process analysis done?
- How is capacity defined and measured in organizations?
- How does the capacity planning framework change with respect to the planning time horizon?
- What are the steps involved in a capacity planning exercise?
- What are the alternatives available for augmenting capacity in an organization?
- How can one use decision tree modelling for studying the capacity planning problem?

Process mapping is a tool to understand the various steps involved in a business process. Data about the process can be collected through brainstorming among the various players connected to the process. Employees working in an area of the process discuss and develop a representation of the actual process on the basis of their working knowledge.

Source: stock.xchng

ideas at Work 8.1

Capacity Expansion Plans at Indian Oil Corporation Limited (IOCL)

Indian Oil Corporation Limited (IOCL) is planning to expand the capacity of its largest refinery at Panipat to 21 million tonnes. Currently, it has a capacity to turn 15 million tonnes of crude oil per annum into refined petroleum products or fuel. The approximate estimate for the investment in additional capacity is about USD 1 billion. The expansion may be accompanied by raising the capacity of the adjacent petrochemical complex. IOCL is also exploring the possibility of expanding the capacity at its Koyali refinery in Gujarat from 13.7 million tonnes to 18 million tonnes at a cost of about ₹55 billion.

Normally, capacity expansion plans are strategic in nature and require an understanding of the emerging demand for the item for which capacity expansion is being contemplated. In the case of petroleum sector, India’s refining capacity will rise to about 333 million tonnes by the end of 2022, from 215 million tonnes at present. With grass-root refineries at Paradip (15 million tonnes) and Nagarjuna Oil Corp’s Cuddalore unit (6 million tonnes), and expansion of some of the existing refineries, the total refining capacity is expected to touch around 271.2 million tonnes by the end 2017. Furthermore, it is expected to go up to 332.9 million tonnes by 2022 according to Mr. Moily, the then Union Minister for Petroleum and Natural Gas.

Capacity expansion plans in process industries require further understanding of the demand for various products that are produced from the main raw material. For example, naphtha cracker can process and extract more than 200 products. Therefore, demand projections for these are integral part of capacity expansion planning. As part of integrating petrochemical value chain and enhancing value from the naphtha cracker at Panipat, Styrene Butadiene Rubber (SBR) project envisages the production of SBR from the Butadiene feedstock available from the naphtha cracker. The project is being executed as a joint venture—Indian Synthetic Rubber Ltd (ISRL)—between IOCL, Marubeni of Japan, and Taiwan Synthetic Rubber Corporation. Synthetic rubber consumption has increased due to rapid industrialization of the Indian economy. The tyre sector is the largest end-use sector for synthetic rubber in India. SBR, which accounts for 40 per cent of the total synthetic rubber demand, is consumed mostly in the tyre sector. As tyre production in India is increasing at a fast pace, the synthetic rubber consumption has also gone up simultaneously.

As evident from this example, capacity planning exercise requires medium to long-term orientation, identification of several alternatives for capacity expansion, and cost implications of these. In addition, capacity expansion exercises involve typically huge cost outlay and it calls for careful estimation of demand, revenue, and so on. It also calls for a structured approach to understand how capacity is estimated and to understand some planning methodologies, tools, and techniques. We shall see some of them in this chapter.

Source: IOC mulls to expand its Panipat refinery capacity, The Hindu, November 29, 2013, http://www.thehindu.com/business/Industry/ioc-mulls-to-expand-itspanipat-refinery-capacity/article5405167.ece

One of the important decision points of an operations system concerns the capacity to be deployed in the system. We often hear about excessive delays and waiting time in service systems such as a teller counter in a bank. Similarly, we hear that some factories work with near-100 per cent utilization of their resources. All these pertain to certain decisions taken with respect to the nature and amount of capacity that an operating unit builds into the system and the manner in which the existing capacity is put to use. Improper choice in the amount of capacity deployed and poor planning of the existing capacity will lead to loss of productivity and overall reduction in the profitability of the operating system. Therefore, a set of tools and techniques are required to address these issues. In this chapter, we shall look at various issues related to capacity planning. The basic building block of capacity analysis is process analysis. After all, the process design determines the capacity of a system. Therefore, we shall begin with an understanding of processes before we address the issue of capacity planning.

8.1 PROCESS AS A UNIT OF MEASUREMENT IN OPERATIONS

Understanding any operations systems invariably begins with an understanding of the processes that are integral to the operations system. A process is the basic building block of operations. It consists of a set of activities that need to be performed by consuming some resources and time. This eventually determines the performance of the operations systems in terms of cost, time, productivity, profit, etc. A few examples will help us understand this better.

Consider a fast-food joint such as Hotel Saravana Bhavan in Chennai. When the customer goes to the counter and places an order for the food items he or she would like to eat, the outcome is determined by the process employed to satisfy this customer demand. The steps involved in serving the demand, the number of people involved, the nature of resources consumed and the time taken to serve this customer will all depend on the process design. The process design will in turn determine aspects such as the time taken to serve the customer, the cost involved, the productivity of the people and the utilization of the resources. These are the performance characteristics of the process in question. Viewed from this perspective, the performance of the processes finally dictates the performance of an operations system itself.

Consider an automobile garage that deals with all aspects of the repair of wheels and tyres (such as wheel alignment, wheel balancing, tyre and tube replacements, and repairing of punctured tires). Here, too, one will encounter a set of issues similar to those at Saravana Bhavan. The design of the process will determine the performance of the automobile garage. Once can extend this logic to larger manufacturing and service systems.

An operations manager may want to understand some of the following issues in the process design:

- Do I have adequate resources to meet the demand? If I need to add some extra resources, where should I add them?
- What is the extent of the utilization of my resources?
- If I need to increase the capacity of my system, how should I modify the process? Should I add some more resources? What will happen to the cost of my operations?

One can find the answers to these questions through process analysis. By process analysis, we refer to the use of some analytical mechanisms to understand the impact of the process design on output, cost, or any other performance metric. It also amounts to understanding the impact of alternative process configurations on the chosen performance metric.

8.2 PROCESS FLOW-CHARTING

The design of a process is a matter of detail. Every activity that constitutes a process must be identified. It is also important to know the time taken for each activity and the nature of flow of materials/information in the process. A pictorial representation of all this information could be developed using process flow-charting. Process flow-charting employs a set of standard symbols and graphical tools to represent all the information about the process. The symbols used are as follows:

□ A step in the process

→ Transportation (movement)

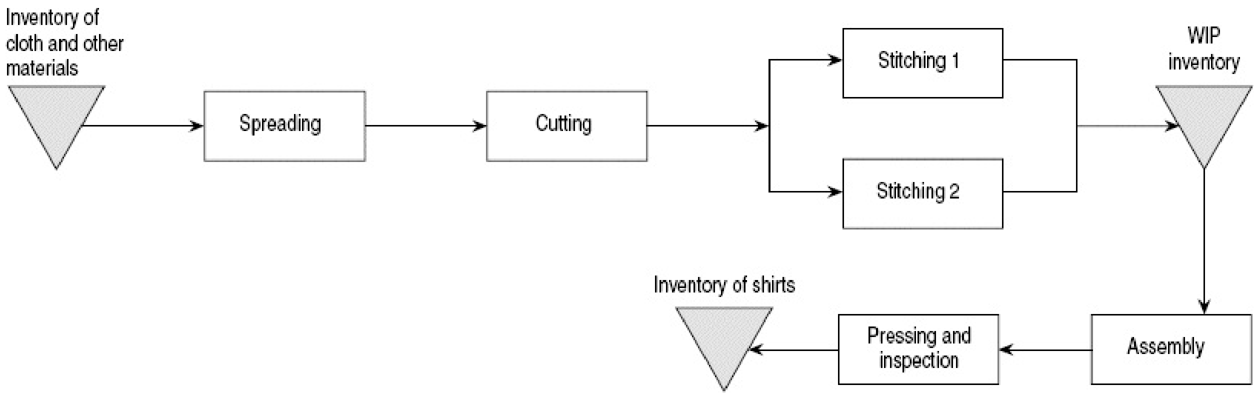
▽ Storage or inventory

Figure 8.1 is a simplified representation of a process flow chart for shirt manufacturing, which consists of five steps in the shirt-manufacturing process and three storage points. The store stocks raw cloth and other materials such as zippers, buttons, and thread. The cloth is moved to the first stage of processing where it is systematically spread out and relevant markings are made. After this, it is sent for cutting. Once the cutting operation is complete, various individual pieces that make up one shirt when put together are segregated into two bundles. One bundle goes to the first stitching operation while the other bundle goes to the second stitching operation. After the stitching is complete, they are temporarily stored. The assembly process consists of matching the pieces and finally attaching them into a completed shirt. After this, the shirt is inspected, pressed, packed, and sent to the stores for final dispatch.

A process flow chart helps an operations manager in many ways. Some of these are as follows:

a. It provides a pictorial and compact representation of the process and enables a quicker and better understanding of the various aspects of the process.
b. By superimposing additional information such as the time taken for each stage of the process, certain useful measures can be computed. For instance, one may be able to estimate the time required to complete the process. Using this information, one can also identify the bottlenecks in the process and the productive capacity of the process. Furthermore, one can also assess the amount of resources that need to be deployed at each stage in order to meet the projected requirements.

FIGURE 8.1 A simplified process flow chart for shirt manufacturing



These aspects are what constitute process analysis. We shall see in some detail how this process analysis is carried out.

8.3 PLANNING PREMISES AND PROCESS IMPLICATIONS

Process and capacity analysis has a closer relationship to the planning premise that the system uses. For example, for a turnkey manufacturer such as Bharat Heavy Electricals Limited (BHEL) or ABB, a question such as “how many power plants can I erect in a planning horizon of, say, a week or a month?” is not relevant. On the other hand, for a volume manufacturer such as Kinetic Motors, such a question will be of great relevance. Therefore, before embarking on an exercise of process analysis, we need to have some understanding of the type of planning premise that an operations system is utilizing. Three generic planning premises are in use in operations management: make to stock, make to order, and assemble to order.

Make to Stock (MTS)

As the name implies, the basic approach to planning in the MTS system is to schedule production for the purpose of replenishing stocks to some predetermined level. Typically, in production planning, the starting point of the exercise is the demand for the product during the planning period. Based on the estimate of the demand and the available inventory of finished goods on hand, the exact production quantity for the planning period is arrived at. In an MTS scenario, the forecasting exercise and the production planning exercise are decoupled by way of having a stock of finished goods. As a result of this decoupling exercise, those in production planning are not required to know what the exact demand is. All that is required is to ensure is that actual production replenishes the stock to desired levels. As and when demand materializes for the product, the demand is met from the stockpile of finished goods. The objective of MTS planning systems is to ensure that the production system efficiently responds to the depletion of finished goods inventory through the planning system.

Three generic planning premises are in use in operations management:

- Make to stock
- Assemble to order
- Make to order

From our description of the MTS planning methodology, it is clear that such systems are more amenable to organizations with fewer product varieties and high production volume, as in the case of continuous and streamlined flow systems. In such a situation, the demand is likely to be continuous and substantial, so that production can proceed on the basis of a few assumptions about the nature of the demand. In the case of demand being higher or lower than what was estimated for a particular period, the stockpile of finished goods will absorb the fluctuations, and organizations do not run the risk of carrying excess inventory for a long time.

From a process and capacity analysis perspective, MTS is suitable for mass production systems. Therefore, the relevant questions for process and capacity analysis are:

a. What is the productive capacity of my process per shift or per day?
b. Where is the bottleneck for this process? If I need to increase the capacity of the process, at which stage of the process should I invest in capacity expansion?
c. Can I improve the productive capacity by means other than investing in new resources?

> Another method of planning for MTS is using “takt time” for scheduling products at various stages in the production system.

Traditionally, organizations use a variety of production planning and control tools for MTS systems. These systems compute the materials and capacities required for production and schedule various operations in the manufacturing system to produce as per plan. One of the recent approaches in implementing an MTS-based planning system is to use a pull-based scheduling system. Another method of planning for MTS is using “takt time” for scheduling products at various stages in the production system. We shall discuss these in detail in Chapters 13 and 18, under just-in-time (JIT) manufacturing and scheduling of operations.

Make to Order (MTO)

At the other end of the planning spectrum is planning and scheduling production only against specific production orders. In this approach, no efforts are directed towards production until a firm customer order is available. Once a customer order is launched into the production system, the requirement details are computed and production is planned. The key implication of this method is that it results in a long planning and execution window for order delivery. A long planning and execution window results in greater manufacturing lead time and the associated problems of large inventory investment and greater uncertainty of operations and outcomes.

Despite these limitations, it may be necessary for certain types of organizations to use the MTO planning methodology. These organizations are typically manufacturers of products with high variety and low volumes. It is evident that an MTS planning framework is infeasible for such organizations as it may result in carrying a very large amount of inventory. The inventory may also face the risk of becoming outdated over time, as customer specifications may be different from what is being carried as finished goods. The problems faced in the MTO planning methodology are not so much related to the difficulty of estimating what is required to fulfil an order. However, the long lead time of the entire operation introduces complexity on account of uncertainty. Therefore, from a process and capacity analysis perspective, a pertinent question to ask may be, “When will this order be executed?”

Assemble to Order (ATO)

When variety is not very high, as in the case of a jumbled flow process, it is possible to work with a planning methodology that is intermediate to MTS and MTO. This approach to planning is known as assemble to order (ATO). The ATO planning framework incorporates some of the features of MTS into the MTO planning methodology to create a hybrid version. In this approach, the system utilizes MTS for the early stages of the manufacturing process. At the later and final stages of the manufacturing system, the planning changes to that of MTO. The basic assumption behind ATO is that while at the component and sub-assembly level there is a high degree of commonality, related variety problems manifest only at the final assembly stage. Therefore, MTO can be postponed up to the point of product differentiation. If there is a high degree of commonality in the parts and sub-assembly level, then the volume of production and demand will be high. Therefore, typical MTS planning will be efficient.

To understand the ATO approach, let us study the case of Titan watches. Despite producing more than 40,000 models and variants, a closer analysis of Titan’s manufacturing system will reveal the following facts: The core movement mechanisms of the watch have very few varieties, regardless of the type of watch into which they are finally assembled. At the next level, the casing will have a little more variety and it may be possible to even manage the production planning of cases using the MTS approach. However, in the manufacture of dials, there is a great deal of product differentiation. Therefore, dial manufacturing and the final assembly of the watches should be largely be on the basis of the MTO planning methodology.

It is obvious from our description of the ATO methodology that this planning framework is more appropriate for mid-volume, mid-variety manufacturing systems having intermittent flow patterns. However, ATO systems are very useful in service systems for a different reason. Service systems are characterized by peak-hour and non-peak-hour conditions and require methods of managing demand during peak hours. There are several ways in which service systems respond to peak-hour requirements. One is to increase the capacity of the system by adding more workers. The other option is to narrow down the choices available to the customer and thereby save capacity from changeover losses and customization. This discussion on alternative planning frameworks is also applicable to service firms that need to respond to peak-hour requirements efficiently.

In order to understand this, let us take the case of a multi-cuisine restaurant providing a wide set of options to its customers. During non-peak hours, it is possible for the service firm to respond to specific customer requests as adequate capacity will be available in the system. Therefore, they will implicitly use the MTO planning methodology. However, service firms will alter their planning strategy as they approach the peak-hour period. In the restaurant example, just an hour before the peak hours begin, the restaurant will pre-cook some of the items and keep them ready for use during the peak hours. For instance, vadas would have been already fried and kept ready. As the demand surge occurs, all that needs to be done is to microwave the precooked vadas and serve them steaming hot to the customer. For varieties of salads and dressings, a work-in-process (WIP) inventory of the required vegetables will be built during the period preceding the peak hours. In other words, what we witness here is a situation where the MTS planning methodology is used just prior to the peak-hour period. Once the required inventory of items is adequately stocked, the restaurant will be able to cut short the lead time and respond swiftly and efficiently to customer demands during the peak hours. The methodology adopted during the peak period is, therefore, ATO. This transition from MTO to ATO via MTS to handle peak-hour requirements should be a generic phenomenon in several service systems.

8.4 ANALYSING PROCESSES

It is clear from the previous discussions that the performance metrics for process analysis are different for MTS and MTO systems. We shall look at some relevant performance measures for these systems.

- *Throughput time:* Throughput time (TPUT) is the elapsed time from the first stage of the process to the last stage of the process. It is also known as lead time. In the case of a new customized print order that a printing press is executing, if the order was launched into the system on Monday morning at 8.00 a.m. and the job was completed by Tuesday evening at 4.00 p.m., then the throughput time for this order is 32 hours.
- *Cycle time:* Cycle time is the elapsed time between two successive outputs from a process that is continuously operating in a given period of time. For instance, in a bread-making process, if a loaf of baked bread comes out of the system every 20 seconds, then the cycle time for the process is 20 seconds. In other words, in a steady-state operation of the process, three loaves of bread will come out every minute. If the process is operational for 450 minutes (7½ hours) then the productive capacity of the process is 1,350 loaves daily.
- *Bottleneck:* That stage of the process that dictates the output of a process is the bottleneck. Let us assume that in the bread-making example, the baking of the bread in the oven takes 20 seconds and all other processes take less than 20 seconds. In this case, the baking process is the bottleneck. The processing time at the bottleneck is the cycle time for the process.

Throughput time is a relevant measure for MTO systems. Measures such as cycle time and bottlenecks, on the other hand, are relevant in the case of MTS systems.

At an overall level, the assumptions in Example 8.1 could be considered for the purpose of capacity computations. However, in reality, several of these assumptions are to be checked and necessary modifications should be made. When there are statistical fluctuations, these could be addressed at the scheduling stage. We have discussed these issues in Chapter 18 (see synchronous manufacturing in Chapter 18 for more details).

EXAMPLE 8.1

A toy manufacturer receives crafted toys from local carpenters and performs the final operations before stocking it for sale. The process consists of five steps. The first step is to arrange a set of four toys in a pallet. After this, the pallet moves to the next station where the toys are pre-treated. This is to increase the toys' life, prevent them from attacks of pests in the future, and also to improve the effectiveness of the painting operation. The next step is to send it to the spray-painting chamber, where it is painted as per the specifications. At present, there is one spray-painting machine. After painting, it is left in an open area for drying. The painting process and the pre-treatment process are specialized so the paint dries quickly. Finally, the toys are inspected and packed. The steps in the process, along with the relevant details, are as follows:

Step 1 (Preparation of toys): 8 minutes
Step 2 (Pre-treatment): 12 minutes
Step 3 (Painting): 20 minutes
Step 4 (Drying): 10 minutes
Step 5 (Inspection and packing): 5 minutes

a. What is the throughput time for this manufacturing process?
b. Identify the bottleneck for this process.
c. What is the cycle time for this process?
d. What is the productive capacity of the process?
e. What are the assumptions behind this computation?

Solution

The process flow diagram is presented in Figure 8.2.

FIGURE 8.2 The process flow diagram

a. The throughput time for the process is the sum of all processing times. In this example, the throughput time is 55 minutes. This implies that if all the required resources are available, then from the time the job is launched at the first step, a pallet consisting of four toys will come out of the system after 55 minutes.
b. The bottleneck is that stage of the process that dictates the output of the process. In our example, the spray painting is the bottleneck.
c. The cycle time is determined by the process time at the bottleneck station in the process. In this example, cycle time is 20 minutes. The implication of this is that when the process operates in a continuous manner, then one can expect a pallet of finished toys to come out every 20 minutes. This is shown in Figure 8.3.
d. In order to compute the productive capacity of the process, we shall compute the production rate at each stage of the process. This is illustrated in Figure 8.4. Stage 2 has a processing time of 12 minutes. It means that the productive capacity is 5 per hour. Similarly, the painting stage has a productive capacity of 3 per hour. It does not make sense to compute the productive capacity for the drying operation as it does not use any constrained resource. For practical purposes, one can stack as many pallets as one wants to on the floor for drying. Based on this computation, we conclude that the manufacturer can produce three pallets (12 toys) per hour. If the manufacturer works with an 8-hour operation, he/she could produce up to 24 pallets per day.
e. These computations are based on certain assumptions about the process. These include the following:

- The process is a continuous operation (that is, it operates at a steady state with no start-up and shutdown issues).

- An adequate amount of resources (including material, men, machines, and other resources) is available.
- Once the operation starts, there are no delays and breakdowns in the system.
- There are no variations and statistical fluctuations (so that the time estimates are fixed and constant).
- The process produces a standard set of items. Therefore, there are no additional time losses due to set-up and changeover other than those already factored into the time estimates.

FIGURE 8.3 Graphical representation of the process with start and end times

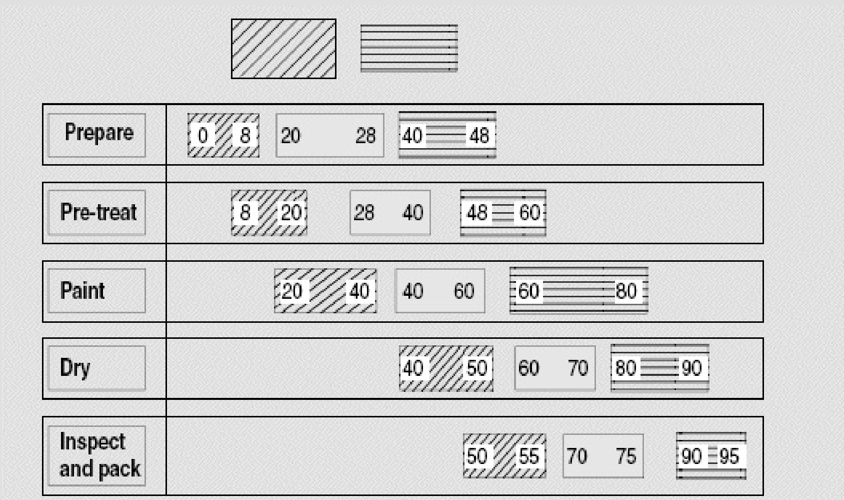


FIGURE 8.4 Production capacity of various stages of the process

EXAMPLE 8.2

Consider Example 8.1. Suppose the preparation process has two parts to it. The first part is setting up of pallets, which requires 4 minutes, and the second part is the actual time of loading the pallet with toys. Each pallet consisting of four toys requires 4 minutes to load. Furthermore, the painting booth can hold up to three pallets during the spraying operation. There are enough number of pallets available in the system. Given this additional information, examine the capacity of the system under the following conditions:

a. The revised process will paint two pallets at a time.
b. The revised process will paint three pallets at a time.
c. There are two pre-treatment units available.

What are the main inferences that one can draw from this exercise?

Solution

Effect of Batch Size

The additional batch that one can process affects the preparation, pre-treatment, inspection, and pack stages of the process. If we process two pallets, then the preparation time will be the total time taken to setup and load toys or [4 minutes + (2 × 4) minutes] = 12 minutes. Therefore, every 12 minutes two pallets of toys will move out of this stage of process. This will translate into 10 pallets per hour. The pre-treatment stage will continue to be five pallets per hour and the inspection and pack stage will also continue to be 12 pal-lets per hour. In the case of painting, in 20 minutes, both the pallets will be painted. This means two pallets will come out every 20 minutes, there by indicating a capacity of six pallets per hour.

In the case of three pallets, in the first stage, it takes 16 minutes [setup time + toy loading time = 4 minutes + (3 × 4) minutes] to prepare three pallets. This translates into a capacity of 11.25 pallets per hour. Table 8.1 shows the capacity details for two pallet and three pallet batch sizes, in comparison with one pallet size.

TABLE 8.1 Capacity Analysis

Batch Size Capacity	1 Pallet	2 Pallets	3 Pallets (Pallets/ hr.)
Prepare	7.50	10.00	11.25
Pre-treat	5.00	5.00	5.00
Spray	3.00	6.00	9.00
Inspect and pack	12.00	12.00	12.00

When the batch size is increased to two or three pallets, the output increases from three pallets per hour to five pallets per hour as the bottleneck shifts from the spraying operation to the pre-treatment operation. Figure 8.5 illustrates these alternative scenarios.

Effect of more Resources

Now we shall revert back to the existing scenario of one pallet batch size and explore the effect of adding one more pre-treatment unit in the system. When the second unit is installed, we find that due to parallel processing of these two units, the number of pallets pre-treated per hour will increase from 5 to 10. However, the paint booth capacity remains unchanged at three pallets per hour. Therefore, the system output will not increase. However, by increasing the batch size to three, we can increase the output to nine pallets per hour. Figure 8.6 pictorially represents this.

Some Inferences

From this analysis, we notice that batch sizes play a crucial role in determining the bottleneck of a process. Furthermore, as several choices are made with respect to the resources and the batch size, the bottleneck shifts from one stage of the process to another. This is referred to as a wandering bottleneck. In our example, addressing the pre-treatment process is crucial to improving the productivity of the process. Before adjusting the batch sizes and deploying additional resources at painting, improving the pre-treatment process becomes crucial.

FIGURE 8.5 Production capacity under varying batch sizes

FIGURE 8.6 Production capacity under varying batch sizes

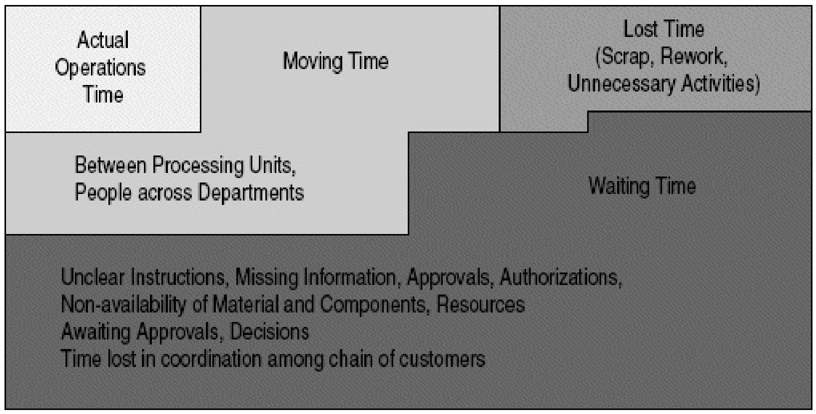
As we have seen in Example 8.2, a process analysis exercise often leads to the issue of improving the process. For instance, in this example, the issue we may want to address is how the process can be improved. Can we increase the production without much investment in the capacity? Can we reduce the process times? Can we redesign the process such that the bottleneck station can increase its output? How can we increase the overall utilization of the stations? One way to improve the process is to understand the existing process in detail and to explore alternatives to simplify it. Let us look at some well-known tools for improving and redesigning a process.

8.5 PROCESS REDESIGN USING BUSINESS PROCESS RE-ENGINEERING (BPR)

Continuous improvement is a matter of systematic study of an existing process and identification of promising opportunities for improvement. Improvements happen only when the extent of usage of resources is reduced while discharging the same set of activities. Alternatively, with the same set of resources, the level of activity must increase. To give a specific example, if there are five people in the purchase department of a firm, then, after an improvement, fewer than five should be able to complete the requirements of the department or the existing five should be able to handle more procurement-related activities.

Organizations embark on a process improvement project to cut lead times. Reduction in lead time makes organizations more responsive to the market and helps them improve customer satisfaction. Typically, four components make up the lead time in organizations. This includes the actual operations time, moving time, waiting time, and lost time. Figure 8.7 provides a pictorial representation of these components and various factors contributing for each of them. As we see in Figure 8.7, the actual operations time is very minimal. In several organizations it occupies 5 – 15% of the total time. The waiting time often amounts to 50 – 60% of the total lead time and the moving time about 10 – 20%. A typical process improvement exercise requires a structured approach to identify various elements of the total lead time and factors contributing to them. It must also enable the process designer to identify the activities that could be eliminated and or redesigned to minimize the time. In this section, we shall briefly look at how some tools are employed for making process improvements.

FIGURE 8.7 Components of lead time in organizations



Business process re-engineering (BPR) is the fundamental rethinking and radical redesigning of business processes to achieve dramatic improvements in critical measures such as cost, quality, service and speed. Hammer and Champy, in their book Reengineering the Corporation, have laid out the broader framework of BPR.[1] According to them, the scope for improvement through BPR is evident in an organization if any of the following are happening:

> Business process re-engineering (BPR) is the fundamental rethinking and radical redesigning of business processes to achieve dramatic improvements in critical measures such as cost, quality, service and speed.

- Extensive information exchange, re-keying of data, and data redundancy, pointing to arbitrary fragmentation of a natural process.
- Large investment in inventory, buffers, and other assets, indicating that the existing process is unable to cope with uncertainty.
- High proportion of checking, control, and progress monitoring, implying excessive fragmentation of the process.
- Inadequate feedback in the process resulting in excessive rework and iteration.
- Increase in complexity of operations, exceptions, and special cases, also indicating the need for simplifying the process by revisiting the process fundamentals.

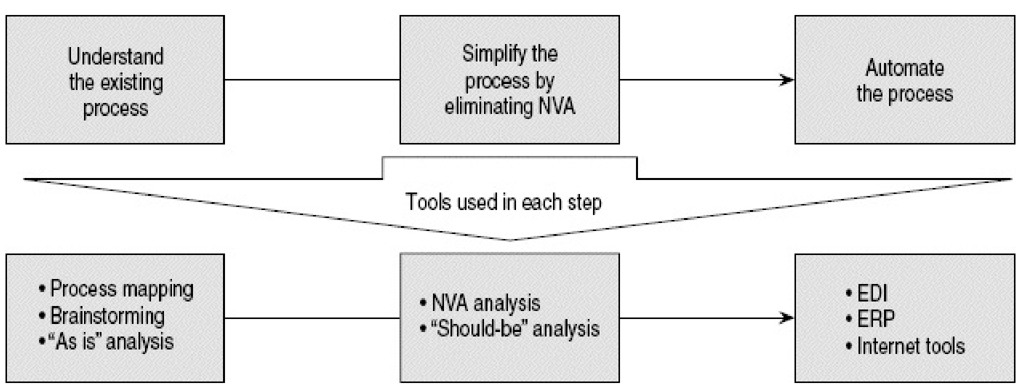
There are alternative frameworks available for undertaking a BPR exercise.[2] Despite some differences in the number of steps involved, all of them fundamentally involve a three-stage process, the understand–simplify–automate (USA) approach to process improvement. Clearly, the first step is to develop a sound understanding of the process. Process mapping is a very valuable tool to develop this understanding as it provides a detailed snapshot of how the process is currently performed. Once the process is understood, the next step is to simplify the process. Non-value-added (NVA) analysis is a valuable tool for this purpose as it helps the improvement team question the relevance of each step identified by the process mapping exercise.

Once the relevance of some of the activities is questioned, it enables the improvement team to look for opportunities for eliminating them altogether, or combining them with some other activity. In some cases, the process may be simplified if the activities are rearranged. In reality, firms develop what is known as the “as-is” version of the process usingprocess mapping. Furthermore, after some NVA analysis they develop a “should-be” version of the process. The final step is to automate the process and reap further efficiency and productivity gains from the new process by using IT tools. The use of a host of Web-based workflow packages, electronic data interchange (EDI), and enterprise resource planning (ERP) are some of the common automation tasks done as a part of the BPR exercise. Figure 8.8 depicts the three-stage methodology for BPR as described here.

The BPR methodology enables an organization to make significant improvements in processes, thereby leading to better performance as certain implementation guidelines are followed in a BPR exercise. These guidelines are briefly explained here:

- Shifting the focus of the entire exercise from activities to results: What this means is that the basis for organizational structure is outcomes and not tasks. Therefore, the organizational structure will shift from functional departments to process teams.
- Performing work where it makes the most sense: The key implication of this is that those who use the output of the process should perform work. In such a scenario, they will be able to control the process and make the required improvements in it. The accountability of the process team towards the outcome of the process will also improve.
- Creating flat organizational structures: Poor process performance is due to multi-layered (deep) organizational structures that deny the process teams an opportunity to own the process and have the required mandate and control to improve the process. Moreover, too many “change of hands” take place and eventually nobody takes ownership for the process performance and outcomes. Instead, whenever problems crop up, they end up pointing fingers at one another. All these issues are eliminated in a flat organizational structure.
- Capturing information once at source: Advances in Web-based tools should be exploited in any process re-engineering exercise. In an era of shared databases and client server architecture, it is important to capture information only once and store it for multiple uses. Capturing the same information at multiple points by multiple entities creates unnecessary complexities due to data integrity problems and makes the processes less efficient. It also introduces unnecessary delays and requires commitment of more resources to sort out the mess.

FIGURE 8.8 Implementing BPR: A three-step methodology



Process mapping, is a tool to understand the various steps involved in performing a business process. The basic premise behind process mapping is that in every organization there are several business processes and these processes consume resources and time, finally driving the cost.

Therefore, improvements in cost, lead time and resource utilization essentially boil down to understanding how processes are performed and identifying unnecessary steps in the process for possible elimination[3]. In a process mapping exercise, data about the process is collected either from available records, an ERP system, or by brainstorming among the various players connected to the process. In the brainstorming approach, the employees working in an area of the process are asked to discuss and develop a representation of the actual process on the basis of their working knowledge. It is possible to construct the complete process steps in this manner over, say, a three-hour session.

> Process mapping, is a tool to understand the various steps involved in performing a business process.

Another method to collect information on a process is to perform an "order walkthrough". An order walkthrough simply involves tracing various steps in a process using an actual customer order. By collecting information about various activities performed to satisfy a customer order, it is possible to trace the actual process. Other methods of process mapping include the bottom-up approach of interviewing each functional area and constructing a possible map of the process and relying on executive judgement.

In a process mapping exercise, data is collected not merely on the various steps in the process, but also on the organizations performing the activity. Specific cost items are also captured to assess possible areas for cost reduction. Table 8.2 illustrates the summary of the outcome of a manufacturing process employed for the manufacture of a critical sub-assembly by a well-known manufacturer in South India. In addition to these measures, it is also useful to collect data on the distance travelled and the time required for the process. Improvement targets pertaining to delivery and lead time require this additional information.

> In a process mapping exercise, the data is collected on the extent of usage of manpower and other resources.

TABLE 8.2 A Summary of the Outcomes of a Process Mapping Study

Description of Categories	Number of Activities	Time (in Hours)	% of the Total Time
Total	**81**	**1680**	**100.0**
Waiting	53	1099	65.4
Moving	18	373	22.2
Adding Cost	5	106	6.3
Adding Value	5	102	6.1

Process mapping is the starting point for any improvement effort in an organization as it equips the improvement team with a wealth of data. While it details how the process is currently performed, it does not indicate whether the various steps are required. Therefore, the next step in the process is to categorize the various activities into alternative heads and analyse their relevance. As explained earlier, **NVA analysis** is a method by which the relevance of some of the existing activities is questioned. Various categories of activities used in NVA analysis are discussed here.

> NVA analysis is a method by which the relevance of some of the existing activities is questioned.

Value-added (VA) Activities

An activity is classified as value-added as long as the customer is willing to pay for that activity. In a manufacturing system, carrying inventory is not value-added as it does not concern the customer if the organization carries inventory or not. On the other hand, activities pertaining to the core manufacturing process are considered as value-added. Similarly, having an inspection department check the incoming or outgoing quality level is a non-value-added activity from a customer's perspective.

Non-value-added (NVA) Activities

All those activities for which the customer may not want to pay are classified as non-value-added activities. These include having a poor plant layout resulting in large distances to be travelled by the production items; increasing the WIP inventory; having an army of progress chasers, production planning, and control personnel; having a large number of indirect labourers; expensive follow up of suppliers; frequent breakdowns of machines; defects; and rework. All these activities invariably add cost and time to the products and services offered, but no value. Having poorly designed processes requiring excessive approvals, Clarification and multiple visits to several sections of the service delivery system will eventually lead to delays, excessive waiting times and poor resource productivity. These are typical examples of non-value added activities in service systems.

Necessary but Non-value-added (NNVA) Activities

Defining non-value-added and value-added activities is a difficult task in reality. Several activities are non-value-added but appear to be value-adding on account of the quality of management practices in an organization. For example, inspection of quality is a non-value-added process in a strictly theoretical sense. However, if an organization does not have a robust quality assurance system, it is highly risky to eliminate the inspection activity. Therefore, in several such cases, it is better to classify them as necessary but not value-adding. The motivation for making an NNVA classification is that it highlights a set of activities that are to be eventually eliminated as and when better systems are developed in an organization.

8.6 DEFINING CAPACITY

Every operating system uses a variety of resources including labour, machines, tools, and fixtures. All these resources are available in fixed quantities for use by the system (unlike materials, availability does not dwindle by the use of these resources). In this sense, capacity is a fixed investment for repetitive use by the system, until it requires replacement on account of depreciation or wear and tear. Capacity denotes, in general, the extent of availability of these resources for use by various processes. It also denotes the maximum output of products and services one can achieve by using these resources. For example, let us consider a machine capable of stamping circular washers that are used in the final assembly of a product. The capacity of the machine can be expressed in one of the following two ways: the number of machine-hours or the number of washers that could be produced.

One can say that in a month, 200 machine-hours are available for processing. Alternatively, if we assume that one can stamp 2000 washers per hour, then the capacity of the machine can be expressed as 400,000 (20032000) washers per month. The former definition is useful when we analyse capacity issues in a localized fashion. On the other hand, at an aggregate level (such as a factory or a division) it will be useful to measure capacity in output terms. Thus, at the Nasik factory of ABB (which manufactures circuit breakers), the firm will compute capacity in terms of the number of circuit breakers (or cubicles/panels) that it can produce per month. On the other hand, at the fabrication plant, it will compute the capacity of the welding machine and hydraulic press in terms of machine-hours.

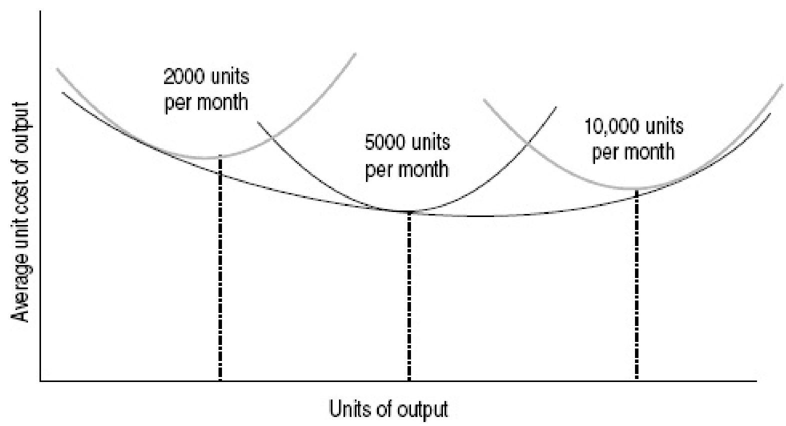
The notion of capacity is very similar in service industries also, For example, a financial services firm may measure their capacity in terms of the number of loan applications processed per day. A management consulting or an accounting firm may measure its capacity by the number of man hours of consultant time available. A hospital will also measure surgeons capacity in a similar fashion.

Irrespective of the method of defining capacity and measuring it, there are certain important issues associated with capacity that an operations manager needs to understand. Capacity has a significant impact on the cost of operation of the system. Capacity investments are large and fixed in nature. Therefore, they manifest as fixed costs of the system. Since the total cost can come down by using a fixed investment more, firms can experience cost benefits from using the available capacity to produce more by judicious planning. A well-known economic principle, economies of scale, indicates the relationship between cost and capacity in an operating system.

When the output increases in an operating system, the system is likely to experience cost advantages on account of several factors. These include spreading of the fixed costs of capacity over a larger number of units, improvements in the utilization of several resources in the system, cost benefits in procurement on account of increased volumes, and efficient use of supervisory and managerial resources and other common resources in the system. Due to these, the average unit cost of the system begins to fall. However, as the output increases, the marginal returns from these gains begin to reduce such that the average total unit cost begins to increase beyond a certain point. Figure 8.9 is a graphical representation of this effect.[4] Knowledge of these costs and benefits helps an organization to choose appropriate levels of capacity deployment and output rates.

The second aspect of capacity and cost is the learning curve effect. When a new technology or process is deployed, the operating personnel are not conversant with the best operating conditions. Moreover, organizational policies and standard operating procedures would not have been established. Therefore, in the initial stages, the productivity levels are low and the capacity tends to be underutilized. The average unit costs of operations tend to be high. However, over time, learning takes place and capacity utilization improves. The output in the system also increases, leading to lower unit costs. Operations managers should be aware of these issues and understand the need to accelerate the learning effects and benefit from using capacity effectively.

FIGURE 8.9 An illustration of economies of scale



The decision regarding how much capacity is required is not addressed just once by an organization. Firms need to revisit the issue of capacity from time to time, in response to emerging market scenarios. The company may have decided on a market expansion strategy and therefore may have to understand whether adequate capacity is available in line with the strategy. In other cases, in response to a competitor threat, a company may decide to invest in more capacity to pre-empt the entry of new players. Government policy changes and changes in the regulatory framework may also induce a company to revisit the capacity issue. A case in point is the Indian textiles industry. In response to the dismantling of quotas worldwide from 1 January 2005, several firms are currently expanding their capacity. According to the Centre for Monitoring Indian Economy (CMIE), the value of new investments in the textile sector has gone up by 35 per cent as on 30 April 2004.

In a proactive mode of capacity build-up, capacity is added in anticipation of the future. In a reactive mode of capacity build-up, capacity is added in demand.

VIDEO INSIGHTS 8.1

Capacity planning is an ongoing activity for every organization. As demand for products and services increase, capacity constraints limit the operations of the system and call for new investments. The emerging situation in the Melbourne Rail Link demonstrates these aspects related to capacity planning. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

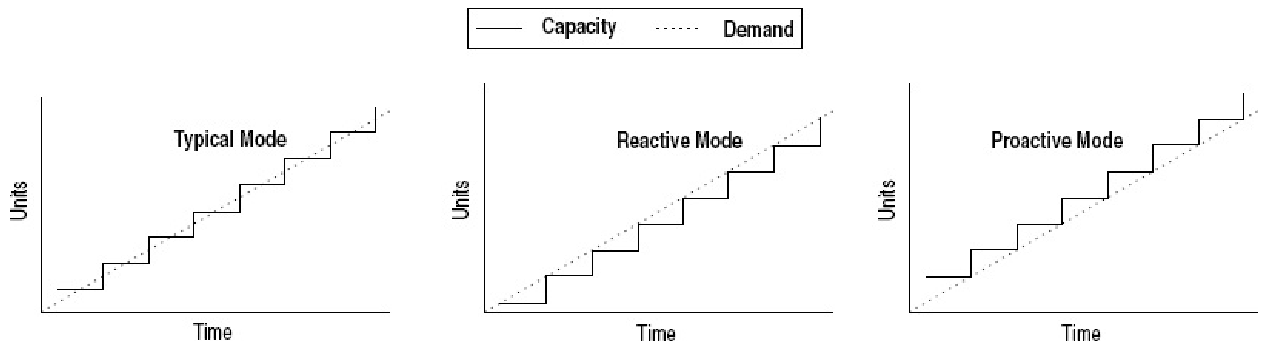
Irrespective of the context for capacity expansion, capacity is generally added in large chunks. It is not possible to add capacity in small increments at frequent intervals. This is because capacity additions happen in certain integral units and invariably call for larger capital outlay and detailed capital budgeting exercises. Further, they also involve longer lead time to source and install in the system. Therefore, capacity decisions are made at less frequent intervals. Consequently, firms go through a cycle of overcapacity–appropriate levels of capacity– under-capacity. This is a typical mode of capacity build-up.

In the reactive mode of capacity build-up, firms wait until demand materializes sufficiently before augmenting capacity.

There are two other alternative methods of capacity build-up available for firms. In the reactive mode of capacity build-up, firms may want to wait until demand materializes sufficiently before they augment capacity into the system. In contrast, in a proactive mode of capacity build-up, capacity is added in anticipation of future demand. In a highly competitive market where temporary loss of sales directly translates into loss of market share, firms may have to plan for a proactive mode of capacity build-up. However, it calls for high accuracy in forecasting future demand. On the other hand, in monopoly situations, firms can afford to adopt a reactive mode of capacity build-up. In several cases, firms tend to utilize a typical capacity build-up mode. Figure 8.10 presents a graphical representation of alternative modes of capacity build-up.

Firms go through a cycle of overcapacity, appropriate levels of capacity, and insufficient capacity. This is a typical mode of capacity build-up.

FIGURE 8.10 Alternative modes of capacity buid-up



8.7 MEASURES OF CAPACITY

The approach taken to measure capacity depends on several factors. First is the issue of volume and variety of products and services offered by the operations system. A high-volume system may find it appropriate to use output measures of capacity and a low-volume–high-variety system may use input measures of capacity.

A petrochemical plant such as Bharat Petroleum Corporation Limited (BPCL) measures its capacity in terms of the number of barrels of crude oil it can process per day. The refining capacity of its refinery in Mumbai is 260,000 barrels per day. Similarly, a PCB manufacturer measures its capacity by the amount of square metres of board that it can fabricate. A television manufacturer often measures its capacity per million picture tubes produced. The Hazira plant of Reliance Industries Limited measures the capacity of its polyethylene plant in terms of tonnes of polyethylene processed. A tool room facility will measure its capacity in terms of machine-hours. All these examples share a common feature, that is, these measures are input measures of capacity. Several firms operating in a low-volume–high-variety situation find it easier to measure capacity on the basis of the quantum of input that it can process in a unit time. One can observe a similar phenomenon in a service setting also. A management consulting firm or a legal consulting firm will measure its capacity by the consulting man-hours available per month. Similarly, a hospital will measure its capacity in terms of the number of beds.

> Firms operating in low-volume–high-variety situations will use input measures of capacity.

On the other hand, an automobile component manufacturer such as the Bangalore-based Toyota Kirloskar Auto Parts measures its capacity in terms of the number of transmission gearboxes it can produce. Similarly, automobile manufacturers measure capacity by the number of vehicles that they can roll out every month. Tata Bearings, a division of Tata Steel, has a capacity of 25 million pieces per annum. Similarly, Mico Bosch has an installed capacity of 100,000 distributor pumps at its Jaipur plant. In all these cases, the volume of production is high and variety is relatively low. Therefore, it is appropriate to use output measures of capacity. An automated car wash facility is a standard high-volume service set-up whose capacity can be measured in terms of the number of cars serviced per day.

The second issue is the level of abstraction desired in defining capacity. At a departmental level, capacity is often measured in terms of the specific units of capacity in question. In the Titan watch factory, the capacity of the electroplating plant and the heat treatment plants are likely to be measured in terms of electroplating and heat treatment hours available per unit time. Similarly, the square metres of paint that can be applied per unit time will indicate the capacity of the paint shop in a fabrication unit. On the other hand, the capacity for the entire division or company is often measured using some appropriate input or output measures of capacity.

> Capacity utilization is measured as a ratio of the capacity put to use to the total available capacity in a unit of time.

The most commonly used method for measuring the effectiveness of capacity usage is the utilization of resource(s). **Capacity utilization** is measured as a ratio of the capacity put to use to the total available capacity in a unit of time.

$$\text{Capacity utilization} = \frac{\text{Capacity put to use}}{\text{Total capacity available}} \tag{8.1}$$

Depending on the method adopted to measure capacity, this definition can be suitably modified. For instance, if output measures of capacity are used, then the numerator will indicate the actual output and the denominator will indicate the installed capacity in terms of the number of units of output. Alternatively, if input measures are used, the numerator and the denominator could be correspondingly redefined.

> When the volume of production is higher and the variety is lower, it is appropriate to use output measures of capacity.

One of the issues that an operations manager needs to have some clarity on is the manner in which the total capacity available is determined. There are several assumptions involved in arriving at this number. The simplest measure is the theoretical maximum capacity available. Consider a machine such as a hydraulic press in a fabrication shop. Considering a month to be of 30 days, the theoretical maximum capacity available is 720 hours per month. However, the firm may have a policy of operating only two shifts. Moreover, there will be some time earmarked for scheduled maintenance of the machine. Excluding all these will result in the effective capacity available during the month. For instance, if 20 hours per month are set aside for scheduled maintenance then a two-shift operation will reduce the maximum available capacity to 460 hours [(30 day × 16 hours) − 20 hours].

The actual capacity realized will be much lower than the effective capacity of the resource. The difference between the effective capacity available and the actual capacity realized is due to several factors that result in causing the capacity to be idle. One way to explain this difference is to make use of a simple equation pertaining to capacity, as practiced by Japanese manufacturers:

$$\text{Capacity} = \text{Work} \times \text{Waste} \qquad (8.2)$$

The Canon production system describes nine different types of waste that occur in a production system. These include waste in: (1) planning, (2) operations, (3) start-up, (4) equipment, (5) defects, (6) materials, (7) indirect labour, (8) human resources, and (9) expense.[5]

Of the nine wastes mentioned here, the first five directly relate to the capacity of the resources. Improper planning of resource usage will bring down the utilization of resources, as they will wait for material, operating instructions, and process sheets. Similarly, waste in operations and start-up may take away valuable time from the resource and bring down the actual capacity of the system. The most frequently encountered example of this is a very long set-up time for a machine before a batch of components can be processed. Waste in equipment results due to improper methods of using the equipment as well as poor maintenance, resulting in significant loss of the time available for processing. Unscheduled breakdowns and longer times to restore the machine to operation may take away capacity from the system.[6] Finally, waste in defects indicates the time lost in processing the defective components as they are eventually scrapped.

8.8 THE TIME HORIZON IN CAPACITY PLANNING

Capacity planning issues vary markedly with respect to the time horizon in which the decisions are made. It is useful to divide the time horizon into the long term, medium term, and short term to understand the nature of issues to be addressed with respect to capacity planning. Table 8.3 illustrates the salient features of capacity planning under the three time horizons.

In the long term, the emphasis in capacity planning is on making the right amount of capacity available to meet the projected growth. Typically, organizations initially make a certain investment of capacity. However, as operations stabilize and market share increases, firms need to take decisions in advance to plan for augmenting capacity. Alternative methods are available to augment capacity. These include de-bottlenecking of certain stages of the process, addition of more resources in certain parts of the operating system, large-scale expansion of capacity by building additional plants, and mergers and acquisitions of other operating units. These options differ in the amount of additional capacity that is brought into the system and the cost and technological aspects of capacity build-up. De-bottlenecking is a commonly employed method in process industries as it is easy to identify the flow and bottleneck points in the system.

TABLE 8.3 Capacity Planning Issues in Varying Time Horizons

Criterion	Time Horizon for Planning		
	Long-term Planning	**Medium-term Planning**	**Short-term Planning**
Time frame	2–5 years	Typically one year	One week to three months
Planning premise	Augmenting capacity for projected growth	Balancing demand–supply	Maximizing availability,efficient use of resources
Key decisions made	Capacity augmentation; capital budgeting exercises	Adjusting demand and supply attributes to balance available capacity with requirement	Resource deployment strategies, maintenance routines, improvement projects to be undertaken
Tools and techniques used	Investment planning, break-even analysis, discounted cash flow techniques, decision trees	Aggregate operations planning; make or buy	Planning and scheduling, total productive make or buy maintenance, waste elimination by continuous improvement, simulation, heuristics, waiting line models

Capital budgeting exercises are an integral part of the decision-making process at this stage. Additions in capacity are likely to further shift the break-even points as fixed costs in the system go up. Therefore, it is also common for management accounting professionals to work on the break-even impact of capacity augmentation decisions. Operations and maintenance personnel plan in advance for the installation of additional capacity and dovetailing the new equipment with the existing system.

In the medium term, the focus in capacity planning shifts to balancing available capacity with demand. In the medium term, firms have some opportunities for limited capacity augmentation by increasing the usage of existing capacity through overtime and introduction of an additional shift. Further, by subcontracting part of the work to external vendors, some capacity inadequacies can be handled on a temporary basis. It is also possible for firms to modify the demand by shifting it from a peak period to a non-peak period. Several methods are available for capacity planning using the options discussed here. These methods are often described as aggregate operations planning. We discuss these strategies in detail in Chapter 15.

> In the medium term, the focus in capacity planning shifts to balancing available capacity with the demand.

ideas at Work 8.2

Nine Sources of Waste

The Japanese concept of equating capacity to the sum of work and waste is a simple yet powerful method for capacity management. A manufacturer of auto components has a hydraulic system that contains master cylinders. The master cylinder is manufactured using as set of six machines. The installed capacity of the master cylinder manufacturing facility was 32,000 per month. However, for a variety of reasons, the maximum production achieved was in the range of 70–75 per cent of the installed capacity. Clearly, as per Eq. 8.2, the waste in the system accounts for the remaining capacity.

A study was initiated to understand how capacity realization could be improved without any major investment in additional machines. The underlying philosophy behind the exercise was to estimate the various sources of waste, as proposed by the Canon Production System. Table 8.4 shows some of the salient aspects of the findings and the major sources of waste.

The study highlighted two major areas of waste: materials and equipment usage. The waste due to start-up also pertains to equipment usage. Based on this study, additional studies were initiated to understand the nature of wastage in the use of equipment. The study showed how poor planning of operations and very long set-up times were resulting in high idle time of the machines. The maximum set-up time was found to be 16 hours, which converted the machine into a bottleneck.

Set-up-time reduction exercises were carried out on the bottleneck machine as well as on the other machines. After a two-month study and the implementation of simple improvements in equipment usage and set-up-time procedures, the maximum set-up time came down to less than three hours. As a result of these efforts, the actual production of master cylinders shot up to nearly 90 per cent of the installed capacity. This experiment clearly established the usefulness of the simple yet a profound equation:

$$\text{Capacity} = \text{Work} + \text{Waste}$$

TABLE 8.4 The Major Sources of Waste

Source of Waste	Amount (in ₹million)	
Waste due to human resources		1.96
Waste due to materials		21.53
Waste due to operations		1.47
Waste due to start-up		5.24
Waste due to equipment		12.90
Underutilization of machines	*9.75*	
Unused machine capacity	*2.50*	
Not maintaining specifications	*0.65*	
Total of the above		43.10
Divisional turnover		135.90
Waste as a percentage of turnover		31.70%

Source: Based on R. Balaji, "Waging War on Waste," Unpublished report submitted in the MPT programme at IIM Bangalore.

Capacity planning in the short run is very different from capacity planning in the medium or long run. In the short run, the maximum available capacity is fixed. Therefore, the capacity planning exercise is confined to making effective use of the available capacity and ensuring that unforeseen developments such as equipment breakdowns and poor planning methods do not lead to keeping the capacity idle. The focus in capacity planning in the short run is on maximizing resource availability and efficient use of the resources. Several operations management tools are available to manage capacity in the short run. These include planning, scheduling methods, and maintenance management methods. Some of these topics are discussed in detail in Chapters 15 and 18. Waiting-line models are a generic class of tools used to analyse capacity issues in both service and manufacturing firms. We discuss this in Chapter 10. Similarly, a detailed analysis of the impact of capacity on the working of the system can also be studied using simulation modelling of the system. See the supplement of the end of the chapter 10 for more details on simulation.

> Capacity planning in the short run is confined to making effective use of the available capacity.

8.9 THE CAPACITY PLANNING FRAMEWORK

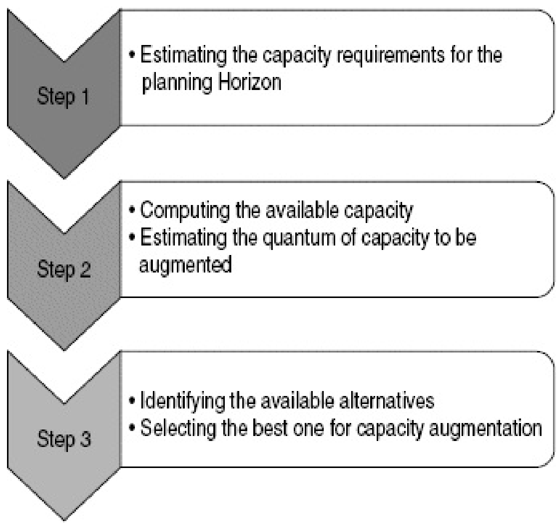
Capacity planning is a systematic approach to three issues pertaining to capacity: estimating the amount of capacity an operating system requires, evaluating alternative methods of augmenting capacity, and devising various methods to use existing capacity effectively.

> **Capacity planning** is a systematic approach to three issues pertaining to capacity:
>
> - estimating the amount of capacity required,
> - evaluating alternative methods of augmenting capacity, and
> - devising methods to use capacity effectively.

A capacity planning exercise is initiated in response to several scenarios that an organization faces from time to time. However, two of these are more common. The first scenario involves changing market conditions, leading to an increase in the demand of the products and services that a firm offers. Due to increased demand, the capacity becomes inadequate and calls for a detailed computation of the new requirement. Moreover, since capacity additions are done over longer intervals, an estimate of future capacity projections is an integral part of the exercise. The second context for the capacity planning exercise is strategic decisions taken with respect to the introduction of new products and new markets. In this situation, there is a need to revisit the capacity issue.

Irrespective of the context, a capacity planning framework consists of three important steps (Figure 8.11). First, a careful estimation of the current and future capacity requirements is to be made. Once capacity requirements are known, it becomes relatively easy to perform detailed computations and identify bottleneck points in the system. This constitutes the second step. In the final step, available alternatives are to be enumerated in order to select the best one. All these steps are described in detail here.

FIGURE 8.11 The capacity planning framework



Estimating the Total Requirement

The estimation of capacity requirements begins with inputs from a forecasting exercise if the intent of the capacity planning exercise is to respond to imminent and future growth projections in the market. There are several techniques available for forecasting which an organization can use to estimate the end product or the service offered.[7] Capacity planning exercises typically make use of medium-term and long-term demand projection methods. These exercises use past data collected at the end-user level and systematically aggregated in the hierarchy before being analysed and projected into the future. Once the projections for the end-product sales are forecast, detailed capacity computations can be done at individual facilities in the plant. On the other hand, the estimation of capacity requirements can also be in response to some targeted capacity build-up in the factory. For example, the medium-voltage circuit breaker manufacturing facility of ABB at Nasik decided to increase the capacity of its plant. In this case, the capacity requirements are computed to meet the revised target.

Once the end-product requirements are estimated using appropriate techniques, detailed computations at the individual resource or division level are required for estimating capacity requirements and matching them with availability. Labour and machines are the two major resources for which capacity planning is required. Therefore, capacity calculations are done on the basis of man-hour and machine-hour requirements per unit of product manufactured.

Estimating Labour and Machine Requirements

The computation of the labour requirements depends on two major factors: the amount of standard labour hours required per unit of the product and the efficiency of the labour. Let,

Projected demand per unit time during the planning horizon = D

Standard labour hours required per unit of product = S_L

Efficiency of labour = E_L

Then,

$$\text{Capacity requirements (labour)} = \frac{D \times S_L}{E_L} \tag{8.3}$$

Although this computation appears simple, in reality, there are certain operational difficulties in estimating S_L and E_L. The standard labour hours are supposed to be established by a standard setting routine in every organization. This will call for studying each process, estimating normal allowances and incorporating them. Moreover, as the process is put into practice, some assumptions are required about the efficiency of the workers. This efficiency is likely to be somewhat low during the initial stages. However, as the employees experience the learning curve effect, the efficiency of the process improves, thereby calling for a revision of these standard labour hours. Despite this, revisions are not done as frequently as the process warrants. This is because the earning potential of the employees is inextricably linked to standard hours and efficiency assumptions. By keeping the standards loose and efficiencies low, it is possible for some workers to earn productivity bonuses even for normal work. Due to these reasons, in a vast majority of industrial organizations, S_L and E_L have an industrial relations angle as well. In recent years, however, the notion of productivity and the manner in which employees are rewarded for good performances in productivity are not linked to these issues. Operations managers need to be aware of these limitations while making a judicious choice of these parameters.

One can use a similar expression for computing the machine requirements by using the subscript M in the place of L.

$$\text{Capacity requirement (machine)} = \frac{D \times S_M}{E_M} \tag{8.4}$$

Computing Capacity Availability

Once the capacity required is computed, one can estimate how much capacity is already available in the system. By performing this computation and comparing with the requirements, one can identify the gaps or excess capacity available for each resource in question. The comparison of the available capacity with the requirement serves several important purposes in a capacity planning exercise. Some of these are:

EXAMPLE 8.3

A manufacturer of medium-voltage circuit breakers is planning for a capacity build-up of 8 cubicles and 13 circuit breakers per day. A year consists of 305 working days. The fabrication division is responsible for manufacturing metal sheet components that are welded together to form the cubicle. Some metal sheet components are welded to host the circuit breakers inside the cubicle. The components are painted after welding. While the fabrication uses a CNC turret press, painting is a manual job. The standard time required at the CNC turret press for fabricating a cubicle is 150 minutes and the time for the breaker housing is 36 minutes. A cubicle requires 43 m^2 of area to be painted and a breaker housing requires 2.60 m^2 of painting. The standard time required to paint 1 m^2 of area is 18 minutes. The machines work at 80 per cent efficiency and the manual labour works at 90 per cent efficiency. Using the given data, compute the labour-hour and machine-hour requirements.

Solution

Capacity planning is done for the planning horizon. In our example, the basic data for the problem pertains to the planning horizon.

Since the demand during the planning horizon is the basis for computing the capacity requirement, we compute the demand using the data. Since eight cubicles are to be manufactured per day, in a year the required capacity is to fabricate (83 × 05) cubicles, or 2,440 cubicles. The computation is as follows:

Planning horizon: 1 year

Number of working days in a year: 305 days

Therefore, the demand for the planning horizon will be as follows:

	Cubicles	**Breaker Housing**
Number per day	8	13
Demand per annum	2440	3965

The standard time for fabricating one unit of cubicle and breaker housing are available. Also known is the efficiency of the machine. Using Eq. 8.4, we can therefore compute the machine-hours required. The computations will be as follows:

Efficiency of CNC turret press: 80%

	Cubicles	**Breaker Housing**	**Total**
Machine-hours required per unit	2.50	0.60	
Machine-hoursrequired per annum	7625.00	2973.75	

One can use Eq. 8.3 to compute the labour hours required in a similar manner. The labour-hour calculation will be as follows: Efficiency of workers: 90%

Standard man-hours for painting 1 m^2: 0.30

	Cubicles	Breaker Housing	Total
Square metres of area to be paintedper unit	43.00	2.60	
Total area to be painted during one year (m2)	104,920.00	10,309.00	115,229.00
Labour hours required per annum	34,973.33	3436.33	38,409.67

- The comparison acts as a basis for the operations manager to understand the consequence of the capacity expansion initiative.
- It helps to categorize the resources into those with adequate capacity and those with insufficient capacity and helps to focus on the latter category for problem solving.
- It provides an impetus for process-plan changes and improvements for uncovering waste, thereby leading to the discovery of more capacity at some of the bottlenecks
- It helps the manager to draw out the capital budgeting and investment requirements of the capacity expansion initiative.

The availability of capacity in a system is a function of two parameters: system availability and resource availability. System availability is a function of the number of working days and the number of hours per day. The number of hours in a day depends on operating policies regarding the number of shifts and overtime practices. Resource availability is a function of maintenance schedules, the breakdown behaviour of the resource (in the case of machines) and absenteeism (in the case of labour). Based on these, the capacity available in the system can be computed. The relevant computational details are as follows:

EXAMPLE 8.4

Consider the fabrication shop of Example 8.3. Suppose the factory works on a two-shift basis with six workers in the paint shop in each shift. There is only one CNC turret press currently available. Suppose prior data shows that the equipment at the shop has a downtime of 12 per cent and the absenteeism rate of the employees is 5 per cent. Assess the impact of the capacity expansion initiative in the plant.

Solution

The capacity requirements have already been computed in Example 8.3. They are as follows: Labour hours required at the paint shop = 38,409.67 Machine-hours required at CNC turret press facility = 10,598.75

Now, let us compute the available capacity using Eq. 8.5. The relevant computations are as follows:

Number of days in the planning horizon	305
Number of working hours per day	16

System availability (hours)	**4880**
Number of turret presses available	1
Percentage of time lost in breakdown and maintenance	12%
Capacity of CNC turret press available (hours)	**4294.40**
Number of workers in the paint shop	6
Percentage of time lost in absenteeism	5%
Total labour hours available	**27,816.00**

Comparison of Availability and Requirement

The comparison between requirement and availability for the CNC turret press and labour in the paint shop is calculated in Table 8.5. Since there is only 72 per cent of the total requirement available in the paint shop, cubicles and breaker housing can be fabricated only to that extent (as shown in the calculations). Clearly, there is insufficient capacity in both these cases.

The firm needs to explore methods for augmenting this capacity to meet the revised capacity expansion initiative. One direct method is to compute the number of additional machines and labour required to meet the shortfall. Using the data already available, we can compute the number of additional hours that one can augment by adding one unit of labour or machine. For example, one more worker in each shift will bring 4636 hours of work (305 days × 16 hours/day × 95 per cent attendance). Using this information, the number of additional machines and workers can be computed as follows:

Number of hours of capacity added by one worker	4636.00
Number of hours of capacity added by one CNC turret pressy	4294.40
Additional workers required in the paint shop	**2.29**
Additional CNC turret presses required	**1.47**

Rounding to the nearest integer, three more workers per shift and two CNC turret presses need to be added to meet the targeted capacity.

TABLE 8.5 Requirement–Availability Comparison for the CNC Turret Press

System availability

Number of working days in the planning horizon = N_d

Number of working hours per day = h

System availability (hours) = $N_d \times h$

Resource availability

Number of machines available = N_m
Machine: Time lost in breakdowns and maintenance = $b\%$
Number of workers available = N_L
Labour: Absenteeism of the workers = $a\%$

Capacity available in the system (in hours)

$$\text{Machine} = N_d \times h \times N_m \times \left(1 - \frac{b}{100}\right)$$
$$\text{Labour} = N_d \times h \times N_L \times \left(1 - \frac{a}{100}\right) \tag{8.5}$$

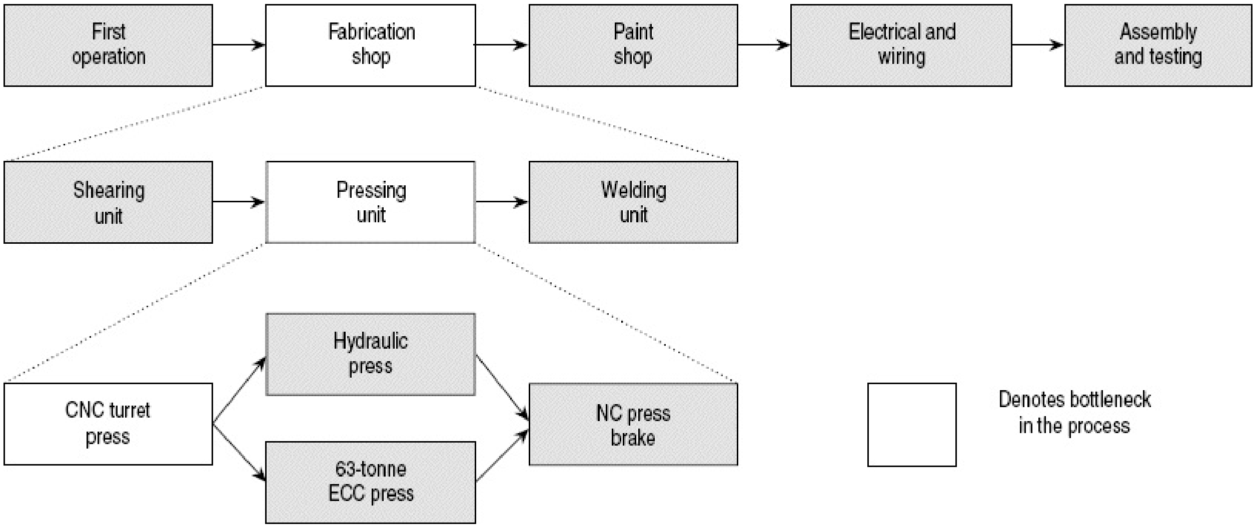
Process Mapping and Capacity Analysis

What we have seen in Example 8.4 is a detailed computation of the capacity requirement for a particular machine in the fabrication shop and the paint shop of the factory. However, the capacity of the fabrication shop is a function of the capacity of alternative resources available in the shop. Therefore, in order to understand the capacity of one stage of the production system (for example, the paint shop), we need to understand the manner and the extent to which the available resources are utilized in manufacturing. One can obtain this information from a process mapping exercise. By process mapping, we mean a representation of all the available resources, the patterns and the extent to which each of these resources is being used. Using this information, we can compute the capacity of each resource available in the shop and the limiting capacity for the entire shop.

The process mapping exercise can be done at any level of abstraction and capacity implications are analysed at that level of abstraction. Continuing with our example, the entire hierarchy of capacity computation could be graphically illustrated as in shown Figure 8.12.

We will consider an example to understand the capacity issues stemming from a process mapping exercise.

FIGURE 8.12 Hierarchies in a capacity estimation exercise



EXAMPLE 8.5

A product is manufactured in a shop using a five-stage process. The first step in the process is to cut the sheet metal to required shapes and sizes using a shearing process. After the shearing process, the components are subjected to pressing operations to alter the shape of the flat sheet as per the design. In the third stage of the process, welding is done to join the components. The next step in the process is a painting operation. After painting, the components are packed and kept ready for dispatch. The time taken for each of these operations is 20, 30, 15, 12 and 6 minutes, respectively. Presently, each stage has only one machine for operation. Map the process and analyse the capacity with respect to the following scenarios:

a. If the shop works on an 8-hour shift with an effective available time of 450 minutes, what is the production capacity of the shop?
b. Where is the bottleneck in the system? If we want to add one machine, where should we make the investment?
c. Identify the additional capacity required for a daily production target of 25 units. Compute the utilization of the machines as per the revised capacity calculations.
d. What are the key inferences of this exercise?

Solution

Based on the description in the question, one can map the process and identify the extent of time the resources will be used at each stage of the process for manufacturing. Figure 8.13 shows the process map. The numbers in parentheses denote the time required at each stage.

a. These timings can be translated into production capacities by dividing the total available time per shift by the required time at each stage. The production capacities are:

$$\text{Shearing} = \frac{450}{20} = 22.50 \text{ units}$$

$$\text{Pressing} = \frac{450}{30} = 15.00 \text{ units}$$

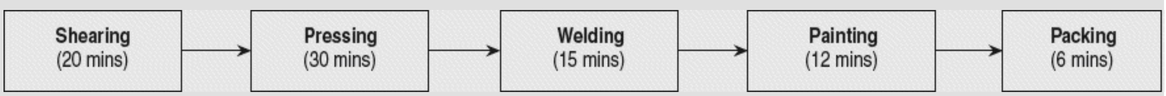
$$\text{Welding} = \frac{450}{15} = 30.00 \text{ units}$$

$$\text{Painting} = \frac{450}{12} = 37.50 \text{ units}$$

$$\text{Packing} = \frac{450}{6} = 75.00 \text{ units}$$

The smallest number in these calculations limits the production capacity for the shop. Therefore, the current production capacity is 15 units per day.
The smallest number in these calculations limits the production capacity for the shop. Therefore, the current production capacity is 15 units per day.

FIGURE 8.13 The process map



b. The slowest process is the bottleneck in the system and it dictates the production capacity. Therefore, it is prudent to channelize the investment at the bottleneck process. By adding one more machine, the situation changes as shown in Figure 8.14.

   Since two machines are available at the pressing stage, the effective time per unit will now be 15 minutes. Therefore, the bottleneck now shifts to shearing and the revised production capacity will be 22.50 units a day.

c. The production target is now 25 per day. Since a day has 450 units, the maximum time that the process can take at each stage is 18 minutes. The packing, painting, and welding sections have timings less than 18 minutes. Therefore, they do not need any more investment in capacity. By adding one more machine at the pressing stage, the effective time will be less than 18 minutes. Similarly, by adding one more machine at the shearing stage, the effective time will be 10 minutes. Using Eq. 8.1, the capacity utilization for the machines is as follows:

Utilization of shearing

$$= \frac{\text{Daily production} \times \text{Process time}}{\text{Number of machines} \times \text{Available time}}$$

$$= \frac{25 \times 20}{2 \times 450} = 55.56\%$$

$$\text{Utilization of phearing} = \frac{25 \times 30}{2 \times 450} = 83.33\%$$

$$\text{Utilization of welding} = \frac{25 \times 15}{1 \times 450} = 83.33\%$$

$$\text{Utilization of painting} = \frac{25 \times 12}{1 \times 450} = 66.67\%$$

$$\text{Utilization of packing} = \frac{25 \times 6}{1 \times 450} = 33.33\%$$

d. Key inferences: The computation of individual capacity availability and requirement is the first step (and an important one) in the capacity planning exercise. The value of this exercise lies in our ability to use this information to identify bottlenecks. A process mapping exercise will help us achieve this objective. The utilization of the shearing process has dropped to 56 per cent due to the addition of a machine. Clearly, the addition of one more unit of resource may not always be the best solution. This points to the need for exploring alternative methods of augmenting capacity.

FIGURE 8.14 The modified process map

8.10 ALTERNATIVES FOR CAPACITY AUGMENTATION

Example 8.5 pointed out the need for looking at alternative methods for capacity augmentation during a capacity planning exercise. The straightforward option is to add more resource units. Although it is simple from an operational decision-making point of view, in reality, the implications could be far too many. The cost of the resource in question, the utilization of the resource, and the ease of implementation of the capacity expansion plan are some of the issues that will influence the choice of this option. Moreover, as more and more units of resources are added, it may significantly impact the long-term operational costs of the system. For example, if several new workers are added, then the cost of the system increases not merely in terms of salary but also in terms of support costs, benefits, and health and post-retirement provisions. Similarly, as more machines are added, equipment maintenance costs will go up in the long run. Furthermore, if the resource in question is very expensive and its utilization is likely to be low, it is a very unattractive option, and operations managers should look at other ones.

Waste Elimination

One method to increase the capacity of the resources in the system is to employ Japanese methods of resources planning and management, as described earlier in the chapter. In a nutshell, it is for the operations manager to make use of Eq. 8.2 and progressively uncover capacity from the system by elimination of waste (see Ideas at Work 8.2 for an illustration of this method of increasing the capacity in the system). Process industries increase capacity by de-bottlenecking operations. Since in process industries, the system is a continuous flow of material from the raw material to the finished goods, merely identifying the bottleneck stage in the process and de-bottlenecking it can increase the capacity of the system. Japanese approaches to waste elimination and/or addition of new capacity in that stage will increase the capacity of the system. However, the bottleneck will shift elsewhere and the process could be repeated.

Multi-skilling of the Workforce

Another approach to increasing capacity is through multi-skilling of the workforce. Often, capacity constraints manifest themselves on account of the non-availability of skills even when adequate capacity is available in machines and other resources. For instance, in a machine shop, there will be enough drilling machines, grinding machines, gear-cutting machines and CNC machines to process all the requirements. However, if the workforce is not multi-skilled, then production may suffer on account of a specific set of skills not being available at some time. There may be just a few workers who can operate the gear-cutting machine and the CNC machine. Therefore, these workers will dictate the capacity of the system. On the other hand, if all the workers have skills to operate all the machines, then it is much easier to absorb fluctuations in both demand and workforce availability.

Multi-skilling not only solves the problem of providing each operating unit or a sub division with the required skills but also increases the flexibility of operating such units. Employee absenteeism does not affect the work seriously. At the shop-floor level, multi-skilling in a machine shop would mean picking up the skills required for operating all the machines and in the assembly shop it would mean working at all stages of assembly. In the fabrication shop, it would call for proficiency in fitting, welding, shearing, etc. On the other hand, at the supervisory level and shop-floor managerial level, it would mean discharging various manufacturing support functions such as production planning and control, inventory and stores management, and procurement.

Developing multi-skilling is an easy but time-consuming programme in any organization. The management needs to focus adequate attention on this aspect and encourage employees to acquire, in addition to the skills required for processing at his/her workplace, the skill to perform the preceding and the succeeding stages of processing. That is a good way to start the process. However, in order to get a sense of direction in this process, organizations need to conduct a skill inventory at every shop. The skill inventory could be used to compute some indices that describe the current status of multi-skilling in the shop. Once this information is available, the management could chalk out various training programmes to help employees in each shop to pick up critical and scarcely available skills first.

Subcontracting/Outsourcing

Capacity augmentation need not always be done in-house. An alternative approach to capacity augmentation is to subcontract the work to competent vendors and service providers. The logic of the subcontracting decision closely follows that of a “make-or-buy” decision that purchase managers and management accountants address in their respective domains. Several considerations influence the subcontracting decisions in firms. Primary among them is the lack of capacity to meet the current demand. The other consideration is the technological intensity and criticality of the item for which capacity is being subcontracted. When the item is of low technical intensity and criticality, then it is less risky to subcontract capacity. The firm will not lose any valuable trade secret or know-how pertaining to the product being manufactured. The third issue is one of cost. When the cost of performing an activity in-house is much higher than what is available outside, then it is appropriate to outsource such activities and use the released capacity for other important activities.

> Firms can react much faster to market requirements by using subcontracting. Subcontracting is also very useful for managing peak-hour demand.

Subcontracting offers several advantages to a firm. First is the flexibility to handle fluctuations in demand. By investing in in-house capacity, the firm may run the risk of under-utilization should the demand for the product/service come down in the future. In-house capacity augmentation is a time consuming process. On the other hand, firms can react much faster to market requirements by using subcontracting. Subcontracting is also very useful to manage peak-hour demand. By having an in-house capacity equal to the average demand during a period, organizations can address peak-hour requirements using subcontracting.

Despite these advantages, subcontracting has some drawbacks. The major challenge in subcontracting is to identify an appropriate vendor for providing subcontracted services. If the selection of the vendor is not done carefully, poor performance of the vendors will impact the firm’s business and market standing adversely.

8.11 DECISION TREE FOR CAPACITY PLANNING

The capacity planning exercise requires methods by which alternative options are evaluated. Two metrics are useful to perform the evaluation. In the **cost-based method**, each alternative can be evaluated from the perspective of the costs and benefits accruing out of the alternative. For example, a firm may be considering three options: not to do anything about capacity, add a new machine, or opt for subcontracting. Another firm may have three options of varying technological and operational capabilities for capacity addition, resulting in different capital costs, operating costs, and useful life of the resource. In each of these examples, one can evaluate the alternatives from the perspective of costs and benefits.

> In the cost-based method, each alternative can be evaluated from a perspective of cost and benefits accruing out of the alternative.

The other method is to use **operational performance based methods** for comparing alternatives. If the choice is to go for multiple resources, one can analyse the impact of the alternatives in terms of utilization of capacity and the waiting time of the jobs. If more machines are added, the waiting time as well as the utilization of the resource will come down. It is possible to analyse and select the best alternative on the basis of these measures.

In operational performance based methods, alternatives are analysed in terms of utilization of capacity and the waiting time of the jobs.

Decision trees are useful to evaluate alternative capacity choices on the basis of the cost of the capacity and the benefits. Further, the inherent uncertainty in the demand for the resource can also be modelled to assess the impact of the decisions. A decision tree is a schematic model in which different sequences and steps involved in a problem and the consequences of the decisions are systematically portrayed. Decision trees comprise nodes and branches. Each node represents the decision point and the branches represent the potential outcomes of the decision. The consequence of each outcome is measured as the cost of the impact, and the uncertainty associated with each outcome could be associated with the requisite branch. Using this basic information, the tree is constructed. After the tree is constructed, each branch in the tree is evaluated with respect to the costs, benefits, and uncertainty. The tree is evaluated from right to left (from end to beginning). As we move from right to left, unattractive portions of the tree are eliminated to arrive at the final decision. The use of a decision tree for evaluating capacity alternatives is explained with the help of Example 8.6.

EXAMPLE 8.6

A manufacturer of electronic accessories for use in computers currently has a capacity of 40,000 pieces per month. The business strategy group for the company recently performed a forecasting exercise to assess the emerging demand for the accessories in the next five years. The study revealed that there is a 40 per cent probability that the growth in demand for the accessories will be strong during this planning horizon and a 60 per cent probability that the growth in demand will be moderate. The study identified three options for the manufacturer to augment capacity. Option 1 is to expand the capacity by adding new capacity to meet the demand. Option 2 is to augment capacity in the existing factory itself by some de-bottlenecking operation (in which case there will be limits to capacity expansion). Option 3 is to go for subcontracting. The sub- contracting option adds marginal capacity and could be used as a temporary arrangement. If there is a strong growth in demand, then the new capacity could be added a year later. The study revealed the following additional information about the emerging scenario and the costs and benefits of each of the alternatives:

1. The cost of adding new capacity is ₹750,000. This cost goes up by 5 per cent if it is deferred by a year.
2. The cost of expanding in the existing factory itself is ₹275,000.
3. The cost of subcontracting is negligible, as no major investments are envisaged either at the supplier side or at the manufacturer side.
4. The revenue accruing from new capacity is as follows: If it is a strong growth, the revenue will be ₹850,000 and in the case of a moderate growth, the revenue will be ₹400,000. These figures do not change even if the new unit comes into operation a year later.
5. The revenue accruing from the expansion of the existing capacity is as follows: If it is a strong growth, the revenue will be ₹550,000 and in the case of a moderate growth, the revenue will be ₹300,000.
6. The revenue accruing from the existing factory with subcontracting is as follows: If there is strong growth, the revenue will be ₹350,000 and in the case of moderate growth, the revenue will be ₹180,000.

Arrive at an appropriate capacity planning strategy using a decision tree.

All revenues are yearly figures.

Solution

Constructing the Decision Tree

There are three decision alternatives at the first stage: add new capacity, expand, or go for subcontracting. After one year, there are two decision alternatives as it is possible to go for expansion or continue with subcontracting for the remaining planning horizon. At each stage there are two possible outcomes for the demand. The decision points are denoted by square nodes and the outcomes by circular nodes. Using this standard notation we construct the decision tree for the problem. Figure 8.15 shows the decision tree.

Evaluating the Nodes and Decision Alternatives

In the decision tree methodology, evaluation is done from right to left. Therefore, we proceed from Decision Point 2.

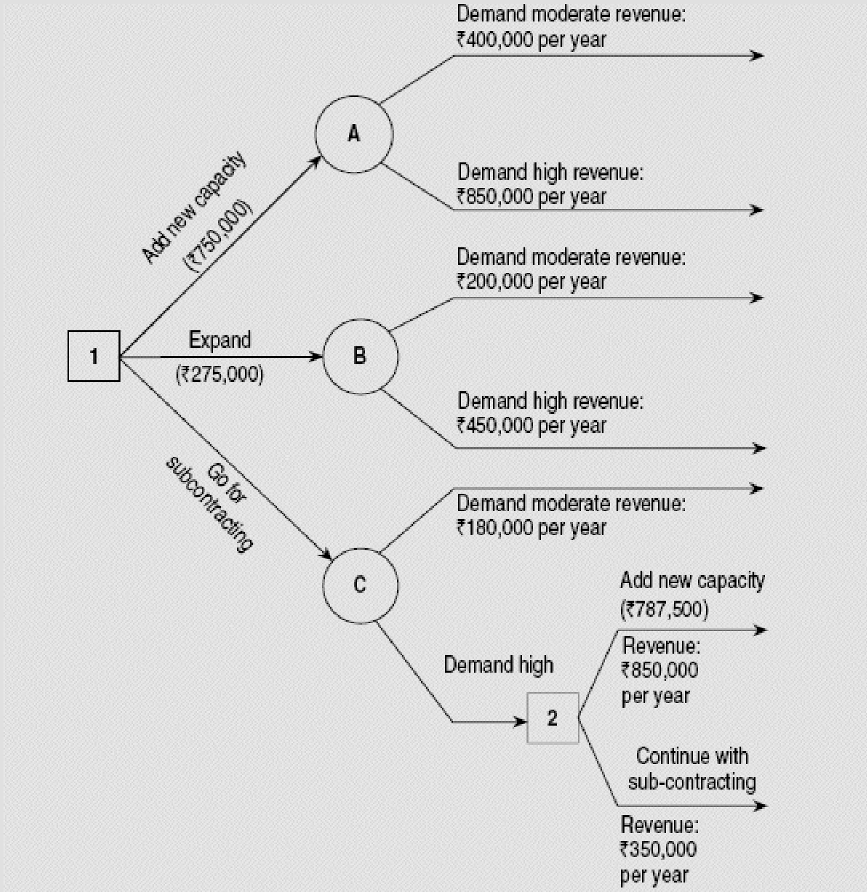
Decision Point 2

Revenue from adding new capacity = ₹850,000 × 4 = ₹3,400,000
Cost of adding new capacity = ₹787,500
Net revenue from this option = ₹2,612,500
Revenue from the subcontracting option = ₹350,000 × 4 = ₹1,400,000
Therefore, the best option at this stage is to go for adding new capacity.

Node A

Revenue in case of high demand = ₹850,000 × 5 = ₹4,250,000
Revenue in case of moderate demand = ₹400,000 × 5 = ₹2,000,000
E[A], the expected revenue at Node A, will be as follows:
E[A] = (4,250,000 × 0.40)1(2,000,000 × 0.60) = ₹2,900,000
Cost of adding new capacity = ₹750,000
Net revenue from this option = ₹2,150,000

FIGURE 8.15 The decision tree



Node B

Revenue in case of high demand = ₹550,000 × 5 = ₹2,750,000

Revenue in case of moderate demand = ₹300,000 × 5 = ₹1,500,000

E[B], the expected revenue at Node B, will be as follows:

E[B] = (2,750,000 × 0.40) + (1,500,000 × 0.60) = ₹2,000,000

Cost of expanding the capacity = ₹275,000

Net revenue from this option = ₹1,725,000

Node C

In the case of high demand, our evaluation of the decision point shows that it is better to add new capacity after one year than continuing with the subcontracting option. This will fetch a net revenue of ₹2,612,500 during the last four years. Moreover, in the first year, it would have fetched a revenue of ₹350,000.

Therefore, Revenue in case of high demand = ₹2,962,500

Revenue in case of moderate demand = ₹180,000 × 5 = ₹900,000

E[C], the expected revenue at Node C, will be as follows:

E[C] = (2,962,500 × 0.40) + (900,000 × 0.60) = ₹1,705,000

There are no costs of subcontracting. Therefore,

Net revenue from this option = ₹1,705,000

Since the expected value of Node A is the highest, we go with the decision of adding new capacity at the beginning itself rather than just de-bottlenecking or waiting for a year to sense the demand. In the decision tree in Figure 8.15, the best option at each decision point is shown with bold lines.

SUMMARY

- Process analysis is the mechanism used to understand the impact of process design on output, cost, or any other performance metric using some analytical tools. It also amounts to understanding the impact of alternative process configurations on the chosen performance metric.
- A pictorial representation of all process-related information can be developed using *process flow-charting*. Process flow charting employs a set of standard symbols and graphical tools to represent all the information pertaining to the process.
- Three generic planning premises are in use in operations management: *make to stock (MTS), make to order (MTO),* and *assemble to order (ATO).*
- The basic approach to planning in an MTS system is to schedule production for the purpose of replenishing stock to some predetermined level. On the other hand, the MTO planning methodology is used by organizations that typically manufacture products with high variety and low volumes.
- Organizations use input- and output-based measures for defining capacity. High-volume–low-variety manufacturers use output-based measures for defining capacity.
- Capacity can be augmented in organizations in alternative modes. Typical modes of capacity augmentation follow a cycle of insufficient capacity–excess capacity–appropriate levels of capacity.
- Capacity = Work + Waste. Therefore, one way of augmenting capacity in organizations is to eliminate waste from the system.
- The capacity planning framework changes with the time horizon. The emphasis in the short term is to maximize capacity availability through efficient use of resources. On the other hand, in the medium term, the emphasis is on matching the supply with the demand on a period-by-period basis.
- The capacity planning framework consists of a three-step process:
  - Estimate the capacity requirement for the planning horizon
  - Identify the quantum of capacity to be augmented
  - Select an appropriate alternative for capacity augmentation
- Selection of an appropriate alternative for capacity augmentation could be done using a decision tree model.

FORMULA REVIEW QUESTIONS

1. $\text{Capacity Utilization} = \dfrac{\text{Capacity put to use}}{\text{Total capacity available}}$

2. Capacity = work + waste

3. $\text{Capacity required (Labour)} = \dfrac{D \times S_L}{E_L}$

4. $\text{Capacity required (Machine)} = \frac{D \times S_M}{E_M}$

5. Capacity available in the system (Hours) − Machine: $N_d \times h \times N_m \times (1 - b/100)$
6. Capacity available in the system (Hours) − Labour: $Nd \times h \times NL \times (1 - a/100)$

REVIEW QUESTIONS

1. What do you mean by process analysis? Why should organizations conduct process analysis?
2. An automobile garage owner wants to perform process analysis in order to improve her customer service process. You have been engaged as a consultant. Prepare a one-page plan of action for the automobile garage owner.
3. What do you mean by process mapping? Explain with the help of an example.
4. Suppose you want to visit your bank to deposit your salary cheque and then withdraw some money from your account. Use your knowledge of process mapping and draw the process.
5. For the example given in Question 4, perform an NVA analysis and prepare a one-page report to the bank manager about the current status of the process. What are your key recommendations to the bank manager with respect to improving the process?
6. What do you understand by the term "business process"?
7. Give two examples of business processes in the following organizations:

    a. Hindustan Machine Tools Limited
    b. A primary school in your locality
    c. A Reliance Communications retail outlet
    d. Indian Railways' computerized ticket reservation system at the New Delhi Railway Station

8. What do you mean by BPR? Why is it an important process improvement tool for an organization?
9. Outline the key steps involved in a BPR exercise. Are these steps generic enough to apply to any business process?
10. Suppose that a travel agency has performed a process analysis with respect to attending customer requests for airline and hotel bookings. The analysis shows that it takes 30 minutes to finish this process and has identified the insufficient number of computers, people, and information as the possible reasons. Suppose the project requires redesigning to bring it to 15 minutes, how will you go about the task?
11. How do you define capacity in an operating system? Are input measures of capacity more appropriate than output measures of capacity?
12. Identify an appropriate measure of capacity in operating systems for each of the following:

    a. A watch manufacturer such as Titan
    b. The paint shop at Maruti Udyog Limited
    c. A healthcare hospital focused on cardiac diseases
    d. The Bangalore Metropolitan Transport Corporation (BMTC)
    e. The motor division of ABB (manufacturing several varieties of motors)
    f. The gear shop at Bharat Earthmover's KGF Plant

13. What are the alternative methods by which capacity could be augmented in an operating system? Explain with some examples.
14. How does knowledge of capacity help an operations manager?
15. What are the alternative metrics available to evaluate available alternatives for capacity planning/ expansion?
16. What are the alternative methods available for building up capacity in a system? Which method is the most suited for implementation?
17. Is capacity management a short-term or a long-term issue? Explain with examples.
18. What are the implications of adding capacity in huge chunks at less frequent intervals?
19. How do you define capacity utilization? What factors influence the utilization of resources in an operating system?
20. Why is capacity planning important? Outline the steps involved in a capacity planning exercise.
21. What do you mean by waste elimination? Does it have any relevance for capacity management?

PROBLEMS

1. Ram runs a small *roti* shop. People can place their order over the phone and come and collect the *roti*. Orders are taken for a standard pack of 5 *rotis*. The entire process is done in batches of 5 *rotis* only. *Roti* making and delivery has five steps. Preparing the dough (3 minutes), rolling (5 minutes), heating (4 minutes), packing (2 minutes), billing and cash (1 minute). Given this process, answer the following:

   a. Prepare a process flow chart and identify the bottleneck for the shop.
   b. If somebody calls Ram over the phone, when should he ask them to come?
   c. Suppose you go to his shop at 9:00 a.m. and then order 15 *rotis*. When will you collect them?
   d. If Ram keeps his shop open for 4 hours, how many *rotis* can he hope to make?

2. There are six stages in a semi-automated process and the relevant details are given in Table 8.6.

TABLE 8.6 Details of the Stages

Process Step	Process Time	Equipment	Labour
Step 1	20 seconds	Machine A	Worker A
Step 2	45 seconds	Machine B	No workers
Step 3	10 seconds	Machine C	Worker A
Step 4	20 seconds	No resources	No worker
Step 5	5 seconds	Machine D	Worker B
Step 6	10 seconds	No resources	Worker B

Use this information to answer the following questions:

   a. How long will it take to respond to an arriving order?
   b. What is the daily production if the system works for 8 hours every day?
   c. Develop a resource loading chart for the manpower and equipment usage.
   d. What is the utilization of each resource in the system?
   e. If we need to increase the production by 25 per cent, what should we do?

3. In Problem 2, consider the following changes:
The processing time at the bottleneck station could be reduced by 33 per cent by investing in better technology. The cost of this improvement is ₹160,000. If there is no demand constraint for this item, is it worthwhile to go for this improvement? How long will it take to pay back if the sale of each item leaves a contribution of ₹20 (Assume an 8 hour-per-day, 25 day-per-month steady-state operation)?

4. A manufacturer of table fans has a factory that works on a single-shift basis. A shift lasts eight hours, but 30 minutes will be lost in normal breakages and allowances to be given to the workers. There are 300 working days in a year. There is a fabrication shop, an assembly shop and a painting shop in the factory. Each unit requires 2 hours in the fabrication shop and 45 minutes each in the assembly and paint shops. The workers are at 80 per cent efficiency. Currently, the shop is manufacturing 20,000 fans per annum. Using this data, compute the following with respect to the manufacturing firm:

   a. If there are 24 workers in the fabrication shop and 12 each in the other two shops, what will the utilization of the workers be at the current level of operation?
   b. How many workers are required if the over-all utilization of the factory is targeted at 90 per cent?
   c. What is the additional number of workers required in each of the shops if the annual production increases to 25,000? (Assume a targeted utilization of 80 per cent in all the shops.)

5. An ortho-specialty hospital conducting micro-surgeries is now operating at a capacity of 20 surgeries a day. On average, each surgery takes 45 minutes of the surgeon's time, one hour of the pre-operative staff's, and two hours of the post-operative staff's in the hospital. A surgeon works for four hours a day while the staff work for eight hours a day. The hospital currently estimates that the surgeons work at a utilization of 94 per cent and the other staff at 85 per cent utilization. The hospital plans to increase its capacity by 20 per cent and it has all other infrastructure facilities to handle this proposed capacity expansion. What it needs to plan for is the human resources required during this expansion. It also proposes to bring down the utilization of surgeons to 85 per cent and that of the other staff to 75 per cent. The excess capacity will be used for training and development activities. If the cost of locating new staff, training, and inducting them into the hospital is ₹20,000 per person and that of a surgeon is ₹80,000, what will the initial costs of the expansion plan be?
6. A firm employs a process that has three steps to complete the process. Step one takes 10 minutes, step two takes 12 minutes, and step three takes 14 minutes. There is setup involved in steps one and three, which takes 4 minutes each. Once set up, step one can process up to two batches and step three up to three batches. Currently they operate with a batch size of one.

   a. What is the hourly capacity of the process now? Which is the bottleneck in the process?
   b. What is the effect of adding one more unit in the bottleneck step? Which is the new bottleneck?
   c. Instead of adding one more unit at the bottleneck, if we increase the batch size to two what will be the process capacity?
   d. What will be the process capacity if the batch size is three?
   e. Which option would you recommend?

7. A restaurant works in a busy locality in Kanpur. At the moment they have adequate cooking capacity and space to seat the customers. They would like to know the adequacy of the service manpower available with them. The order takers spend on an average 15 minutes per arriving batch of customer and the servers spend 48 minutes.

   a. If there are five order takers and 12 servers, how many batches of customers they can serve every day?
   b. If a batch of customer arrives on an average every 4 minutes, can they handle the demand with the existing staff?
   c. The restaurant found that during peak hours a batch of customer arrives every 3 minutes. Will they be able to handle the demand?
   d. How many order takers and servers should they employ if they want to work with an utilization of 75% (during non-peak hours)?

8. A travel agency attends to various travel planning requirements of its clients. They work six days a week and are open between 9.30 am and 6.00 pm. They have lunch break between 1.30 pm and 2.30 pm. Typically, servicing a client requirement takes about 22 minutes. There are five travel consultants currently employed. There is 10% absenteeism of employees.

   a. If they receive service requests at the rate of 8 per hour, what is the utilization of the service consultants?
   b. They want to expand their operations so that they can handle 100 requests per day. They would also like to work with a targeted utilization of 80%. Identify the number of travel consultants to be employed under the following conditions:

   i. No changes in the current operating conditions
   ii. Lunch break is reduced to 30 minutes instead of 1 hour
   iii. They work one more hour by starting at 9.00 am and closing the office at 6.30
   iv. Process improvements brought down the average service time to 20 minutes per client.

9. TSMC manufactures semiconductor chips for companies such as Nvidia and Qualcomm. A simplified process for chip manufacturing at TSMC consists of three steps. Step one is Depositing, step two is Patterning and step three is Etching. Table 8.7 gives the required processing time and setup time. Assume the unit of production is a wafer. The plant operates for 8 hours a day. The demand is 800 wafers per day. Also assume that a setup can only begin once the batch has arrived at the machine. All units of a batch need to be processed before any of the units of the batch can be moved to the next machine.

TABLE 8.7 Data for Problem 9

Process Step	Depositing	Patterning	Etching
Setup Time	15 minutes	30 minutes	No setup
Unit Processing Time	0.25 min/ wafer	0.15 min/ wafer	0.30 min/ wafer

a. What is the process capacity in wafers per hour with a batch size of 500 wafers?
b. Which batch size would minimize inventory without decreasing the process capacity found in part (a)?
c. A process improvement leads to a setup time reduction in step two (Patterning). The new setup time is now 12 minutes. For which batch size is step two (Patterning) the bottleneck?

10. An eye hospital has made an elaborate study on its process and the arrival pattern of the customers to the hospital for eye examination and corrective procedure for a certain kind of illness. Since the patients are directed from a pre-screening section, all of them are subjected to a similar treatment. All the arriving patients go through the same set of steps. However, only one in four go through the HFA and OCT stages. On average, it was found that 12 patients arrive every hour during the operation of the hospital. The details are given in Table 8.8. The time (minutes) is an average over some period of observation.

a. Develop a process flow chart for this problem. Use the process flow chart and indicate the capacity of the various stages of the system.
b. How long will an arriving patient be in the system?
c. Estimate the capacity of manpower and other resources required for the hospital.
d. Are there sufficient numbers of resources in the system?
e. What is the cycle time for the system? Which is the bottleneck stage?
f. If the hospital is willing to make further investments in manpower and equipment, can you help them prioritize their investments?

TABLE 8.8 The Details for the Problem

	People Involved (number Available)	Equipment Involved (number Available)	Process Time Activity (minutes)
Registration	Receptionist (1)	None	1
Vision	Refractionist (1)	Refraction room (1)	3
Refraction	Refractionist (2)	Refraction room (2)	8
Preliminary investigation	PG Student (6)	Slit lamp (2)	15
HFA (visual-field examination)	Technician (1)	Visual field-testing machine (1)	20
CCT (measuring central corneal thickness)	Technician (1)	CCT machine (1)	3
OCT (scanning of the optic nerve)	Technician (1)	OCT machine (1)	20
Dilation (administering dilating drops)*	Nurse (4)	None	30
Constriction (administering constricting drops)*	Nurse	None	60
Final	Medical officer (4)	Slit lamp (5)	5
Counselling	Counsellor (3)	None	5

Note: **Two minutes are spent by the nurse in applying drops to a patient. Nurses conduct both the tasks in an inter-changeable fashion.*

MINI PROJECT

Making continuous improvements is an essential requirement of all organizations, no matter how successful they are. Choose one organization from any one of the following list to conduct an improvement project:

a. Any retail branch of a bank.
b. Any medium-sized post office in your neighbourhood.
c. The hostel administration in your college hostel.
d. The general office administration in your college or any nearby office.
e. Any small or medium manufacturing firm in your locality.

For the organization that you have chosen, undertake an improvement project along the following lines. First, talk to the head of the organization to understand the major problems and concerns. Based on your understanding of the problem and consultation with the members in the organization, identify a set of measures that needs to be improved in order to solve the problem and set some meaningful targets for the same over the next six months. Collect data to assess the current status of these measures, the business processes affecting its performance and the activities that currently constitute these business processes. Perform the necessary analyses of the various business processes and write a final report detailing the steps and your recommendations to the organization regarding the nature of efforts to be undertaken for improving the situation and solving some of the problems listed. Also, clearly identify the challenges in the process and the nature of the precautions that the unit head should take while implementing your recommendations.

CASE STUDY

Vasudhri Tooling Limited

Introduction

Vasudhri Tooling Limited (VTL) is promoted by a technical training foundation and managed by a board of directors. VTL has two production units, one in Bangalore in Karnataka state, and the other near Vellore in Tamil Nadu. Both have independent and sophisticated tool rooms and component divisions for the manufacture of plastic-moulded and sheet-metal components. The unit at Bangalore has a separate CNC division and product engineering division for the development of products. VTL has dedicated ancillaries where all the assembly-line know-how, equipment tooling and technical supervision and control are held.

The main activities of VTL include the design and manufacture of press tools and injection moulds, along with the manufacture of sheet-metal parts and injection-moulded/ compression-moulded parts. The company’s main activities fall into the category of manufacture of electrical products for automobiles. The major products manufactured by the company are steering-column combination switches for four-wheelers/trucks, parking lamps, headlamps, blinker lamps (indicators), wiper-speed controls, hazard-warning switches and central locking systems. All the major players in the automotive industry in India are VTL's customers. In addition, VTL markets its products in the after-sales segment as spares.

The Manufacturing Process for Combination Switches

The product consists of plastic, sheet-metal, and standard parts. All the plastic and sheet-metal parts are made "in-house", both at the Bangalore plant and the Vellore plant.

The Vellore plant supplies parts to Bangalore. The materials are centralized at the Bangalore plant, which has the necessary infrastructure facilities.

Assembly Operations: As a policy, VTL has its assembly operations subcontracted by developing dedicated assembly units. Presently, there are four assembly units (sub contractors): Unit 1 at Vellore; Unit 2, 40 km away from the VTL plant at Bangalore; and Units 3 and 4 about 4 km away from the Bangalore plant. VTL has placed its production and quality assurance engineers at each unit. The operators are trained and functionally controlled by VTL. All materials are sent to subcontractors for assembly. The management of material movement is a very critical activity in ensuring that the line is run to full capacity daily to get the desired daily output. The frequency of the dispatch of material varies with each unit. However, some materials are sent daily due to shortages. Presently, the materials are sent in sets due to excise regulations.

One of the major sub-assemblies of this product is the wiring harness. It has 20 cables crimped with terminals which are inserted into plastic connectors. The other side of the cables is soldered to a PCB which has certain copper rivets that acts as contacts for electrical functions.

Products are reworked by the replacement of certain parts. Whenever reworking is not possible, such products are defaced and scrapped. Products are packed online and dispatched to customers on alternate days of the week. In case of urgencies caused due to a shortfall in production or demand for higher quantities from the customer, the products are sent by air on a daily basis at an additional cost.

The Background of the Problem

The surging demand for four wheelers has put pressure on manufacturers to produce high volumes. The auto component industry is also under pressure to upgrade technology, improve quality, and increase capacities. The buyers' major expectations are quality, price, delivery, new-product introduction, and meeting fluctuating demands. The major problem at VTL can be attributed to two reasons: high lead time for receipt of components from the component division, and high material movement. There is too much unnecessary movement of material in the process of the switch assembly, due to which fire fighting and chasing is done at every level to achieve the targeted production and dispatches. The inventory in the pipeline, especially the WIP, is high (refer to Table 8.9).

VTL's management felt that one way to increase capacity was to reduce lead time. Therefore, a study was initiated to estimate the lead time for manufacturing the combination switches (see

Figure 8.16). The study focused on an overall reduction in the manufacturing lead time of combination switches especially in the areas of manufacturing processes and movement of materials. By implementing the study findings, the management was hopeful of improving the performance of the division by reducing lead time for manufacturing.

The Lead Time Reduction Study

To carry out the manufacturing cycle time reduction project, the switches manufactured for one major customer were selected. These models of switches accounted for about 50 per cent of the total production per month. Once successful, the same could be implemented in other models in a phased manner. A batch size of 600 switches was considered for this study. The production of these switches was 600 pieces per day. The dispatch was made in batches of 1500 to 1800. Data was collected in the following operations to determine the existing manufacturing cycle time of the combination switch: final assembly process, wiring harness assembly process, sub-assembly process for wiring harness, rework, rejections, material movement, and waiting times including processing.

The various stages of operations in the final assembly were broken down into activities and feedback was obtained regarding the time taken at each activity level. Each activity level was defined and the process time for that activity including all operations was measured. This involved inputs such as worker skills, equipment type, work done, methods used, and the sequence of activities. The “out” stage at each activity level was taken as the input for the subsequent activity. A similar approach was used to determine the cycle time for the wiring harness assembly and the sub-assembly process.

The number of stages the material moved through before getting into the stores as sub-assembly was determined. Also, the documentation procedure and the number of documents prepared were determined. The flow chart in Figure 8.16 shows the details of the process and the lead time. The details of the processing time and total lead time are given in Table 8.10.

The lead time for each of the four processes was calculated:

- Final assembly time: 33.5 hours
- Wiring harness assembly time: 50.0 hours
- Wiring harness sub-assembly time: 32.5 hours
- Material delivery time from Unit 3: 8.0 hours

Hence, the total manufacturing lead time for production of switch assembly for a batch of 600 switches = 33.5 + 50.0 + 32.5 + 8.0 = 124.0 hours.

TABLE 8.9 WIP Inventory of Combination Switches

Month	Production Quantity	Value of Production	Value of RM Consumption	Work in Process (WIP)	WIP to Value of Production (percentage)	WIP to Value of Consumption (percentage)
April	23,043	61.33	42.64	25.94	42.30%	60.83%
May	34,535	85.58	64.79	21.77	25.44%	33.60%
June	31,099	86.86	70.88	23.30	26.82%	32.87%
July	38,075	109.49	84.29	31.90	29.14%	37.85%
August	34,118	84.68	62.80	22.70	26.81%	36.15%
September	25,452	72.07	56.90	23.93	33.20%	42.06%

The study was concentrated around activities that consumed time for the highest non-value-added activities in the manufacturing cycle, and worked towards eliminating wasteful activities to shorten the lead time. The study identified operations that took time beyond permitted limits or had been added over a period of time to meet quality and quantity requirements. The time taken for such operations had increased the lead time considerably.

FIGURE 8.16 Results of the manufacturing lead time study at VTL

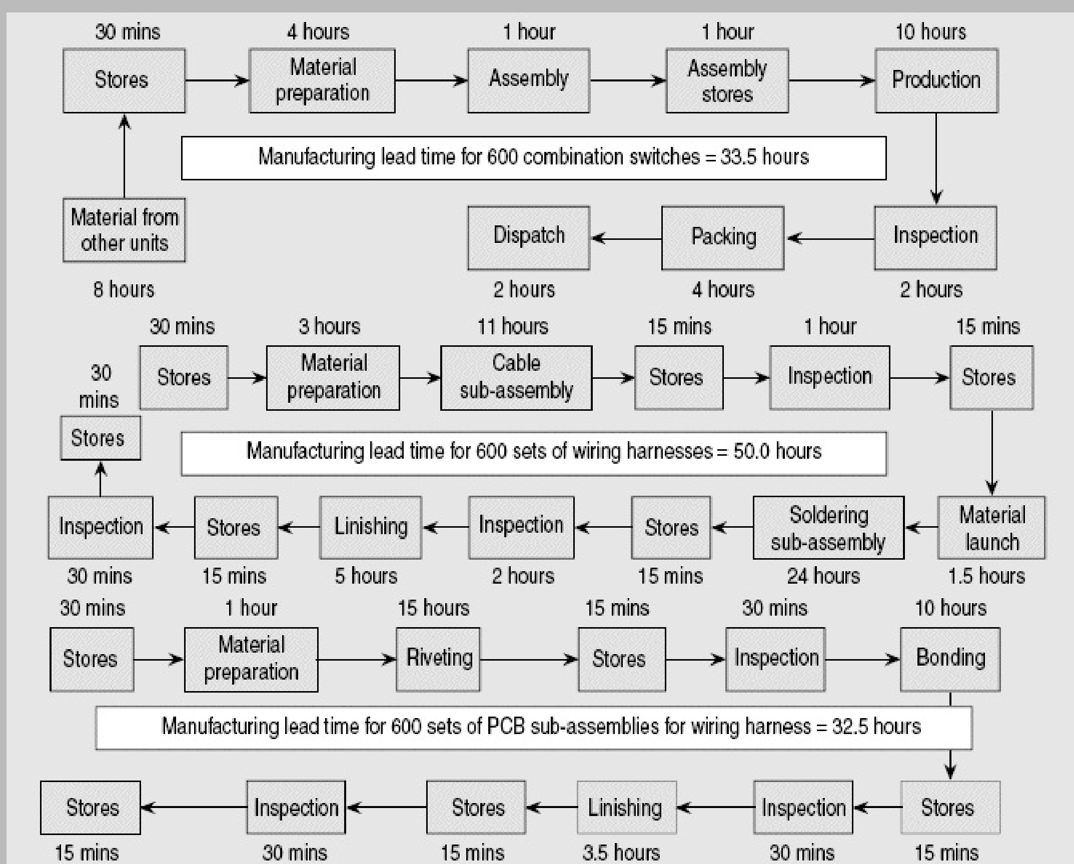


TABLE 8.10 Lead Time for a Batch of 600 Combination Switches

Activity	Observed Lead Time	Value-added	Non-value-Added	Other (delay)	Value Added to Lead Time (percentage)
Final assembly	33.50	8.50	1.50	23.50	25.37%
Wiring harness assembly	50.00	16.00	10.00	24.00	32.00%
Wiring harness sub-assembly	32.50	10.40	16.10	6.00	32.00%
Material movement	8.00	0.75	6.25	1.00	9.38%

The study identified certain areas that should either be eliminated or streamlined, which would result in lead time reduction. These are as follows: excessive material movement, wiring harness operation streamlining (existing), reorganizing the stores activities, elimination of duplicate-inspection activity in the organization, elimination of the PCB bottom plate in the wiring harness sub-assembly, and reduction of rework online.

QUESTIONS FOR DISCUSSION

1. What is your assessment of the problem that VTL is currently facing? Will efforts to reduce lead time help VTL improve its competitive position?
2. Based on the data available, list the major causes for long lead time at VTL.
3. What should VTL do further in their efforts to reduce lead time? Identify three major areas that require attention for reduction of lead time. Do you have any suggestions to provide?

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CHAPTER 9

Design of Manufacturing Processes

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What are the factors that significantly determine process design in organizations?
- How are process choices and flow characteristics of jobs linked? Do they have any bearing on the structural aspects of organizations?
- What are the well-known process design options available?
- How do volume–variety–flow dimensions influence the layout decision in an organization?
- What are the different types of layouts available?
- How can we assess the appropriateness of a layout design?
- How can one design a product layout, a process layout, and a group technology (GT) layout?
- What software packages are available for solving the layout problem?
- Will new technology make process design any simpler?

Over the years, Milltec has realized the importance of addressing manufacturing process design and layout issues. Through a process of continuous improvement, Milltec employees and management have realized that several benefits arise out of designing an appropriate layout and workplace organization.

Source: Milltec Machinery Pvt. Ltd.

ideas at Work 9.1

Process Design at Milltec Machinery

Milltec Machinery Private Limited is a Bangalore-based manufacturer of equipment for rice and flour mills. During the short period for which they have been in operation, they achieved significant growth on account of the product range they have been able to bring to this sector of the industry. They manufacture a range of machines under four broad product categories: re-cleaning, hulling, polishing, and grading. Within each category, they have three or four sub-product categories and a range of sizes and operating characteristics, resulting in over 200 different products. Machine-tool manufacturing typically involves a certain amount of customization.

Designing appropriate manufacturing processes, selection of the right machine tools and other manufacturing resources is critical to improved performance and operational control at Milltec. Milltec employs the latest technology in manufacturing. It believes in producing machinery of international standards at affordable prices. Laser cutting is used in all sheet-metal operations to ensure precise assembly. Milltec uses the CNC press brake for uniform bending of sheet-metal parts. CNC machining centres are utilized to produce machined components. Milltec uses MiG welding stations for the welding operations.

Once the type and number of machines required for the manufacturing process is identified, the next important step is to design an appropriate layout of these resources on the shop floor. At Milltec, manufacturing is organized on a functional basis. The fabrication shop is spread over 750 m^2. The assembly and paint shops are spread over 2,000 m^2 and the machine shop over 500 m^2. Milltec has a dedicated engineering department to cater to the erection and commissioning of projects. It also has an R&D department.

Over the years, Milltec has realized the importance of addressing manufacturing process design and layout issues. Through a process of continuous improvement, Milltec employees and management have realized that several benefits arise out of designing an appropriate layout and workplace organization. These benefits include better production planning and control, less work-in-process inventory, reduced cost of production, better employee morale, and greater visibility of problems at the workplace.

Source: Company sources, http://www.milltecmachinery.com

Designing of processes is an important and early step in operations management. The designing of manufacturing processes essentially consists of certain choices we make with respect to the flow of parts in a manufacturing system. For instance, we need to decide on the types of machines to use, the number of machines of each type, and the manner of their placement on a shop floor. As a prerequisite to this, a detailed analysis of how each component will be manufactured is required. This would mean determining the number of steps involved in manufacturing, the machines used, and the time spent in each of these steps. It is more commonly referred to as process planning. Process planning is technical and is mainly a production engineering activity. We do not focus on this aspect of process design in this chapter.

Once the technical elements of process planning are finalized, at a higher level, the **design of processes** indicates how the manufacturing resources are organized in the operations system so that flow patterns are optimized and appropriate operations management tools can be used to effectively control the overall operations. Process design is defined by the nature of the activities that we pursue in an operating system. If the manufacturing system caters to a wide range of products, it demands a certain type of process design, as opposed to one that mass-produces just one or two variations of a product. By choosing an appropriate process, it is possible to streamline the product flow and deploy appropriate operations management practices commensurate to the process design.

> The **design of processes** essentially consists of various choices that we make with respect to the flow of parts in a manufacturing system.

9.1 DETERMINANTS OF PROCESS CHARACTERISTICS IN OPERATIONS

Before we understand the various process choices available to an operations manager for configuring a manufacturing system, let us understand the factors that influence the choice of alternative processes. Generally, three important aspects have a significant influence on the process: volume, variety, and flow.

Volume

Volume indicates the average quantity of products produced in a manufacturing system. In reality, organizations differ on this from one end of the spectrum to the other. Turnkey project management organizations such as Larsen and Toubro (L&T) and Bharat Heavy Electricals Limited (BHEL) will typically have a production volume of just one. At the other extreme, organizations catering to the consumer non-durable and FMCG sectors have high volumes of production necessitating continuous production. Examples include the manufacture of spark plugs, electric bulbs, soaps, standard electrical fittings, and common household utilities. Many chemical process industries also belong to this category. Between these two extremes, we have mid-volume manufacturers who offer several versions of products. There are numerous examples of mid-volume manufacturing in consumer durables, white goods, and several industrial products. Hindustan Motors, for instance, manufactures several types of earth-moving equipment that belong to the mid-volume category.

Three important aspects have a significant influence on the process: *volume*, *variety*, and *flow*.

Variety

Variety refers to the number of alternative products and variants of each product produced in a manufacturing system. Let us consider a watch manufacturer such as Titan Industries Limited. Titan offers more than 40,000 varieties of watches. These varieties stem not only from alternative product lines but also from variants in each product line. Similarly, consider a car manufacturer such as Tata Motors. The Tata Indica is available in several models. Basically, there are the petrol and diesel versions. However, within the petrol and the diesel versions, there are variations such as the GLS, GLX, VX, VXi, AX, and so on. While one version will have power steering, the second will have power steering and power windows, the third may have automatic transmission, and so on. A choice of colours adds another dimension of variety to passenger car manufacturing.

An increase in the variety of product offerings is likely to introduce variety in manufacturing processes. More varieties may mean alternative production resources, materials, skill of workers, and an increase in the number of stages of production. It may call for better operations management practices. Planning and scheduling may become more complex on account of these added choices in the manufacturing system.

One sees a similar phenomenon in service systems too. Assume that a travel agency was earlier engaged only in selling tickets for bus journeys from Delhi to Chandigarh. In the course of time, if the agency added booking of bus tickets to multiple destinations, rail tickets, air tickets for domestic travel, and air tickets for international travel, one can imagine how many alternative choices of processes, skill sets and resources are required by the travel agency. Operations management in the case of additional services is far more involved and complex.

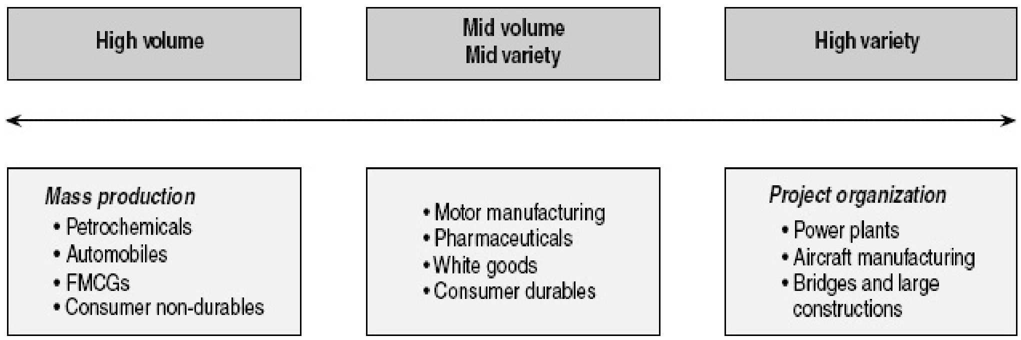
Flow

Irrespective of the nature of activities involved, all manufacturing systems require certain input material with which the processes begin. The material undergoes a conversion process from the raw material stage to the finished goods stage. *Flow* indicates the nature and intensity of this phenomenon. Knowledge of flow provides vital clues to the operations manager about production planning and control issues that need to be addressed. It also provides useful information about the complexities of operations management in an operations system.

Volume, variety, and flow are linked to one another. In general, volume and variety will have an inverse relationship. When the volume of production is very high, the firm is likely to be engaged in the manufacture of fewer varieties of products. On the contrary, if the firm caters to a wide range of products and services, then the production volume of each of these variations is likely to be very low. Figure 9.1 identifies typical examples belonging to three categories: (i) high volume–low variety, (ii) mid volume–mid variety, and (iii) high variety–low volume. Furthermore, volume and variety influence the flow patterns in a manufacturing system.

Therefore, process design choices available to an operations manager could be understood by analysing alternative flow patterns. Using this approach, we shall understand how volume, variety, and flow influence the process design in an operations system.

FIGURE 9.1 Relationship between volume and variety in operations systems



9.2 TYPES OF PROCESSES AND OPERATIONS SYSTEMS

Process characteristics are largely determined by the flow of products in a manufacturing system. Therefore, it is useful to first identify the nature of flow in operations and then identify the process choices available to the operations manager for each category of flow. Generically, three types of flows can be identified in manufacturing systems: continuous, intermittent, and jumbled.

> Three types of flows exist in manufacturing systems: continuous, intermittent, and jumbled.

Continuous Flow Systems

A continuous flow system is characterized by a streamlined flow of products in the operating system. Typically, in such systems, the conversion process begins with the input of raw material at one end. It progresses through the system in an orderly fashion to finally become finished goods. The production process is sequential and the required resources are organized in stages. Continuous flow is largely a result of technological constraints and a high volume of production. In the manufacture of petrochemicals, steel, pharmaceuticals, cement, and glass, the reason for continuous flow is technological constraint. For example, in a glass manufacturing unit, once the manufacturing process begins, it cannot be stopped until finished glass components come out of the system.

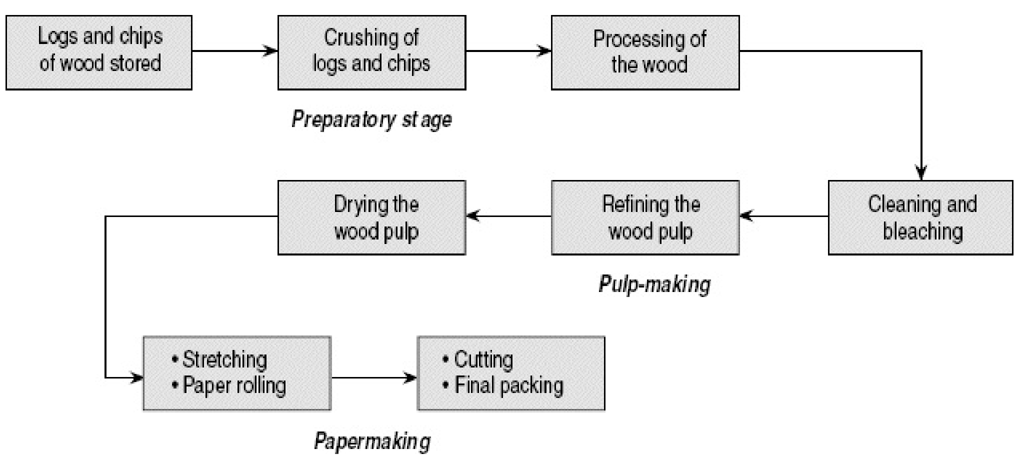
On the other hand, in a discrete manufacturing industry, the high volume of production of very few varieties results in a streamlined flow. Consider the case of Mico’s manufacturing of spark plugs. Due to fewer variations and the large volume of production, the production system is configured in such a manner that an orderly flow is possible. Similarly, in a fast-food outlet offering very few variations for breakfast during the peak hours in a busy locality, the system will have a highly streamlined flow. Despite the similarity of streamlined flow in process industries and mass production systems, there are important differences with respect to operations management practices between the two. Therefore, it is useful to discuss these issues separately for these two categories.

Process Industries

Process industries have peculiar characteristics compared to discrete manufacturing industries. Process industries have a closed manufacturing set-up and finished goods are typically obtained at the end of the manufacturing process. In some cases, it is possible to derive products during the intermediate stages of the process in the form of by-products. An example of a process industry is paper manufacturing. Figure 9.2 illustrates the paper-manufacturing process in simple terms.

An analysis of the paper-manufacturing process will reveal several features of a process industry. As shown in the figure, there are three stages in the paper-manufacturing process: the preparatory stage, pulp making and papermaking. During the preparatory stage, logs of wood and chips of various sizes are first fed into the system. The logs of wood and the chips are broken into smaller and uniform pieces in a crusher. After the pieces are cut into uniform pieces, they are “cooked” in a huge chamber where some chemicals are also added. During this process of cooking, the pieces are digested and the fibres are laid in a uniform pattern. This is done through a chemical process. After this process is complete, it is ready for making wood pulp. The pulp-making process is nothing but further refining of the wood fibre and cleaning and bleaching of the material. Finally, excess moisture is removed to form the pulp. At this stage, the pulp is almost devoid of moisture and is in a near-solid state. Therefore, it is possible to press it into the required thickness and remove further moisture. This is the last stage of the process known as papermaking. The dried and processed paper can be rolled into reels and cut to required lengths and shapes.

FIGURE 9.2 The paper-manufacturing process



The papermaking example illustrates certain distinctive features of process industries:

- Once the logs (raw materials) are fed into the system, it is not possible to stop the system until the dried wood pulp reaches the paper-rolling and cutting (final) stage.
- Since the process is continuous, there should be a balance of capacity between all the stages in the manufacturing process to maintain an even flow of the material from the raw-material stage to the finished-goods stage. Otherwise, there will be a capacity mismatch, which may result in gross underutilization of resources.
- The productivity of the system is directly related to the flow rate (or throughput) of the product.
- Typically, process industries require huge capital investments in the manufacturing system as incremental addition at a later stage is not possible. Due to this, high productivity implies lower production costs and vice versa.
- An important operations management task in process industries is making continuous process improvements and capacity de-bottlenecking to maximize the flow rate in the system.
- As the flow rate directly determines productivity, it also implies that failure of any intermediate stage in the system will have an adverse effect on the cost as the entire system will have to be stopped (see Ideas at Work 9.2 for an illustration of this).

VIDEO INSIGHTS 9.1

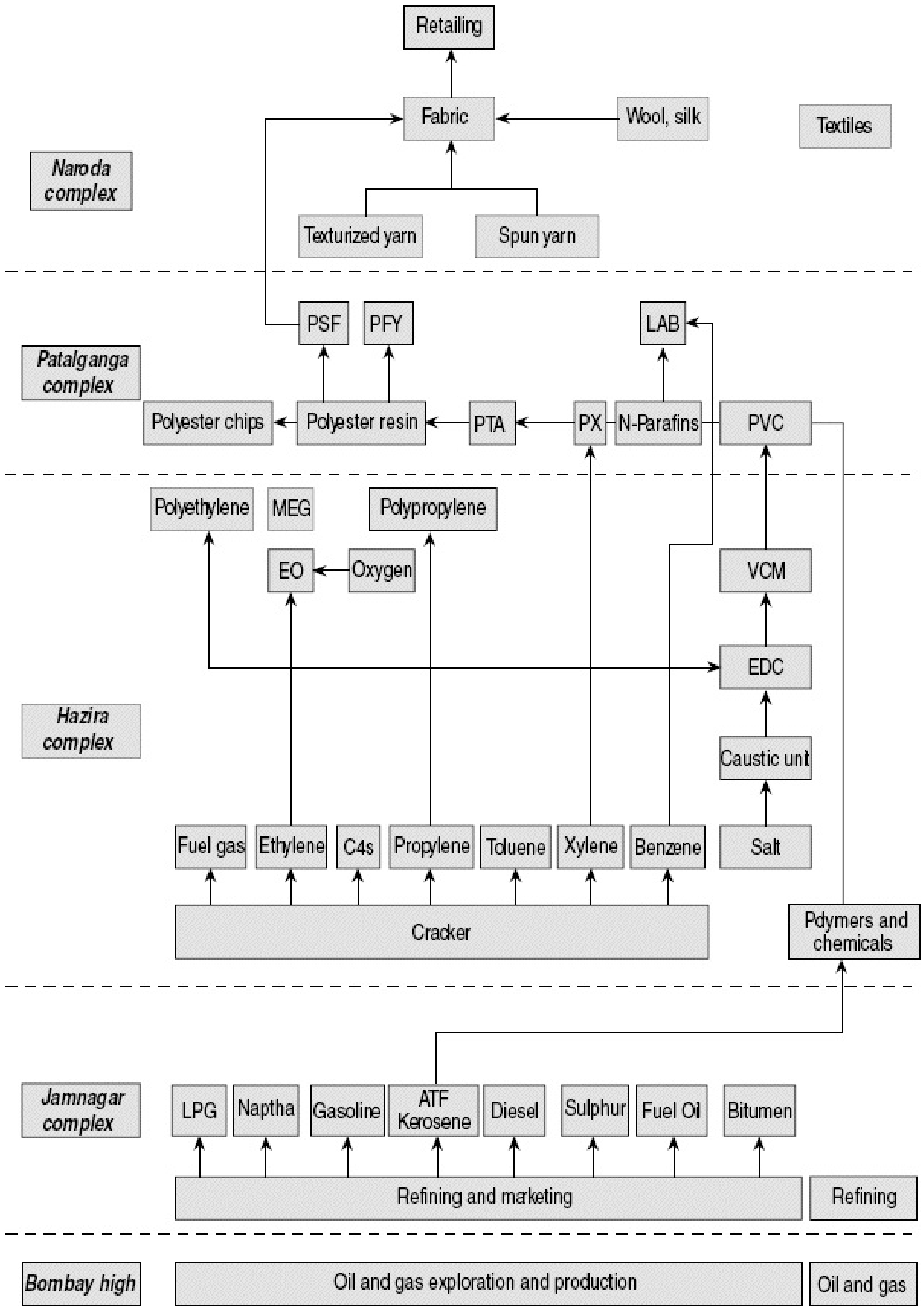
A continuous or a batch manufacturing system typically used by process industries and mid-volume manufacturing organizations faces a different set of issues when it comes to various operations management practices. In order to understand this, it is valuable to make a factory visit to one such manufacturing system. Manufacturing of sugar and apparels is representative of such industries. To know more about how these are being manufactured, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

The need to keep the production facilities continuously running in a process industry directly translates into a need to be good in maintenance management. Therefore, process-industry firms invest more time in developing good maintenance practices.[1]

Moreover, the amount of spare-parts inventory that they carry will be a significant portion of the overall inventory in the system. Ideas at Work 9.2 illustrates how disruptions in the production process, though unavoidable, can raise the costs incurred by process-industry firms and increase their losses. Due to the continuous and closed-loop nature of the entire manufacturing process, process industries tend to have very little work-in-process inventory.

Although not evident from the paper-manufacturing example, process industries benefit vastly from the vertical integration of their operations as well as from the addition of several secondary conversion facilities. This is because, at certain intermediate stages of the processing, by-products are released from the manufacturing system. Having the facilities to process them into useful products will lower the overall cost of the production system and increase revenue generation opportunities. The other alternative will be to transport the by-products to another point of demand at an extra cost. One of the best examples of vertical integration can be seen in the development of various facilities by Reliance Industries Limited. Figure 9.3 provides a good illustration of the backward integration concept for process industries.

FIGURE 9.3 Backward integration in process industries: the case of Reliance Industries



Source: Based on the author's research

ideas at Work 9.2

The Polyester Filament Yarn Plant at Reliance Industries Limited

Let us take the example of the polyester Limited at Patalganga to understand how disruptions are a costly, though unavoidable, part of process-industry firms.

In simple terms, the manufacture of polyester filament yarn is done in three stages. In the first stage, the pre-polymerization activities include feeding in the required chemicals and catalysts for further processing. The second stage is continuous polymerization. During this stage, the polymer is created in molten form by a continuous polymerization unit and sent for spinning. In the third stage, the molten polymer enters into the spinning machine through packs. Packs are small cylindrical assemblies packed with steel powder that act as filters. When the molten polymer passes through the pack, the impurities contained in it are removed. The polymer finally enters the spinning machine, where it is finally wound on bobbins. There are metering pumps to monitor the flow of the polymer as it comes out of the continuous polymerization unit. There are 64 metering pumps that monitor the flow of polymer into each spinning machine. A single inverter controls all the 64 metering pumps.

Disruption of production for certain changeover requirements is unavoidable. Changeovers are necessitated by the need for changing the packs as packs have a finite life. Since packs act as filters, over a period of time, impurities accumulate in the pack and this increases the pressure. When the pressure reaches a certain threshold, the metering pumps will not be able to function properly. At this stage, the production needs to be disrupted for a pack change. A pack changeover involves the following steps: First, the metering pumps are stopped and the throughput of the continuous polymerization unit is reduced. After the existing packs are removed, the pre-fabricated ready-to-use packs are pre-heated to 280°C–300°C and then inserted. The metering pumps are then started and the continuous polymerization unit's throughput is restored to its original value over a period of time.

There are many losses due to this disruption. The continuous polymerization unit works continuously as stopping it will jeopardize the entire production unit. During the time the system is put on hold, the entire molten polymer produced will be wasted. There will also be losses due to quality until the unit stabilizes. Normally, when there is a throughput fluctuation, the viscosity of the polymer is altered and this results in waste and downgraded quality of finished products. Similarly, after every disruption, the polymer takes about two and a half hours to change from bright to semi-dull. The output during this entire period is also wasted. Other costs include manpower costs and the opportunity cost of lost production.

The example clearly shows how important is it for process-industry firms to avoid breakdowns, unnecessary stoppages and changeovers. Therefore, investment in good maintenance practices and higher levels of spare-parts inventory are characteristic features of process industries.

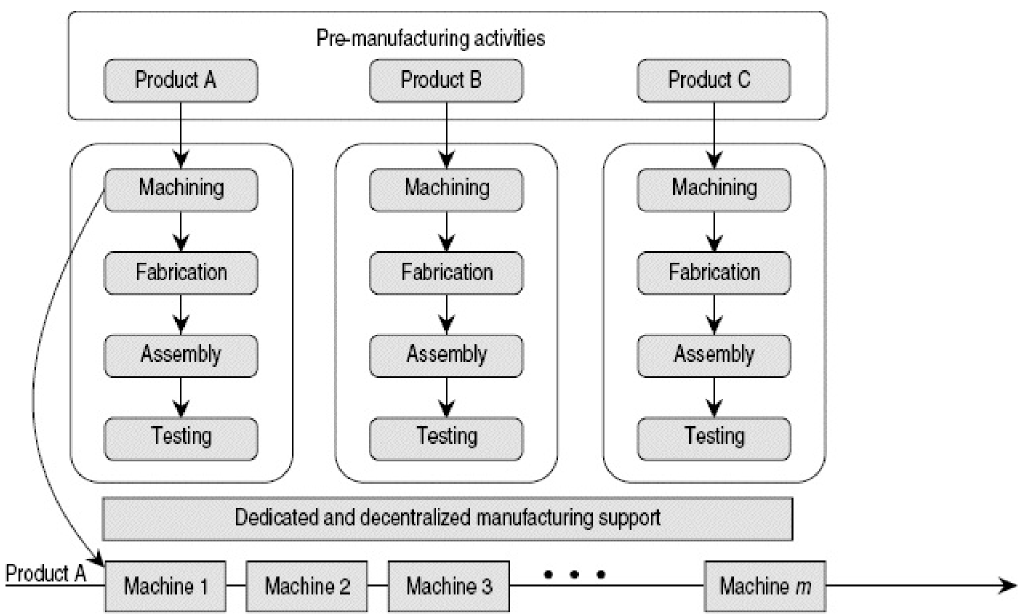
Source: Based on the author's research.

Mass production

The mass production system in the discrete manufacturing industry is another example of continuous and streamlined flow in the manufacturing system. In a mass production system, the volume of production is very high and the number of variations in the final product is low. Therefore, it is possible to organize the entire process by dedicating the required manufacturing resources for each product variant and arranging the resources one after the other, as per the manufacturing sequence. Such a structure is typically known as a product-line structure. Due to this arrangement, a streamlined flow is possible. Automobile and two-wheeler manufacture, the manufacture of electrical components (such as switches), and that of healthcare products (such as disposable syringes)—all are typical examples of high-volume production. Other examples include the manufacturing of several consumer non-durables.

Process design for streamlined flow can be visualized at two levels in a mass production system. At the overall level, each product will flow across departments in a streamlined fashion. Furthermore, within each department, there will be an orderly flow of components and materials. In operations management terminology, the manner in which the manufacturing resources are arranged for mass production is referred to as a *flow shop*. Figure 9.4 depicts the department-level design as well as the typical flow-shop structure within each department.

FIGURE 9.4 Process design and flow structure for a mass production system



As in the case of process industries, balancing of capacity across various stages of the manufacturing system is required to maximize throughput and productivity. Moreover, line stoppages due to breakdown and asynchronous production practices will also be detrimental to the working of the system. Therefore, better maintenance management practices and appropriate design of product-based layouts are important operations management practices to be followed in a mass-production system.

VIDEO INSIGHTS 9.2

Automobile manufacturing has always been in the forefront of bringing new innovations in manufacturing technology, processes, and design of manufacturing systems. Therefore, one can develop a good understanding of the design of manufacturing systems by closely observing manufacturing of passenger cars. Manufacturing of Honda Amaze at the Tapakura plant in India and Mercedes Benz C class cars in an overseas plant demonstrates these concepts well. To know more about these, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Intermittent Flow

All manufacturing firms do not have the benefit of high volume and low variety like a mass production system. As customer preferences increase, the need for creating more variety also increases and firms respond to this requirement by expanding the product line. Moreover, as competition increases, organizations try to retain their market share by introducing new products. An illustration of this is the passenger car segment in the country. The passenger car segment was delicenced in 1993. Until then, there were very few car manufacturers. They also offered fewer variations. However, once the competition increased and customer expectations went up, product variety also went up.

Intermittent flow systems are characterized by mid-volume, mid-variety products/services.

When variety increases, the volume of production for each variation will be less compared to a mass production system. Therefore, dedication of manufacturing resources for each variation may not be a feasible option. Manufacturing resources will be shared by a group of products. Since each product may have different processing requirements and sequences of operations, the flow will become complicated. Therefore, the manufacturing process is characterized as mid-volume, mid-variety systems and process design for this type of system must address issues arising out of intermittent flow.

Discrete and process industries have alternative ways by which they can address the flow complexities arising out of a mid-volume, mid-variety scenario. In the case of process industries, one way to minimize this flow complexity is to operate the system in batches. In one batch, one set of variations is manufactured and in the next batch, another set of variations is manufactured. In between these two batches, the necessary set-up and changeover of resources are made to facilitate smooth production and maximize productivity. Such an arrangement results in intermittent flow systems.

Reliance Industries Limited manufactures more than 30 grades of polyethylene in their Hazira plant. These include several variations used in industrial, medical, and food-grade applications. While dedicated processing facilities are available for some variations on account of their huge volume of production, several other grades need to share the same set of manufacturing facilities for production. There are variations in the manufacturing processes across these products. For example, food-grade applications require certain precautions to be taken. The nature of additives to the process is also different. Therefore, after one variation is manufactured, the plant is stopped and the required changes are made to the process before the next variation is produced. Similarly, in the manufacture of drugs and various formulations in a pharmaceutical industry, the batch-processing method is applied.

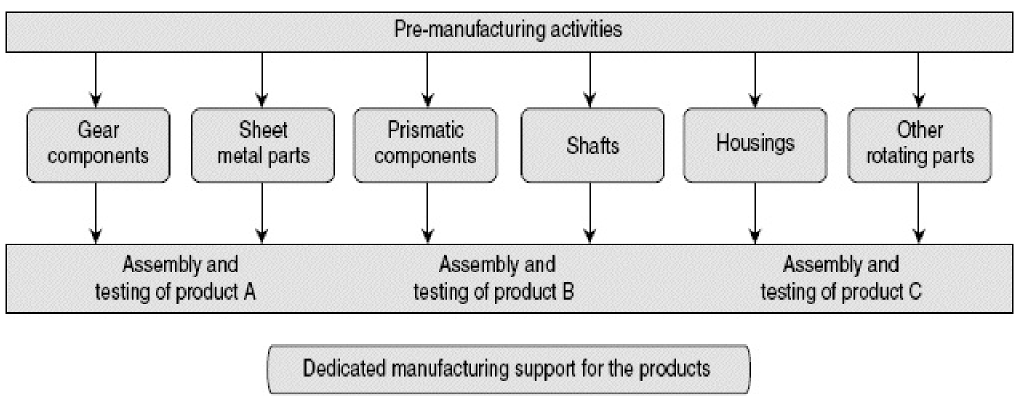
In the case of discrete manufacturing systems, the entire manufacturing set-up can be split into units in which similar processing requirements can be combined and manufacturing resources arranged to cater to these requirements. One batch of components may be produced in one of these units and another batch in yet another unit. In each batch, components of different product variations will be combined since they share the same processing requirement.

Figure 9.5 shows an illustration of the process design for intermittent flow in discrete manufacturing systems. As shown in the figure, the manufacturing resources are organized on the basis of similarity of manufacturing operations among several variations. Components of various product variants flow in an intermittent fashion from pre-manufacturing activities up to the final assembly and testing stage, taking alternative routes and timings to complete the process.

By now, it is evident that operations management issues in intermittent flow systems are very different from those of continuous flow systems. The notion of flow balancing is not an issue in the case of intermittent flow systems. However, capacity planning for catering to the overall requirements of the various varieties is important. Capacity estimation is difficult in an intermittent flow system compared to a continuous flow system. The major issue pertaining to the overall working of an intermittent flow system is the issue of changeover from one variety to another. Production planning and scheduling must critically analyse the impact of alternative changeovers and develop an optimal changeover sequence while planning for production.

Capacity estimation is a complex task in an intermittent flow system.

FIGURE 9.5 Process design for intermittent flow in a discrete manufacturing system



Designing an appropriate structure and manufacturing layout is critical to the working of batch manufacturing systems. Inappropriate choices in structure often lead to complicated material and information flows. This results in complex production planning and control problems. The tractability of the products and related information becomes difficult and may call for more paperwork, and control mechanisms to resolve them. Typically, the level of supervision and coordination will increase and organizations may resort to progress chasing and expediting of late jobs. All these will finally result in long lead times in manufacture, poor delivery reliability, excess and unwanted inventory, high overheads, and high overall cost of manufacturing.

> Customer orders are typically for one-off items and organizations cannot benefit from any batching and repetitive manufacturing practices, unlike continuous flow and intermittent flow systems.

Jumbled Flow Systems

The third category of flow is jumbled flow, which occurs on account of non-standard and complex flow patterns characteristic of certain manufacturing systems. The flow pattern is non-standard and complex because there are unique process designs for each and every customer order. Moreover, customer orders are typically for one-off items and organizations cannot benefit from any batching and repetitive manufacturing practices, unlike continuous flow and intermittent flow systems. This adds to the complexity of the flow. All these characteristics demand different operations management practices, unlike the previous two categories of flows. In reality, two types of manufacturing systems have jumbled flow. These include project organizations and customized manufacturing systems.

Project organizations

Consider a turnkey project executor such as BHEL or L&T. The projects that they undertake are typically large-scale, involve high levels of customization and have long lead times (in the order of a few years). When the product or service offered is of a very large scale, it introduces problems that are not encountered in normal operating systems. In such a case, multiple entities are involved (architect, engineers, government regulatory bodies, construction workers, local communities and society and so on). It also involves multiple stages of the process (design of buildings, foundations, superstructures, electrical systems, heating and air-conditioning systems, fabrication activities, acoustics, and so on). The flow not only becomes jumbled but also complex and managing such a large set of activities requires different methods of planning and control.

Due to a high degree of customization, the degree of uncertainty in all the above cases is likely to be signifi cant. Planning tools that incorporate uncertainty are essential in managing such situations. Second, the number of entities involved in accomplishing the various tasks is numerous. Furthermore, these entities have several complex interactions amongst themselves.

The performance standards of one entity and deviations from the specifications at one part of the system have a significant impact on the others.

ideas at Work 9.3

Process Redesign for Improving Flow

An appropriate choice of processes can have a significant impact on reducing the complexity of managing operations in a manufacturing system. On the contrary, using an inappropriate process design will introduce avoidable complexities arising out of bad process flow leading to poor visibility, excessive efforts in production planning and control, and high investments in the process inventory. Several manufacturing organizations have realized the importance of addressing this aspect.

A case in point is the changes proposed by a manufacturer of earth-moving equipment having a large manufacturing set-up. The manufacturing setup in the organization consists of a plate shop, fabrication shop, machine shop, heat treatment shop, gear shop, final drive assembly, and main assembly. The product profile and the product range were characterized by large variety and low volume, resembling one end of the spectrum of a mid-volume, mid-variety scenario. A certain amount of customization was inevitable as the product was manufactured, which resulted in more variety at the end product level.

The performance of the gear shop was crucial to improving the delivery, cost, and quality performance of the products manufactured in the company. A variety of spur, helical, and worm gears along with geared components are manufactured in the shop, which caters to final drive and swing machinery, the engine, and the transmission of various kinds of earth-moving equipment.

The components manufactured in the gear shop involve a large variety (over 625 at the time of the study) ranging in size from 50 mm diameter to 1,000 mm diameter. Moreover, many components involved intricate shapes and sizes. The shop had 107 machine tools which were arranged in three bays. A majority of the lathes were placed at the rear of the second and third bays. Similarly, gear-cutting machines were located on the left side of the second bay and grinding machines at the rear of the first bay. Given the complexity of operations involved in gear manufacturing and their large variety, the existing set-up posed serious problems in managing operations.

Based on the principles of group technology, a new process design for the gear shop was arrived at. To begin with, eight groups were formed on the basis of manufacturing similarity. For example, all components belonging to the group “large simple gears” would have the key “hob-shave” operation. Similarly, all components belonging to the “ring gear” group had “shape-grind” as the key operation. The eight groups were acceptable from a process-flow sequence point of view and would greatly reduce inter-bay movement. Based on further analysis, and taking additional constraints into consideration, seven groups were finally formed. With the addition of just four more machines, the groups were made independent. In order to change over to the new layout, only 38 machine tools required relocation out of the 107 available in the shop.

The proposal also recommended changes in the manufacturing support functions. For instance, in the revised layout, inspection responsibility was decentralized and left to the groups. The required resources and floor space were identified. Major changes were proposed in the organization structure. The new set-up was to have seven heads of cells, who would be responsible to their internal customers. All “vital” manufacturing support functions, such as quality, tooling, and process plans, were made available to each of these heads; hence, accountability was likely to be high.

The major advantage of the proposed design was the drastic reduction in the distance travelled. The distance travelled by the components within the shop would be reduced from 68.5 km to 35.0 km, a reduction of more than 52 per cent. Such a reduction would result in drastic savings in material-handling costs, lead time and WIP inventory. Further improvements in material handling due to closer location of successive machines were also envisaged. Moreover, improved process flow and better traceability and control were the other benefits of the exercise.

Source: Adapted from B. Mahadevan, *The New Manufacturing Architecture* (New Delhi: Tata McGraw Hill, 1999), pp. 98–102.

Virtually no process design is possible in such a situation. However, operations management principles are required to manage situations arising out of the jumbled flow inherent in project organizations. Scheduling of various activities and control of these is an essential requirement and appropriate tools are required. Similarly, handling uncertainty and decision making in the context of uncertainty is also an important requirement.

Customized manufacturing systems

Another example of jumbled flow is a highly customized manufacturing system such as a tool room operation. While the production volume may not be as low as one unit as in a project organization, it could nevertheless be minimal. On the other hand, the number of customer orders could be very large, resulting in large variety. Since each customer order could potentially demand unique process requirements, the resulting flow in the system becomes highly jumbled. There are several examples of customized manufacturing available in practice. These include PCB fabricators, a variety of sheet metal fabricators, tool room operators and printing and publishing. In operations management, such shops are referred to as *job shops*. In job shops, machines of the same type are grouped together. This is inevitable because no single customer order can justify dedication of resources, on account of its low production volume. Figure 9.6 is an illustration of the process flow in a job shop.

Good scheduling practices could minimize the capacity-related problems in jumbled flow systems.

The operational complexity arising out of such a jumbled flow is high. The most significant issue is one of capacity management. Considerable time is lost due to the repeated set-up of processes. Since each customer order requires different levels of capacity, the estimation of capacity that is already committed and that which is remaining is very hard to make. Good scheduling practices could minimize such capacity-related problems. The other significant issue is managing operations in the system. Due to jumbled flow, criss-crossing of jobs in the system results in poor visibility. Problems are often hidden and a build-up of work in the process inventory takes place. Therefore, good process inventory management practices are essential. Cost accounting and estimation systems are crucial for job shops as there is a constant need to quote for specific customer orders.

FIGURE 9.6 Process flow in job shops

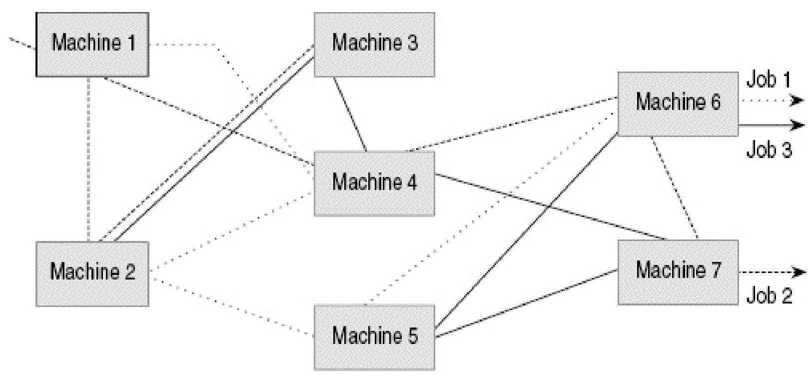


TABLE 9.1 Salient Features of Various Flow Patterns in Manufacturing Systems

Flow Characteristics	Continuous	Intermittent	Jumbled
Product characteristics	High volume, very low variety	Mid volume, mid variety	Very high variety, low volume
Examples of production systems	Process industry, mass production systems in discrete manufacturing	Batch production in process and discrete manufacturing	Project organizations, tool rooms, general purpose fabricators
Issues of importance	Flow balancing, maintenance, capacity utilization and debottlenecking backward integration	Manufacturing system and layout design, changeover management, capacity planning and estimation	Capacity estimation, scheduling, production control, cost estimation
Operations management tools and techniques	Line balancing, maintenance management, process optimization planning and product layout design, flow shop scheduling, pull type scheduling, single piece flow design	Forecasting, capacity planning and estimation, optimized production optimization sequencing, group technology layout design, materials management	Project management and scheduling, capacity planning and scheduling, functional layout design, job order costing, work-in-process management

Table 9.1 summarizes the salient features of various process flow alternatives and the key operations management issues relevant to the above discussions. It is evident from the table that

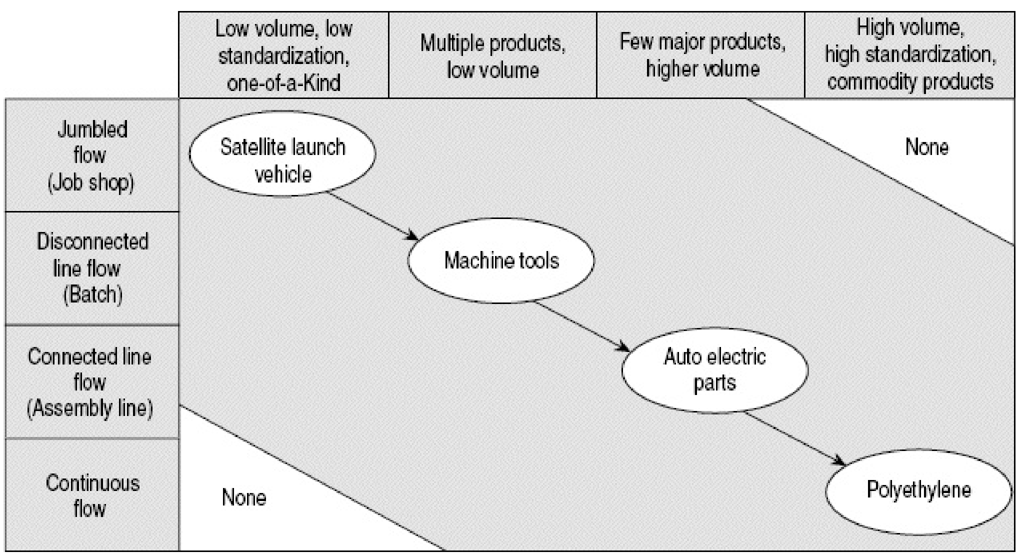
continuous flow systems are relatively easier to plan and control. Capacity planning and scheduling are far simpler than the other two categories. At the other extreme, jumbled flow systems pose complex challenges to operations management. Therefore, in the past 20 years, manufacturing organizations the world over are making concerted efforts to streamline their flow and look for alternative methods of converting job shops. Similarly, firms are also investigating methods of implementing **just-in-time (JIT) systems** as they seek to create a streamlined flow of components and products in a manufacturing system.[2]

> **Just-in-time (JIT) systems** seek to create a streamlined flow of components and products in a manufacturing system.

9.3 THE PROCESS–PRODUCT MATRIX

So far we have discussed various aspects of the alternative process choices that an operations manager possesses and the relationship between process choices and flow patterns in a manufacturing system. The culmination of all these ideas is the process–product matrix. A process–product matrix depicts all these relationships in a compact form, as shown in Figure 9.7.[3]

FIGURE 9.7 The process-product matrix



Source: Adapted from Hayes, R. H. and S. C. Wheelwright, "Link Manufacturing Process and Product Life Cycles," *Harvard Business Review* 57(1), (1979): 133–140. Reproduced with permission.

One dimension of the matrix represents product characteristics and the other process characteristics. Product characteristics essentially indicate the degree of customization and the volume of production. On the other hand, process characteristics indicate the complexity and divergence in the process. When organizations have a high volume of production, the flow will be streamlined. Similarly, when the variety is high, the flow will be jumbled. As shown in the figure, these two situations represent the two extremes in the figure and are not applicable. Each combination has unique operations management issues to be addressed, as we have already seen.

9.4 LAYOUT PLANNING

Imagine yourself visiting a multi-specialty hospital for a master health check-up. What if the radiology department was located in the second floor, the general physicians were sitting in the ground floor at the rear side, ECG and treadmill test facilities were located in the fourth floor and so on. Finally, imagine that you need to walk out of the main complex and go 50 metres away to another building to have your breakfast after you give your fasting food samples and return to the main complex to continue with the process. Such instances are not uncommon. How many times have you felt that you were made to walk too much in a hospital when you went for a health check-up or when you went to a financial institution asking for a loan sanction or to a government office to pay some utilities bill or make some inquiries? What is the core problem in these examples? How many times you have noticed that components travel excessively in a factory before they complete their processing requirements? In simple terms, these examples suggest that, with a better arrangement of resources, it is possible to improve operations and provide better service to the customers.

> **Layout planning** in manufacturing and service organizations involves the physical arrangement of various resources available in the system to improve the performance of the operating system, thereby providing better customer service.

Layout planning in manufacturing and service organizations involves the physical arrangement of various resources available in the system to improve the performance of the operating system, thereby providing better customer service. Typically, in the case of a manufacturing organization, there may be over 200 machine tools of various kinds that need to be located in a machine shop. Similarly, in the case of a service organization such as a hospital or a hotel, there are various resources to be physically located. We can identify the best possible locations for various resources in an organization though a good layout planning exercise. Layout planning provides a set of tools and techniques that help an operations manager decide where to locate resources and also to assess the impact of the alternative choices that he/she may have for locating the resources.

A good layout design will ensure that a vast majority of jobs in a manufacturing system will have to travel shorter distances before completing their processing requirements. Similarly, in the case of service organizations, customers will have to walk shorter distances and spend less time in the system to complete their service requirements. This ensures that the costs and the lead time of the processes come down. On the other hand, a bad layout design will result in longer distances being covered before a process is completed. This creates several problems in organizations and key performance measures suffer. The most significant and visible effect is the time taken to complete the process. Longer distances would mean that more time is needed to complete the process. In the case of manufacturing organizations, more material-handling leads to higher material-handling costs. Eventually, in both service and manufacturing systems, this leads to poor quality.

We have already discussed alternative configurations of manufacturing systems on the basis of volume–variety–flow. Revisiting this issue will provide the required inputs to the layout problem.

> The relationship between "volume– variety–flow" provides crucial inputs to the layout problem.

9.5 TYPES OF LAYOUTS

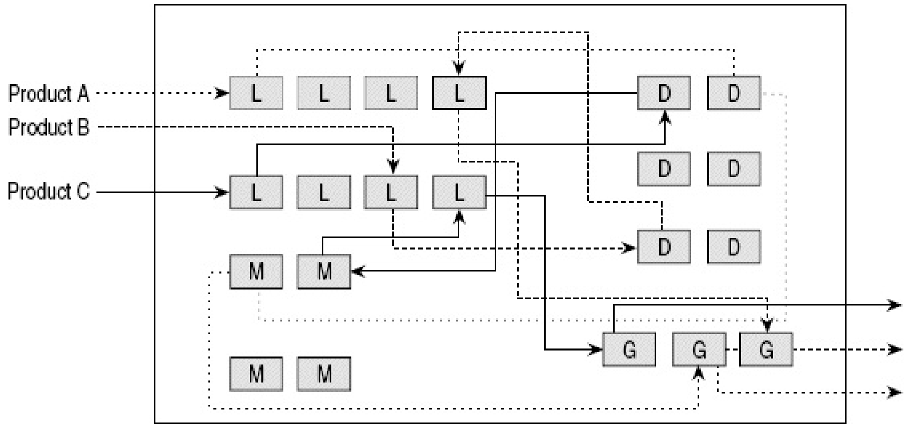
Over the years, operations management researchers and practitioners have evolved four major types of layouts. These include product layout, process layout, group technology layout and fixed position layout. The salient aspects of these layouts are described here.

> As the flow becomes more cumbersome, the type of layout may significantly influence the ability of the operations manager to effectively plan and control operations on the shop floor.

Process Layout

A process or a functional layout is an arrangement of resources on the basis of the process characteristics of the resources. Consider a machine shop consisting of lathes (L), grinders (G), milling machines (M), and drilling machines (D). A sample process layout for this shop is shown in Figure 9.8. In the example, components belonging to Product A first visit a lathe, then a drilling machine, a milling machine, and finally a grinding machine. The sequence of visits is a function of the process plan and is available in a route card. The major implication of this design is that when the number of components manufactured is large, there will be enormous criss-crossing in the shop, as components need to visit machines in multiple combinations. This increases material handling and poses challenges for production control.

FIGURE 9.8 Example of a process layout



A process layout is an arrangement of resources on the basis of the process characteristics of the resources available.

Each department in a **process layout** is typically organized into functional groups. Thus, all the lathes will be organized into a lathe department. Similarly, there will be a drilling department, a milling department, and so on. In the fabrication area a similar arrangement would be a welding department, a fitting department, a shearing department, and so on. All manufacturing support areas are also arranged on a functional basis. Examples include a maintenance department, quality control department, procurement, stores, and production planning.

Product Layout

A product layout is an alternative design for the arrangement of resources. In this case, the order in which the resources are placed exactly follows the process sequence dictated by a product. For the above routing information the product layout will be as shown in Figure 9.9. In a product layout, the required set of resources for every product is dedicated. Due to this, the resources are arranged in the order of the machining requirements resulting in smooth component flow in the shop. Since each product will have its own set of resources, material handling is simpler and it is possible to invest in fixed-path material-handling systems to speed up material transfer between successive workstations. The production control issues are much simpler in a product type of layout compared to the process layout.

In a product layout, the resources are placed to follow exactly the process sequence dictated by a product.

Very often the final assembly in several manufacturing plants follows a product layout. The assembly workstations are designed in such a manner that at each workstation a part of the job is completed. The feeder stations are linked to the assembly workstations to ensure material availability. As the product moves through the assembly, the process is completed. Testing, final inspection, and even packing could be part of this layout, so that at the end of the line it is ready for dispatch to the market. If you visit the Chinchwad plant of Tata Motors at Pune, you will notice that there are nearly 180 workstations involved in the final assembly of the Tata Indica. As the chassis moves through these stations, the car is assembled in a progressive fashion, and at the end the car is ready for dispatch. In product layouts, the design of the layout is far more important as it results in a certain degree of operational control. Once the design of individual workstations is properly made, many problems are solved.

The notion of product and process layouts applies not only to manufacturing settings but also in a service setting. A classic example is the banking system. For several years, the layout in the banking operation was process based with the resources arranged on the basis of their function they do. Thus, we have savings bank clerks, current account clerks, cashiers, tellers and so on. However, in recent times, the layout is more product or customer based. In this arrangement, manpower and resources are organized on the basis of customer segments that need to be catered to. Figure 9.10 shows alternative layout choices between Bank A and Bank B.

In the case of Bank A, customers arrive at the waiting area and a member of the customer relationship staff attends to all the requirements of the customer. In contrast, in the case of Bank B, the staff is organized on the basis of functions. Depending on the nature of work involved, customers will visit different sections in the bank and get their services done.

Both process layouts and product layouts have certain advantages and disadvantages. Therefore, one needs to choose an appropriate layout depending on the specific circumstances. Table 9.2 lists some of the salient advantages and disadvantages of both these types of layouts. A product layout simplifies production planning and control problems. It also enables smooth production and high production rate. However, since a high level of dedication of resources is required it may increase the cost of operation and may be an unfeasible option in most cases. Only in the case of high-volume manufacturing can an organization justify the dedication of several resources.

FIGURE 9.9 Example of a product layout

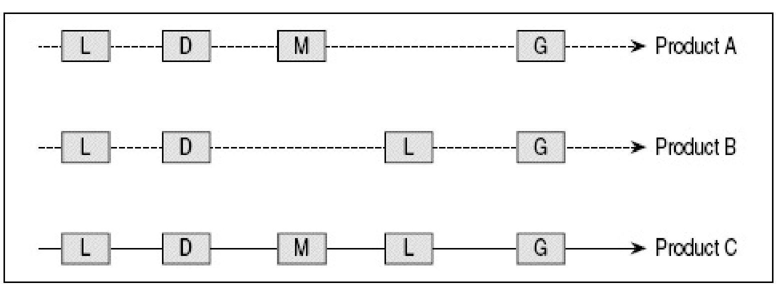
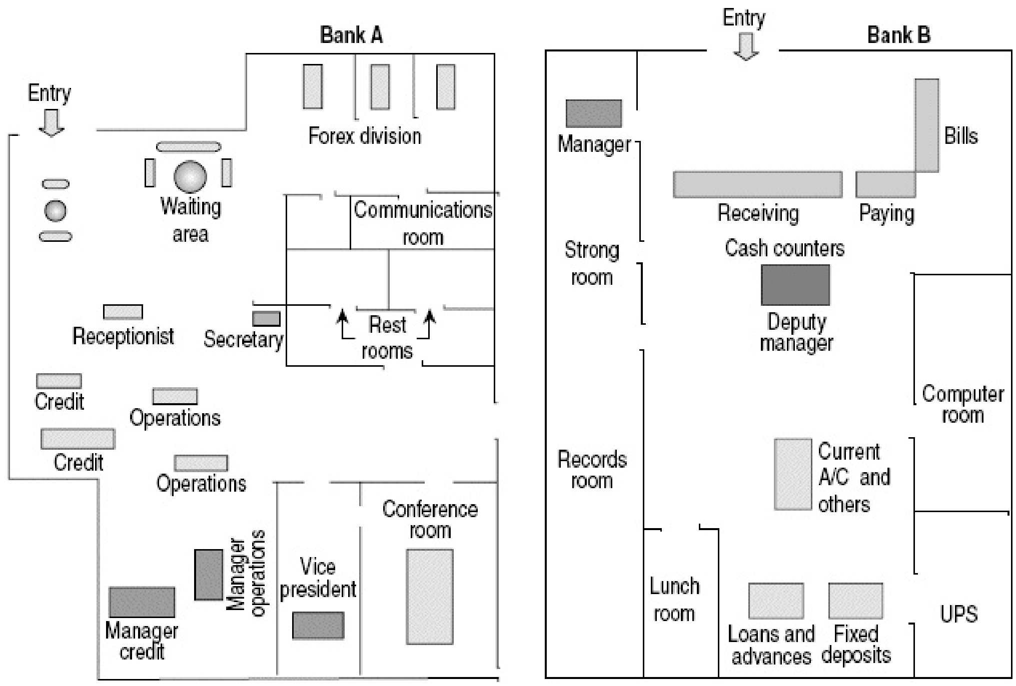


FIGURE 9.10 Product and process layouts: an example from banking



The advantages of process layout include greater flexibility and better utilization of resources. However these are more than offset by several drawbacks. Organizations using process layouts often experience problems, which include the following:

- Enormous criss-crossing of the jobs, resulting in poor visibility of flow of jobs. This makes progress chasing a difficult task.
- Heavy load on material handling, leading to bottleneck situations in the material-handling system.
- Difficulty in production planning, scheduling, and control of the jobs.
- Very high throughput times, which in turn increases the investments in stocks, stock holding costs, damages, and material obsolescence.
- Poor delegation of work and poor accountability.
- Low motivation and low job satisfaction for the workforce.

Moreover, process layouts promote functional silos in organizations, which are considered to be undesirable today.[4]

On account of these issues, another type of layout that combines the benefits of both process and product layouts is being widely adopted by organizations today.

TABLE 9.2 Advantages and Disadvantages of Product and Process Layout

	Process Layout	**Product Layout**
	Sharing of specialized and costly equipments	Standardized product/process routing
Advantages	More flexibility	Operational control is simpler
	Less vulnerable to breakdowns	High output rate is possible
	Large inventory build-up	Low tolerance for breakdowns

Disadvantages	Operational control difficult	Duplication of equipment leading to high cost
	Excess material handling	Lower flexibility due to dedication of resources

Group Technology Layout

There has been an increasing trend towards more variety, thereby pushing volumes down. The industrial fans and blowers division of ABB was manufacturing nearly 725 models. Titan Industries increased the number of its watch models from about 850 in 1993 to over 1,200 in 1996, an average of more than 100 new models every year. (Currently, the number of models that they offer has increased by orders of magnitude and is in excess of 40,000). Reliance Industries Limited, India's largest private sector company operating in petrochemicals, was planning to introduce several new grades of high-flow high-density polyethylene (HDPE) and low-density polyethylene (LDPE) with a view to entering five new markets of polyethylene in the year 1995–1996. With this, the number of variations that they would handle at the polyethylene plant was likely to be over 40. It is estimated that more than 70 per cent of manufacturing industries will have a mid-volume, mid-variety scenario. Therefore appropriate layout planning methods for mid-volume, mid-variety manufacturing is required.

> **Group technology (GT)** is a philosophy that seeks to exploit the commonality in manufacturing and uses this as the basis for grouping components and resources. The implementation of GT is often known as *cellular manufacturing*.

Group technology (GT) layout provides an alternative method for configuring resources in organizations that have mid-volume, mid-variety product portfolios.[5]

GT is a philosophy that seeks to exploit commonality in manufacturing and uses this as the basis for grouping components and resources. The implementation of GT is often known as *cellular manufacturing*. In cellular manufacturing, the available components are grouped into part families. An appropriate measure for manufacturing similarity is used to identify part families. Corresponding to each part family, machine groups are identified and the layout is formed accordingly. An example of a group technology layout for the process layout is shown in Figure 9.11.

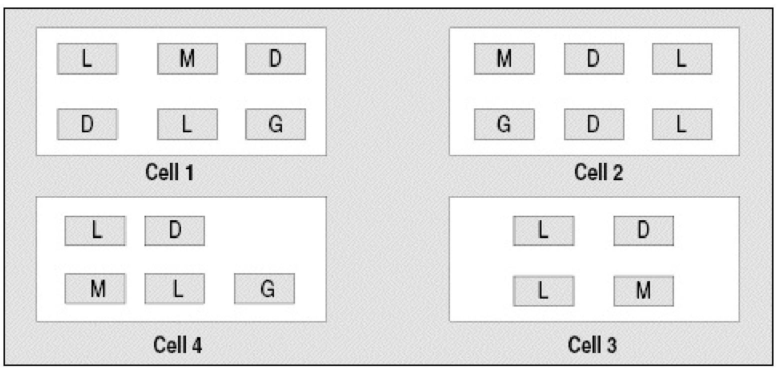
The benefits of GT are many. Once the part families and the machine groups are identified, the layout ensures that each cell has only a certain number of components to be processed. In essence, it is akin to breaking a monolithic structure into smaller, more manageable, and independent units of production. Because of this, production planning and control become much simpler. The components seldom travel outside their respective cells for processing. Therefore, material handling becomes easier and traceability improves. Moreover, employees will be able to relate better to their workplace and make concerted improvements in the process. The new structure will also help to implement several other operations management practices such as small group improvement activities, kaizen, and just-in-time manufacturing practices.

Fixed Position Layout

There are several situations in which the product manufactured is very bulky, difficult to move and is often made in quantities of one. In such situations, the layout design ought to be very different. One cannot employ any of the layouts described so far. Typical examples include building very large machine tools and equipment, ship and aircraft building, and preventive and breakdown maintenance of such large systems. Since such equipment is very large and bulky, it dictates several choices with respect to the layout. The orientation of the equipment will dictate the placement of specific resources required for the process. Layout planning in such cases is often a question of a good workplace organization. By proper workplace organization it is possible to exercise greater control on the process and remove unwanted processes and delays from the system.

> Fixed position layouts are typically employed in large-project type organizations.

FIGURE 9.11 Example of a group technology layout



For reasons mentioned above, fixed position layouts are typically employed in large-project type organizations. Some examples include the nuclear engineering division of BHEL at Tiruchirapalli, the final assembly hanger of the Advanced Light Helicopter manufactured at Hindustan Aeronautics Limited's (HAL) helicopter division at Bangalore, and the Indian Space Research Organisation (ISRO) launch site at Sriharikota. The emphasis in fixed-positioning layouts is not so much on optimum positioning of resources required for the process. On the other hand, it should enable managers gain better control of material flow (see Ideas at Work 9.4 for an example).

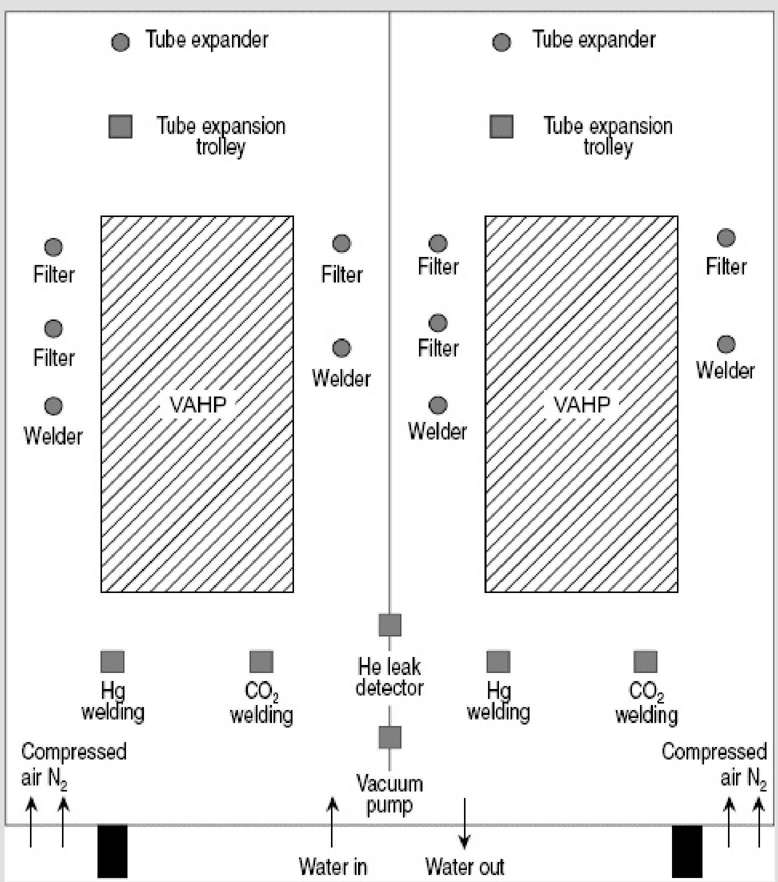
ideas at Work 9.4

Workplace Organization at Thermax

Thermax is a manufacturer of large and complex systems for heat exchange and environmental control applications. Their vapour absorption heat pump (chiller) shop is an example of a fixed position layout. Chillers are huge pieces of equipment weighing several tonnes. They are manufactured using a fixed position layout. The manufacturing process begins by first locating the lower shell of the chiller on the shop floor and progressively adding the components. The upper shell is finally mounted and the equipment is tested before packing and dispatch.

Previously, they were assembling as many as 40 chillers. The only consideration to start assembly was space availability to place the lower shell. As a result, these chillers were at various stages of production and were cluttering the shop. Production planning and control was very complex. It was difficult to understand why inventory was piling up and lead times were increasing. There were several reasons for chillers not being assembled. These included non-availability of material, labour, and other resources.

FIGURE 9.12 Details regarding the orientation of the workers and other requirements



An alternative layout was designed to address this problem. In the revised scheme of things, the workplace was clearly demarcated with finer details of how the lower shell of the chiller should be placed and how other resources were to be deployed for the production process. Even the minutest details regarding the orientation of the workers and other requirements such as air, carbon dioxide, and welding machines were worked out (see Figure 9.12). Eighteen such provisions were made. This ensured that not more than 18 chillers could be assembled in the shop at a time. Figure 9.12 has the revised layout.

The exercise had several benefits. There was a reduction in the work in progress from 40 to a maximum of 18. According to the manager of the shop, in the revised layout, problems became more visible. From his cabin, he could identify which of the cells were working and which were not. If he walked past the cell, he could know the exact nature of the problem in the non-working cells. The new layout made production control a visible and easy task.

Source: S. K. Wale, "Improving Manufacturing Effectiveness Through Implementation of Stall Built System in Chiller Shop at Thermax Ltd, Pune" (Bangalore: Unpublished report submitted at IIM, 1996)

9.6 PERFORMANCE MEASURES FOR LAYOUT DESIGN

The layout design should result in greater efficiency of the manufacturing system. This is the simple goal of any layout planning exercise. However, in order to assess how good the layout is, it will be useful to employ a few measures. Such measures help a layout designer not only to choose between alternative layout choices that he/she may have but also to set some targets for improvement in the future. Table 9.3 has a sample set of measures and the basis for measurement.

The most fundamental measure for layout design is the distance travelled by the jobs on the shop floor. Often organizations use a scale model of the existing layout and strings and pins to trace the path of the jobs to measure the total distance travelled. A good layout design must ensure that unnecessary movements and excessive material handling are avoided. Table 9.4 shows the impact of an existing layout in a manufacturer of earth-moving equipment with four product lines. Production and assembly of 1,080 components of Product A on average resulted in a total travel of 375.7 km. Products C and D were added much later in the factory. The average distance per item for all the four product lines confirmed that the company had not made any major layout changes in the last thirty years, despite adding new product lines. As products travel long distances, the lead time goes up, the overhead costs increase, and the investment in inventory also goes up.

The most fundamental measure for layout design is the distance travelled by the components pertaining to a customer order in the system.

TABLE 9.3 Performance Measures for the Layout Problem

Performance Measure	Basis for Measurement
Distance travelled by jobs in the shop floor	Kg-Metres of job movement for each product
Space utilization index	Minimum space required to actual space utilized
Material-handling costs	Rupees per month
Lead time of the processes	Hours per average product
Investment in work in progress	Rupees per month
Interdepartmental moves	Number and quantum of interdepartmental moves
Utilization of the resources	Per cent to total capacity
Ease of production control	Number of job cards and control documents generated; size of the progress chasing staff
Number of ownership changes	Number of times the job changes hands

TABLE 9.4 Effect of Layout on Different Product Lines

Product Line	Total Distance Travelled (In Metres)	Number of Items Manufactured*	Average Distance Per Item
Product A	375,655	1,080	347.83
Product B	415,125	757	548.38
Product C	288,710	301	959.17
Product D	297,110	405	733.60

Note: *The total distance travelled includes only those of the items manufactured on the shop floor. The number of items that were finally assembled into the final product includes many bought-out items in addition to these.

In addition to measures to assess the impact on lead time and inventory, another useful measure is the ease of production control. A better layout will enable an organization to have greater visibility of operations and ease of control. Finally, recent ideas pertaining to business process re-engineering suggest that if the jobs change fewer hands, then there are greater advantages from pinpointing responsibilities on groups of people. Jobs with fewer interdepartmental moves and ownership changes have a greater chance of getting completed faster. Therefore, these measures may also be useful.

9.7 DESIGN OF PROCESS LAYOUTS

The design of a process layout involves a three-step process. The first step is to identify the number of departments required and the space requirements for each department. The second step is to estimate the magnitude of flow across these departments. The last step is to use the above information to arrive at the final layout of the departments so that the cost of material handing is minimized. These steps are explained here:

TABLE 9.5 Distance Between Six Blocks

	A	B	C	D	E	F
A		20	30	40	30	60
B			50	70	50	20
C				30	70	40
D					50	20
E						20
F						

- *Step I—Identify the number of departments required*: Since process layouts are made on the basis of functional similarity of the resources, this is a fairly straightforward decision. For example, in a machine shop, all the lathes are grouped together to form a lathe shop, all the grinders are grouped to form the grinder shop, and so on. There will also be separate departments for receiving, final inspection, and shipping. Once these units are identified, it is possible to also estimate the sizes of each of these departments. The number of resources to be placed in the shop dictates the size. The distance between the blocks in the shop floor in which the departments are to be located could also be measured. This information will be of use in the layout design exercise. On the basis of these estimates, the required data for the layout problem could be gathered. Table 9.5 has the distance in metres between six blocks (A to F) for locating six departments on a hypothetical shop floor.
- *Step II—Estimate the magnitude of flow*: The second step in the design process is to estimate the flow of material between departments and the cost of moving one unit across departments. In a process-focused layout, jobs visit various departments before the processing is complete. Further, the production requirements of each job in each resource will vary. Therefore, consolidating all this information will indicate not only the load on each resource but also the quantum of interdepartmental flow. Interdepartmental flow is the sum of flows between two departments irrespective of the direction of the flow. For instance, an interdepartmental flow of 100 units between Departments 1 and 2 may include 65 units of flow from Department 1 to Department 2 and 35 units of flow from Department 2 to Department 1. At the end of this consolidation exercise, one can arrive at a matrix of interdepartmental flows as indicated in Table 9.6 for a sample of six departments.
- *Step III—Arrive at the final layout of the departments*: Once the basic data is available, appropriate methods could be used to solve the layout problem. Qualitative and quantitative approaches are available to arrive at the final layout of the departments. These are discussed here.

TABLE 9.6 Matrix of Interdepartmental Flows

	1	2	3	4	5	6
1		100	30	40	0	30
2			90	0	150	20
3				0	70	40
4					50	20
5						70
6						

The Qualitative Approach to Layout Design

In this approach, some qualitative measures are used to decide which department is to be located next to another department. One simple method is to use the interdepartmental flow as the basis on which closeness between one department and another could be established. However, often it is difficult to exactly quantify why two departments need to be close to each other or should not be located side-by-side. For example, even when the interdepart-mental flow of jobs between a heat treatment shop and quality control section may be high, it is better not to locate them side-by-side. This is because the quality control section may use high precision gadgets for testing and calibration, and locating the heat treatment shop alongside may call for costly measures for isolation of particle impurities, pollution control, and cooling of the high temperature ambience. Similarly, it may not be desirable to locate a high tension testing facility, in an electrical goods manufacturing industry, in the midst of other shops for safety considerations.

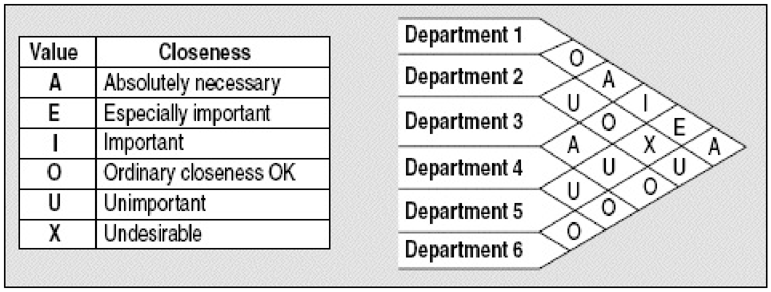
Based on such criteria, it is possible to arrive at qualitative measures for closeness requirements of a department vis-à-vis other departments. The qualitative measures link some criteria to the closeness required between a pair of departments. Figure 9.13 shows one of the popular methods used for qualitative ranking of closeness and an example of ranking for locating the six departments.

> The qualitative measure links some criteria to the closeness required between a pair of departments.

Using the closeness ratings between departments, layouts can be constructed. In the above example, Departments 1 and 3 are to be located close to each other. Similarly, Departments 1 and 6 should also be close to each other. Using this information, an initial layout can be constructed. Accommodating all the requirements may often turn out to be infeasible. However, alternative combinations may ensure better locations that improve the appropriateness of the layout. Therefore, one method is to begin with an initial layout that is feasible and progressively check the appropriateness of the new layout obtained. This may be done by selectively exchanging parts of the layout plan through swapping of a subset of locations among each other. A pair-wise exchange could be a systematic approach to enumerate all the possible layouts that one can get from an initial layout.

> There are software packages available for the qualitative design of process layouts. These include ALDEP and CORELAP.

FIGURE 9.13 Qualitative ranking for designing process layouts



Smaller layouts can be analysed using visual methods and by trial and error. However, if the number of departments involved is many, then the use of software packages may be inevitable for layout design. Software packages like ALDEP and CORELAP are used for the qualitative design of process layouts.

The Quantitative Approach to Layout Design

The quantitative method in making layout designs uses certain measures for assessing the impact of the layout and seeks to arrive at the best method for locating the departments. Let us assume that we are interested in arriving at an appropriate layout for six departments (1 to 6). The six departments are to be located in six locations (A to F). Since the basic purpose of a good layout design is to minimize excessive travel of jobs over long distances, let us use the material-handling cost as the basis for designing an appropriate layout.

Let,

C_{ij} denote the cost per unit of transporting a unit distance from Department i to Department j
F_{ij} denote the interdepartmental flow between Department i and Department j
D_{ij} denote the distance between Department i and Department j
n denote the number of departments to be laid out (9.1)

The total cost of the plan is given by:

$$TC = \sum_{i=1}^{n} \sum_{j=1}^{n} F_{ij} D_{ij} C_{ij} \qquad (9.1)$$

The interdepartmental flows, the distance between the blocks, and cost information are gathered during a layout planning exercise, as indicated in the previous section. Therefore, once the decision regarding which department will be located in which block is made, the total cost of the plan could be computed using Eq. 9.1. The use of the quantitative method requires some logic for arriving at the best layout. The above can be modelled as a mathematical programming problem with the objective function of minimizing the total cost of the plan. The mathematical programming problem is one of assigning the department to the blocks, subject to the constraint that one block can hold only one department. Further, the number of blocks assigned should be equal to the number of departments.[6]

A popular heuristic for the assignment problem forms the basis for the computerized procedure known as **computerized relative allocation of facilities (CRAFT)**. CRAFT utilizes the improvement method for obtaining the best layout. In CRAFT, an initial feasible layout is formed and a series of improvement opportunities explored through a pair-wise exchange of departments. If there are n departments, a pair-wise comparison involves $n(n - 1)/2$ evaluations. After all these evaluations, the best possible pair-wise exchange is identified. If further reduction in the cost is possible by making this change, then the location of the two departments is changed. For example, in a six-department example, let us assume that the cost reduction by pair-wise exchange of departments is as shown in Table 9.7 for four pairs (we shall further assume that all other pair-wise exchanges result in an increase in material-handling costs).

Computerized relative allocation of facilities (CRAFT) is a computerized procedure that utilizes the improvement method for obtaining the best layout.

TABLE 9.7 Cost Reduction by Pair-wise Exchange of Departments

Department Pair (i, j)	Cost Reduction
(1, 4)	250
(3, 5)	350
(2, 4)	150
(5, 6)	110

Therefore, the location of Departments 3 and 5 will be exchanged. If the total cost of material handling at the beginning of this iteration was ₹20,000 the new material-handling cost will be ₹19,650. The procedure continues in this manner until no more improvement is possible.

Software Packages for Layout Design

Solving layout problems using manual methods is rather difficult when the number of departments is more than 10. In most realistic situations, such numbers are common. Therefore, the use of computerized methods is inevitable. In response to these requirements, several software packages have been developed.

There are three underlying approaches to the use of computer packages for designing layouts. One is the *construction method*. In this method, the solution begins with an empty layout solution and one department is added at a time. When all the departments are added to the shop floor, the final solution is obtained. Automated layout design programme (ALDEP), Computerized relationship layout planning (CORELAP), and plant layout evaluation techniques

(PLANET) are three known software packages that utilize construction logic. In general, these software packages may result in departments having unrealistic shapes. For this reason, such methods are more useful in providing layout designers with some alternative ideas and initial solutions rather than a final solution.

> There are three underlying approaches to the use of computer packages for designing layouts: *the construction method, the improvement method,* and *performance evaluation modelling.*

On the other hand, in the *improvement method*, the starting point for a solution is a feasible layout. The feasible layout may not be the best layout. Therefore, the solution is improved progressively. When no more improvement is possible, the procedure stops and the available solution is the best solution. There are two known packages available in this category. These are computerized relative allocation of facilities (CRAFT) and computerized facilities design (COFAD). COFAD is a modification of CRAFT that incorporates the choice of a material-handling system in the layout design process.

The third approach to layout design is to use recent advances in object-oriented modelling techniques and build *performance evaluation models*. In this approach, software is used to build a model with 3-D objects of the layout that the designer has in mind, and to assess the impact of the design using several parameters. These parameters could include, for example, equipment and material-handling utilization, congestion in the material-handling network, build-up of inventory in the shop floor, and manufacturing lead time. Often, after building these models, a simulation analysis of the layout could be done to assess the parameters listed above. Since the cost of developing and analyzing these models has been progressively coming down, recent approaches to designing layouts are directed towards arriving at a configuration through performance evaluation.

9.8 DESIGN OF PRODUCT LAYOUTS

There are several examples of mass production systems in operation today. A two-wheeler manufacturer such as Bajaj Auto Limited sold nearly 3,422,400 motorcycles in 2013–2014, which translates into a monthly sale of 285,200. It is expected that the daily production of vehicles is nearly 11,400. Various sub-assemblies in the Bajaj plant need to be configured to match the production rate. Similarly, the final assembly stations also need to have the required number of resources at each station to meet the targeted demand. In such a scenario, much of the control and scheduling boils down to appropriately arriving at a balanced flow of components on the shop floor. A product layout design essentially caters to this objective by estimating the exact number and the sequence of resources required in the manufacturing system for a targeted production level. Essentially, the layout design seeks to identify the minimum number of resources required to meet a targeted production rate and the order in which these resources are to be arranged. In the process it seeks to establish a balance among the resources so that production is smooth. Therefore, the technique employed for this purpose is known as the line-balancing technique.

Let us consider a mass production system with multiple tasks such as the manufacture of computers. If you visit the final assembly shop of the plant, you will invariably find a line layout. At one end of the assembly components will be fed into the system in multiple stations and the computer will be progressively assembled. Initially the mother board will be assembled with the required components. As it proceeds, the hard disk, optical drives, fans, power systems, serial, parallel and USB ports, and SMPS will be added to the box before it is finally secured with the cover plate. If you visit other mass producers like a car manufacturer such as Hyundai or an industrial valve manufacturer such as Audco India Limited you will notice a similar structure of manufacturing and assembly process. In all these cases, you will notice multiple tasks and precedence relationships among them.

> **Line balancing** is a method by which the tasks are optimally combined without violating precedence constraints and a certain number of workstations are designed to complete the tasks.

Each task *i* requires a finite time, denoted by t_i and may have some precedence relationships with the other tasks. Further, the tasks require certain skills and resources such as machines and tools. **Line balancing** is a method by which the tasks are optimally combined without violating precedence constraints and a certain number of workstations are designed to complete the tasks. If there are three workstations, A, B, and C, in which 7 tasks are performed in a manufacturing system, then the workstation times are nothing but the summation of the task times assigned to each workstation. Let the workstation times be denoted as W_A, W_B and W_C. Clearly, a balanced design is one in which the workstation times do not vary widely. In such a situation, the resources will be uniformly utilized and the flow of material will be even. Further, there will be a good rhythm in operations. The maximum of the three workstation times determines the interval between the production of two successive components. If W_A = 5 seconds, W_B = 3 seconds and W_C = 7 seconds, one component will come out of the system every 7 seconds. This measure is known as the *cycle time*.

Cycle time could be considered as the reciprocal of production rate. If in a period of 20,000 seconds a shop produced 10,000 pieces of a component, then the production rate is 1/2 per second. Conversely, the cycle time is 2 seconds. Cycle time could be actual or desired. If we compute on the basis of actual production, it represents the actual cycle time. On the other hand, if we compute the cycle time on the basis of what we desire the production to be, then it is desired cycle time. Maintaining the desired cycle time requires better management and work practices. The expression for cycle time is as follows:

$$\text{Actual (desired) cycle time} = \frac{\text{Available time}}{\text{Actual (desired) production}} \tag{9.2}$$

The problem of designing a balanced set of workstations suffers from the classical trade-off issue. If we combine more tasks into fewer workstations, we may require fewer workstations but the cycle time will be high, leading to reduced production rate. At the other extreme, if the tasks are kept separate and as many workstations are designed, we may increase the production rate beyond what is required at the risk of deploying more resources and workers with poor utilization. Therefore, solving the line-balancing problem calls for counterbalancing these opposing costs and striking the right trade-off between increased production and better utilization of resources.

Cycle time could be considered as the reciprocal of production rate.

The production rate, cycle time and the number of workstations are interrelated. Moreover, the number of workstations has a bearing on the average resource utilization. Using these measures it is possible to design an appropriate number of workstations. These relationships are indicated in the following expressions:

$$\text{Minimum no. of workstations required} = \frac{\text{Sum of all task times}}{\text{Cycle time}} \tag{9.3}$$

$$\text{Average resource utilization} = \frac{\text{Sum of all task times}}{\text{Number of workstations} \times \text{Cycle time}} \tag{9.4}$$

EXAMPLE 9.1

A factory working in two shifts each of 8 hours produces 24,000 electric bulbs using a set of workstations. Using this information, compute the actual cycle time of the plant operation. There are 8 tasks required to manufacture the bulb. The sum of all task times is equal to 12 seconds. How many workstations are required to maintain this level of production assuming that combining of tasks into those workstations is a feasible alternative?

Solution

Available time = 2 × 8 × 60 × 60 = 57,600 seconds

Actual production = 24,000 electric bulbs.

Therefore, using Eq. 9.2 we compute the cycle time for each bulbs as

$$\frac{57{,}600}{24{,}000} = 2.4 \text{ seconds.}$$

This means that the factory is producing 1 bulb every 2.4 seconds.

$$\text{No. of workstations required} = \frac{12}{2.4} = 5$$

Therefore, the tasks are to be split among the five stations such that each workstation will have 2.4 seconds as the sum of its task times.

EXAMPLE 9.2

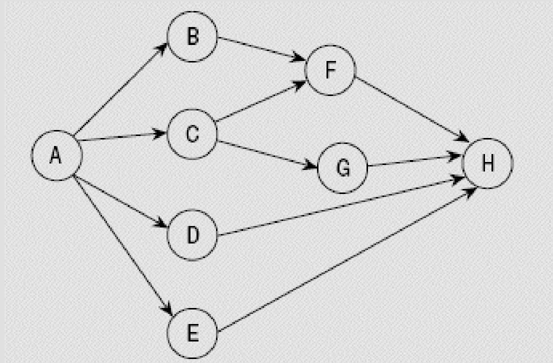
A computer manufacturer needs to design assembly stations in the factory where the cabinet housing the hard disk, mother board and other accessories is to be made. The factory currently works for one shift of 8 hours. The tasks and their durations are given in Table 9.8. Figure 9.14 shows the precedence relationship among the tasks.

a. If the cycle time is 80 seconds, what will the daily production of cabinets be?
b. If the desired production rate is 320 cabinets per day, what is the maximum permissible cycle time?
c. What is the maximum and minimum number of workstations required to maintain this daily production rate?
d. Design an assembly set-up with 5 workstations and 6 workstations. What are the key inferences of this exercise?

TABLE 9.8 The Tasks and Their Duration

Task	Description	Duration (Seconds)
A	Assemble and position the base unit	70
B	Install hard disk	80
C	Install mother board	40
D	Insert ports	20
E	Install speaker	40
F	Connect relevant modules to mother board and disk	30
G	Install controller	50
H	Visually inspect and close with a cover plate	50

FIGURE 9.14 Precedence relationship among the tasks



Solution

(a) Total available time per day = 8 × 60 × 60 = 28,800 seconds

If the cycle time is 80 seconds, then the daily production of cabinets can be obtained using Eq. 9.2. Daily production rate is given by:

$$\text{Daily production rate} = \frac{\text{Total available time}}{\text{Cycle time}}$$
$$= \frac{28{,}800}{80} = 360$$

(b) Since the desired production rate is only 320 cabinets, one can obtain the maximum permissible cycle time for the assembly stations.

$$\text{Maximum cycle time} = \frac{\text{Total available time}}{\text{Desired production rate}}$$
$$= \frac{28{,}800}{320} = 90 \text{ secon}$$

The computations show that while a cycle time of 80 seconds may yield a much higher production rate, the workstations can be designed for a cycle time of up to 90 seconds without falling short of the desired daily production. Once the cycle time crosses 90 seconds, the manufacturer may not be able to produce 320 cabinets every day.

We know that the maximum number of workstations required to maintain the desired daily production rate is equal to the number of tasks that are to be performed. This is because we can simply assign one task to one workstation. In our example, the maximum number of workstations is eight, as there are eight tasks.

In our example, the sum of all task times is 380 seconds. Therefore, combining all the tasks into a single workstation will result in a cycle time of 380 seconds. This is not permissible. Therefore, the minimum number of workstations is dictated by the maximum cycle time permissible.

(c) The minimum number of workstations is given by Eq. 9.3 as

$$\frac{380}{90} = 4.22 \cong 5$$

As long as we have five workstations, our cycle time may not exceed 90 seconds and we will be able to meet the production rate.[7]

(d) Design of assembly shop with five workstations (Table 9.9 presents the details)

We assign tasks to the five workstations on the basis of the following two criteria:[8]

i. The workstation times should not exceed the maximum permissible cycle time of 90 seconds
ii. The precedence relationships among the tasks need to be honoured

The average utilization of the resources can be computed as follows (Eq. 9.4):

$$\text{Average utilization} = \frac{\text{Sum of all task times}}{\text{No. of workstations} \times \text{Cycle time}}$$

$$= \frac{380}{5 \times 90} = 84.4\%$$

(e) Design of assembly shop with six workstations (Table 9.10 presents the details):

We assign tasks to the six workstations using the same set of criteria as before.

Key Inferences

The above computations clearly show the trade-off issues in line balancing. A design with five workstations will meet the current production rate with an average utilization of 84.4 per cent. However, when we increase the number of workstations by one, the utilization comes down by 4.8 per cent, but the production rate could increase by 11.1 per cent (since the daily production rate will increase from 320 to 360 on account of cycle time coming down to 80 seconds from 90 seconds). There are cost and strategic implications of these two alternatives and management could take an appropriate decision at the time of finalizing the design.

TABLE 9.9 Design of the Assembly Set-up with 5 Workstations

	Workstation 1	Workstation 2	Workstation 3	Workstation 4	Workstation 5
Tasks assigned	A,D	B	C,G	E,F	H
Workstation times	90	80	90	70	50
Cycle time	90	90	90	90	90
Workstation idle time	0	10	0	20	40
Workstation utilization	100%	89%	100%	78%	56%

TABLE 9.10 Design of the Assembly Set-up with 6 Workstations

9.9 DESIGN OF GROUP TECHNOLOGY LAYOUTS

GT layouts are designed with the objective of subdividing a universe of machines and components into sub-groups such that each sub-group of components forms a part family and is endowed with a corresponding sub-group of machines known as a machine group. GT layout design is done with the systematic analysis of a machine-component incident matrix.

> GT layout design is done with a systematic analysis of a machine-component incident matrix.

Consider an example of 20 components requiring processing in 10 machines. Let us denote the components using numbers and the machines using alphabets. A machine-component incident matrix (MCIM) indicates the relationship between the components and machines using a binary representation. Figure 9.15 has the MCIM for our hypothetical example.

In a GT layout design, the MCIM is analysed to detect possible sub-groups. If the sub-groups are non-overlapping, then the resulting design has independent resources and components. Each sub-group is also referred to as a *cell*. Therefore, the resultant structure obtained by reconfiguring a manufacturing system with a GT layout is known as a *cellular manufacturing system*. Methods of identifying cells from the basic MCIM involve using a matrix manipulation or other methods to rearrange the rows and columns to obtain sub-groups. For our example, the cells are clearly identified by rearranging the rows and columns as shown in Figure 9.16.

> The resultant structure obtained by reconfiguring a manufacturing system with GT layout is known as a *cellular manufacturing system*.

FIGURE 9.15 MCIM for our hypothetical example

Components

Machines	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	1			1			1													
B			1	1	1			1												
C		1	1		1			1												
D	1			1			1													
E													1	1	1		1	1		1
F	1			1			1													
G						1			1		1	1				1			1	
H						1			1		1	1				1			1	
I													1	1	1		1	1		1
J						1			1		1	1				1			1	

FIGURE 9.16 Rearranged rows and columns

Components

Machines	2	3	5	8	10	1	4	7	20	18	17	15	14	13	6	9	11	12	16	19
B	1	1	1	1	1															
C	1	1	1	1	1															
D						1	1	1												
A						1	1	1												
F						1	1	1												
E									1	1	1	1	1	1						
I									1	1	1	1	1	1						
G															1	1	1	1	1	1
H															1	1	1	1	1	1
J															1	1	1	1	1	1

This structure of the matrix is known as a block diagonalized structure. The advantage of a block diagonalized structure is that it enables us to directly read the cells on visual inspection. In this case, four cells are formed with part families and machine groups as shown in Table 9.11.

A vast number of methods are available for identifying an appropriate set of sub-groups. The earliest and most popular among these is the *production flow analysis (PFA)* proposed by Burbidge. Later, the use of clustering techniques, matrix manipulation methods, graph theory, and mathematical programming were proposed by a number of researchers.[9] The **rank order clustering (ROC) method** uses simple matrix manipulation methods to identify the cells in an MCIM. The ROC method rearranges the rows and columns of the MCIM in an iterative manner that will ultimately, and in a finite number of steps, result in a matrix form in which both the rows and columns are arranged in order of decreasing value when read as a binary word.

TABLE 9.11 The Four Cells with Part Families and Machine Groups

	Part Families	Machine Groups
Cell 1	2, 3, 5, 8, 10	B, C
Cell 2	1, 4, 7	A, D, F
Cell 3	13, 14, 15, 17, 18, 20	E, I
Cell 4	6, 9, 11, 12, 16, 19	G, H, J

> The earliest and most popular method for design of cellular manufacturing systems is the *production flow analysis* (*PFA*) proposed by Burbidge.

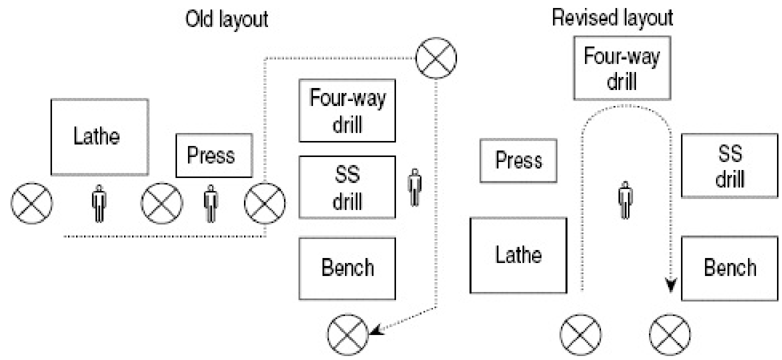
9.10 ONE WORKER–MULTIPLE MACHINE LAYOUTS

Earlier, machines were usually operated manually. Therefore, every machine needed to be attended by one worker. However, today, manufacturing organizations use semi-automatic machines and fully automatic machines. By semi-automatic machines, we mean those with automatic processing capability, but requiring a human interface for the loading and unloading of components into the machine. On the other hand, in a fully automatic machine, the machine has automatic processing capability and is linked with an automated material handling and material transfer mechanism. In this case, as soon as processing in one job is complete the material-handling system will shunt the completed job out of the machine into a material storage system or a conveyor (or some form of material-handling system) and will load the next job into the process.

> One worker–multiple machine layouts promise significant reduction in manufacturing lead time, better space utilization, and cost reduction due to better utilization of resources and manpower.

There are numerous applications of semi-automatic machines in manufacturing systems. In the case of semi-automatic machines, an operator's task is to merely load the parts on to the machine and unload parts from the machines after the processing is over. Therefore, it is possible for one operator to manage more than one machine. The one worker–multiple machine opportunity adds new dimensions to the layout problem. It is possible to achieve effective utilization of floor space during the layout design. Moreover, material-handling tasks can be simplified and an optimal load–unload sequence that maximizes the output from the system may dictate the actual layout of the machines. On the other hand, an improperly designed layout, in the case of a one worker–multiple machine scenario, may result in worker fatigue, loss of productivity and deterioration of quality.

FIGURE 9.17 One worker–multiple machine layout



Source: N. Ravichandran, "A Journey Towards Manufacturing Excellence," CII Quality Summit 2000: 61–115.

Figure 9.17 is an illustration of the nature of transformation and benefits that organizations obtain by employing one worker–multiple machine layouts. This example is one of several such cells formed in the manufacturing facility of Lucas TVS at Padi in Chennai. As is evident from the figure, the layout promises significant reduction in manufacturing lead time, better space utilization, cost reduction due to better utilization of resources and manpower, improvement in quality due to reduced material handling and, finally, a reduction in the distance travelled by the jobs before the completion of processing.

9.11 TECHNOLOGY ISSUES IN PROCESS DESIGN

Batch manufacturing has always had inherent limitations on account of the mid-volume, mid-variety nature of manufacturing. Work-in-process levels are generally high and machine utilization tends to be low. Jobs spend a high proportion of time waiting for a machine to be set up, waiting to be moved or waiting for other jobs on the machine to be completed. Batch production often requires an army of progress chasers to keep jobs flowing through the manufacturing facilities. In batch type manufacturing, some studies conducted revealed that only 5 per cent of the total time spent in the shop contributed to actual metal cutting operation. The rest accounted for wastage of capacity, unnecessary waiting of jobs and so on. One way to improve productivity is to use technology to obtain a better process.

> An **FMS** is a manufacturing system consisting usually of numerical control (NC) machines connected by an automated material-handling system. It is operated through central computer control.

Advancements in the field of manufacturing technology have had an impact on process design. Versatile machines that are capable of handling the work of several traditional machines have provided some relief in simplifying process flow. These machines also provide considerable flexibility to address some of the issues pertaining to mid-volume, zmid-variety manufacturing systems. Of the several developments, flexible manufacturing systems (FMS) have been most prominent. The development of manufacturing technology has been accompanied by developments in material-handling technology, which have also contributed to process improvements. We shall look at these developments in this section.

Flexible Manufacturing Systems

An **FMS** is a manufacturing system that usually consists of numerical control (NC) machines connected by an automated material-handling system. It is operated through central computer control and is capable of simultaneously processing a family of parts with low to medium demand, different process cycles and operation sequences. From the definition of an FMS, one can characterize its features as follows:

- It is an attempt to solve the production problem of mid-volume and mid-variety parts for which neither high production-rate transfer lines nor highly flexible standalone NC machines are suitable.
- It is designed to process, simultaneously, several types of parts in the given mix.
- It is equipped with sophisticated flexible machine tools that are capable of processing a sequence of different parts with negligible tool change over time.
- Parts are transferred from machine to machine by a computer-controlled *material-handling system (MHS)*.
- It consists of three subsystems: the machining system, the material-handling system and the control system.

A schematic representation of the structure of an FMS is given in Figure 9.18. Machine tools are the main machines used in manufacturing while auxiliary equipment are those used for other purposes, such as measuring quality using coordinate measuring machines. The primary MHS transports the work pieces from one location to another in an FMS. On the other hand, the secondary MHS transports work pieces from the machine table to the storage point in front of the machine tool.

Two general classes of FMS technology have been identified. The most recognized form is the multi-machine tool type, sometimes called the classical FMS. This is an automated production system for mid-volume, mid-variety production, consisting of machine tools tied together by an MHS. The second type of FMS is the standalone unit, usually consisting of a single machining centre or CNC lathe. This is sometimes referred to as a *flexible manufacturing cell (FMC)*. Such FMCs are equipped with automatic carousels or rotary tables for loading a small variety of work pieces. In some cases, an integral robot arm is employed for loading and unloading chores. Figure 9.19 shows typical machines used in flexible manufacturing systems.

FIGURE 9.18 Structure of an FMS

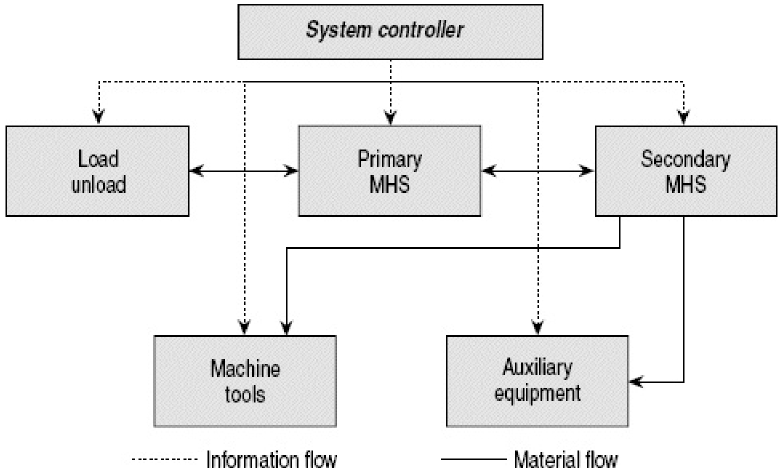
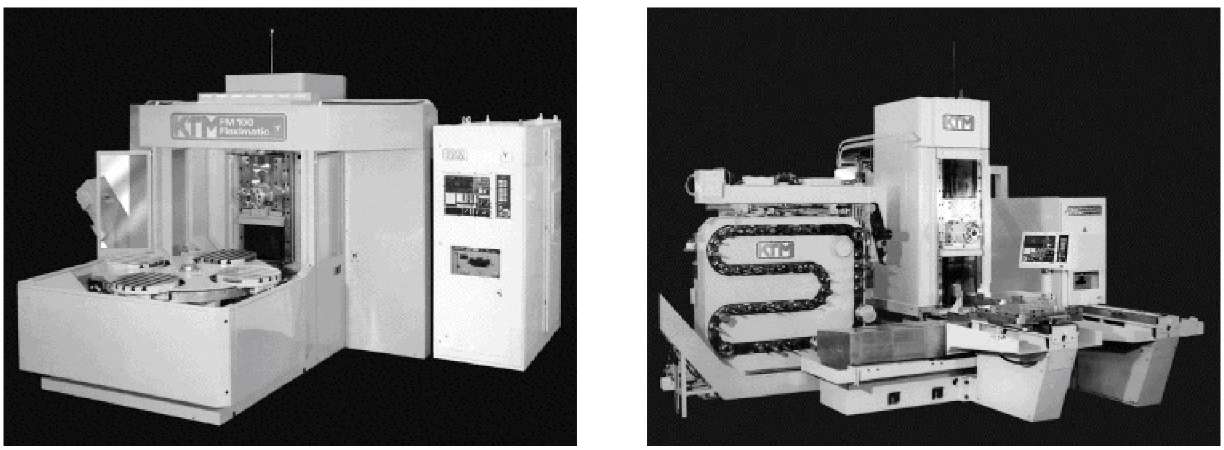


FIGURE 9.19 Typical machines used in FMS



FMS technology results in the reduction of direct and indirect labour force. With the level of automation that is employed in such systems, it is possible for a worker to tend to a group of machines in the system. The following is the role of human labour in the FMS:

- Loading and unloading, tool set-up, tool replacement, work piece set-up off line
- Maintenance of the system, multi-task monitoring (3 to 8 machines)
- Supervision of the overall system, taking decisions using the information supplied by the computer system etc.

The technologically advanced features of the FMS, in part, simplify process design and complexities in flow in an intermittent flow system in batch manufacturing by offering several flexibilities, some of which are as follows:

- *Machine flexibility*: This is related to the ease of making changes required to produce a given set of part types. The measurement of these changes includes, for example, the time taken to change tools in a tool magazine to produce a different part family, the time taken to assemble new fixtures, and so on. Technological progress, proper operation assignment and the technological capability of bringing part and tool together, along with other such factors, will improve this flexibility.
- *Process flexibility or mix flexibility*: This is the ability to produce a given set of part types, each possibly using different

materials in several ways. This, in essence, relates to the mix of jobs, which the system can process simultaneously. Process flexibility increases as the machine set-up cost decreases, and by having multipurpose adaptable CNC machines.

- *Product flexibility*: It is the ability to produce a new set of products economically and quickly. Product flexibility can be measured from the time required to switch from one part mix to another.
- *Routing flexibility*: This is the ability to handle breakdowns and to continue processing the given set of part types. This ability exists if either a part type can be processed via several routes or each operation can be performed by more than one machine.
- *Volume flexibility*: This is a measure of the ability to operate an FMS profitably at different production volumes. This flexibility can be measured by how small the volumes can be for all part types with the system still being run profitably.
- *Expansion flexibility*: It is the capability to build a system and expand it as the need arises, easily and in a modular fashion.

Automated Material-handling Systems

When manufacturing is automated, the material-handling system (MHS) must also be automated. Otherwise, it will not be possible to ensure full utilization and smooth flow of work. Besides, an automated process cannot be totally controlled unless there is an MHS that is an integral part of the factory control system. An integrated MHS is made up of three basic elements, that is, an automated storage system, an automated transport system and an automated material transfer system.

> An integrated MHS is made up of three basic elements:
>
> - an automated storage system,
> - an automated transport system, and
> - an automated material transfer system.

Automated storage system

An automated storage system is used for large-scale bulk storage as well as for small inline buffer storage. The *automated storage and retrieval system (AS/RS)* is the technology that takes the maximum advantage of the cubic space while inherently offering security and inventory control. With warehouse feeding by conveyor, an AS/RS can be used for storage operations ranging from maintenance supplies to raw materials for production, packaging and work in process. Automated storage and retrieval systems are in the forefront of warehouse automation.

As inventories have reduced, massive AS/RS operations are no longer warranted. *Carousels* have become sources of parts for assembly operations and the buffer storage of sub-assemblies during processing. They find increasing application as buffer storage units in flexible manufacturing systems. Two varieties of carousels are available—the horizontal type and the vertical type.

The *horizontal carousel* consists of a continuously looping conveyor belt, which carries segments of storage shelves or carriers. The *vertical carousel* is a cube-shaped storage structure containing two endless conveyor chain or cable loops that travel over the top and bottom sprockets. The loops are separated by supports, shelves, or carriers between them. Loads of various types and configurations can be placed on the carriers.

Automated transport and material transfer systems

Automated transport systems are used to move parts and products from the storage systems to the production operations while automated material transfer systems are used to load and unload materials at the workstations. It is customary to designate automated transport systems as primary MHS and automated transfer systems as secondary material-handling systems.

The *automated guided vehicle (AGV)* system forms one of the most exciting and dynamic tools in material handling today. While technological developments gave AGVs more flexibility and capability, it is market acceptance that has given AGVs a variety of applications to allow them to become the accepted standard material-handling method that they are today. AGVs are battery powered vehicles that can move and transfer materials by following prescribed paths around the manufacturing floor. They are neither physically tied to the production line nor driven by an operator like a forklift truck. Three basic techniques are used to guide AGVs:

- Wires buried in the floor are electrically detected by the vehicle.
- Lines painted on the floor are detected by a photoelectric sensor on the vehicle.
- A computer controlled guidance system with wireless communication links to the AGVs.

AGVs can also communicate with factory computer control systems, either by making a physical link at each stopping point, or by infrared or digital radio transmission. This provides a means to track and control the flow of materials and alters the instructions to the guided vehicle. The central computer provides overall control functions such as dispatching, routing, traffic control, and collision avoidance. The recent advancements in AGVs include SGVs (self-guided vehicles) and free-ranging vehicles. AGVs usually complement an automated production line consisting of conveyors or transfer systems by providing the flexibility of complex and reprogrammable movement around the manufacturing process.

Assembly-line AGV applications are being introduced in manufacturing systems. These guided vehicles carry major sub-assemblies such as motors or transmissions to which parts are added in a serial assembly process. The vehicle proceeds into an assembly area and stops at an assembly workstation. When the process is completed, it enters the next assembly area, and this process is repeated several times. When the assembly process is complete, the finished assembly, say an engine block or a chassis, is unloaded from the vehicle, which is then sent to the start area for the assembly process. One such application was found at the Tata Motors plant in Jamshedpur. It uses an AGV system for rear axle assembly. The assembly line consists of 18 stations and the AGVs progressively move through these stations.

Conveyors exist in a wide variety of forms such as overhead, monorail, carry-and-free, power-and-free, underfloor drag-chain, floor-slot, gravity-feed, belt conveyors, and plastic link chains. All these systems are readily available in a wide variety of sizes, load-carrying capacities and speed capabilities. The intelligence for a conveyor system is provided by placing a large number of sensors around the conveyor and connecting them. It is this sensor and gating or routing technology that often complicates the implementation of a sophisticated conveyor system. These have a considerable impact on the overall cost of the system.

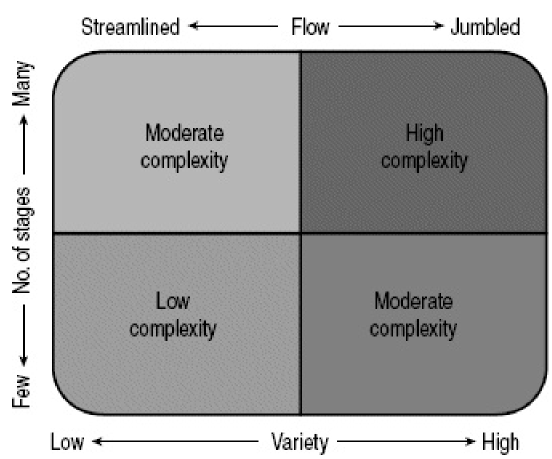
The use of a robot for materials handling can be beneficial for a number of reasons. The industrial application of robots is wide-ranging, particularly in assembly operations. In addition, robots are predominantly used as secondary material-handling systems in FMS. They typically perform most of the loading and unloading chores at each machining centre or buffer location. In an effort to realize most of the advantages of robots and conveyors, the gantry loading system has been developed. Various types of gantry loaders are available.

FMS designers, over the past few years, have developed a rail-guided transport system, which is effectively a compromise between a conveyor system and an AGV. It is a vehicle similar in appearance to the AGV, but is constrained to run on rails. If an FMS can be arranged in a straight line, a rail-guided transport mechanism could well be an attractive means of load transfer between the various locations on an assembly line. Towline systems consist of carts that are powered either by an in-floor chain or by an overhead chain. The control systems available today make it feasible to programme tow carts and send them from one workstation to another. Towline systems are generally most advantageous when utilized in a relatively fixed path and in a consistent stations situation.

9.12 COMPLEXITY IN OPERATIONS MANAGEMENT

From the foregoing discussion on alternative flow patterns and process design alternatives for manufacturing systems, factors that introduce complexity in operations management can be identified. Figure 9.20 summarizes these factors and their effects.

FIGURE 9.20 Factors affecting the complexity of operations management



First is the issue of flow pattern in a manufacturing system. As the flow pattern deteriorates from a continuous and streamlined pattern to intermittent and jumbled, we find that the complexity of operations management increases. In the case of project organizations, operations management needs to deal with long lead times and a high degree of uncertainty. The other issue is the number of stages in the production, irrespective of the process flow pattern. As the number of stages increase, the number of options to be considered increase, along with the size of the problem, leading to complex operations management issues. To give a simple example, scheduling of operations in a shop with 10 machines and 20 sequences of parts is much easier to handle than scheduling of 20 machines with 40 process sequences. Similarly, predicting the nature of disruptions, such as machine breakdown and tool breakdown, is relatively easier in a shop having 20 machines than in one with 40 machines.

> As the flow pattern deteriorates, the complexity of operations management increases.

Finally, the most significant aspect of operations management complexity arises from variety. Variety can manifest itself in several ways in a manufacturing system. This includes variety in product lines, product families and specific variations of the product, variety in process routing that could be employed for manufacturing, and variety in the type of technology used for manufacture of the product. All these add to the complexity of operations management, as seen in this chapter.

SUMMARY

- *Volume, variety* and *flow* exert significant influence on process design in organizations.
- Process industries and mass production systems generally have a streamlined flow of products.
- Mid-volume and mid-variety manufacturing systems have intermittent flow. Capacity estimation is difficult in such systems compared to continuous flow systems.
- Project organizations and customized manufacturing systems have jumbled flow. Capacity estimation and scheduling of jobs are quite difficult. Therefore, operations management complexity is high in jumbled flow systems.
- A *process–product matrix* depicts the relationship between process flow characteristics and volume of production in an manufacturing organization.
- Product layouts are useful for high volume–low variety situations. At the other extreme, fixed positions and project layouts are useful for high-variety situations.
- Product layout and process layouts are used in the discrete manufacturing industry. They have several advantages and disadvantages.
- Mid-volume and mid-variety manufacturing systems can benefit from a group technology (GT) layout.
- Several software packages are available for designing process layouts. CORELAP, ALDEP, COFAD, and CRAFT are among the popular packages in this group.
- Product layout design seeks to identify the minimum number of resources required to meet a targeted production rate and the tasks to be assigned to each of these resources, using a technique called line balancing.
- GT layouts are designed with the objective of subdividing a universe of machines and components into sub-groups such that each sub-group consists of part families and machine groups.
- A number of methods are available for designing GT layouts. These include production flow analysis (PFA), rank order clustering (ROC), mathematical programming and clustering methods.
- New manufacturing technologies such as *flexible manufacturing systems (FMS)* have the potential to simplify flow complexities in mid-volume and mid-variety manufacturing organizations due to increased flexibility.
- No. of stages, variety and flow characteristics determine the complexity of operations management. By a careful design of the process, some of the complexities can be minimized.

FORMULA REVIEW

- The total cost of the process layout, $TC = \sum_{i=1}^{n} \sum_{j=1}^{n} F_{ij} D_{ij} C_{ij}$
- Actual (desired) cycle time = $\frac{\text{Available time}}{\text{Actual(desired) production}}$
- Minimum number of work stations required = $\frac{\text{Sum of all task times}}{\text{Cycle time}}$
- Average resource utilization = $\frac{\text{Sum of all task times}}{\text{Number of workstations} \times \text{cycle time}}$

REVIEW QUESTIONS

1. What are the key determinants of process characteristics in operations? Give specific examples to show how they influence process characteristics.
2. Is there any relationship between volume, variety and flow with respect to process design?
3. How is the continuous flow system different from the intermittent flow system? What are the key implications for operations managers?
4. Give three examples for each of the following and identify two important issues of interest to an operations manager:

   a. A mass production system
   b. A continuous flow system
   c. A flow shop
   d. An intermittent flow system
   e. Job shop
   f. A process industry
   g. A batch production system
   h. Project organization

5. As an operations manager, which areas would you focus on if you were to manage a jumbled flow process?
6. How does the choice of the layout affect the operational performance of an organization?
7. What is the relationship between the volume, variety and flow characteristics of an operating firm and its layout?
8. What are the different types of layouts? How should an organization decide on which layout to choose?
9. Is a group technology layout any different from a product layout? Give reasons for your answer.
10. Identify an appropriate layout for each of the following situations. Justify your choice in a sentence or two:

    a. A manufacturer of garments for Van Heusen
    b. A multi-cuisine restaurant in a posh residential area in Mumbai
    c. The overhaul of helicopters
    d. A fabricator of custom-made PCBs for a large number of electronic applications
    e. An eye hospital
    f. A motor manufacturer manufacturing 4 product groups for worldwide markets
    g. A manufacturer of large turbines for power sector applications

11. Suppose you are given three alternative designs for the layout of a shop floor in a manufacturing organization. How will you decide which of the three is the most appropriate?
12. Critically compare quantitative and qualitative approaches to designing process layouts.
13. How does a construction method of layout design differ from the improvement method? Which method is preferable and why?
14. What do you understand from the phrase “cellular manufacturing system”?

15. What are the reasons for the growing application of group technology concept for layout design?
16. What do you understand by the term FMS? What are the characteristic features of an FMS?
17. How does an FMS help in improving the process design in the case of mid-volume, mid-variety manufacturing?
18. What are the various types of automated material-handling devices available for use in a computer integrated manufacturing system?
19. What do you understand by the term complexity of operations management? Explain.

PROBLEMS

1. A mass producer of an industrial component currently has a daily production rate of 1,200 pieces. The company works for 16 hours a day. The production process currently employs five stations. There are 12 tasks involved in the manufacturing process and together they need 190 seconds.

    a. What is the actual cycle time for the component?
    b. Compute the average utilization of resources employed to manufacture the component.
    c. If the company wants to work with 85% utilization, by how much they should increase the daily production to achieve this?
    d. Suppose, there is a 10% increase in the demand. Do they need to make any changes in the layout?

2. A company procures a few components from the market and assembles them into a standard product and supplies it to its customers. There is enough demand for the product. If the company employs four stations for the assembly, it has 92% average utilization of the resources. The sum of the task time for the process is 180 seconds.

    a. What is the cycle time for the process?
    b. What is their daily production rate if they work in an 8-hour shift?
    c. If they add one more station in the assembly process what would be the new cycle time if the utilization drops to 79%?
    d. By how much can they increase the production on account of the reduced cycle time?

3. Following data are available in the design of a product-based layout in which a certain number of work stations are deployed. The sum of all task times is 200 seconds. The cycle time is 50 seconds and the average resource utilization is 80%. If one more work station is added, the utilization drops to 74.07% and the new cycle time is 45 seconds.

    a. How many work stations are used in the product layout design?
    b. What is the daily production rate if a day consists of 450 minutes?
    c. What is the maximum production possible in the current design?

4. A manufacturer of spark plugs for the mass market would like to design the final assembly shop and requires certain data for the process. The factory works for two shifts and the total available time is 15 hours per day.

    a. There are five tasks involved in the final assembly and the task times (in seconds) are 3.5, 4.5, 2.0, 3.0 and 4.0. What are the minimum and the maximum outputs possible from the factory?
    b. The daily production needs to be 4,000 plugs. What should be the cycle time of the operations at the assembly shop?
    c. If the firm wants to use three workstations, what will be the best output possible? By how much will the output increase if it adds one more workstation?

5. A fast-food restaurant that operates in Connaught Place, New Delhi, specializes in offering food during peak hours. The restaurant operates only for two hours in the morning and promises faster turnaround for customer orders. The restaurant needs to design the workstations at the front end of the kitchen to assemble all customer orders. The back end of the kitchen provides the required food items. A study of the tasks, their dependencies and times taken on an average to assemble reveals the information shown in Table 9.12:

TABLE 9.12 Dependencies and Time Taken to Assemble/serve Food

Task ID	Description	Task Time (Seconds)	Predecessor
A	Set up the serve tray	20	None
B	Arrange plates, cups, tissues	20	A
C	Place the main item in the plate	35	B
D	Fill in the side dishes	35	B
E	Place a filled in water cup	20	D
F	Arrange cutlery items in the plate	20	C, E
G	Verify the order	15	F
H	Prepare a bill for the order	35	G

a. If, during a typical peak hour operation, the restaurant is able to take 144 orders, what is the maximum permissible cycle time for the assembly workstations?
b. If the restaurant desires to set a target of the above cycle time, what is the minimum number of workstations they should have at the assembly?
c. Design the assembly with the minimum number of workstations. Can it serve 180 customers during the peak hour? If not, arrive at a feasible design.
d. For the final design that you have made, compute the average utilization of workstations.
e. The restaurant management is aware that the bottleneck is in terms of their capacity to serve. If they could increase the capacity, they would earn additional revenue. The marginal revenue from an order will be ₹100 and the marginal daily cost of adding a workstation is ₹2,700. What should the management do?

NET-WISE EXCERCISES

1. Caterpillar is the largest maker of construction and mining equipment. To know more about the products offered by them, visit http://india.cat.com/cda/layout?m=81920&x=7 and click on **Products**. Navigate through their product lines and offerings.

Haldia Petrochemicals is the one of the largest petrochemicals complexes in India. Go to http://www.haldiapetrochemicals.com/index.jsp and click on **Products** on the left side of the screen. Visit various sub-links in this section. Also click on the link **About Us**. There is a subsection on manufacturing processes. Visit other parts of the Web site. Take a look at the photos of the plant loaded onto the main page.

Based on your understanding of the two organizations, compare and contrast the product flow and process characteristics.

a. Identify three distinct features of Caterpillar and relate them to the design of the manufacturing process for the organization.
b. Why would you classify Haldia Petrochemicals as a process industry? Identify three characteristics that you find in Haldia Petrochemicals that are peculiar to a process industry.

MINI PROJECT

1. There are several manufacturing and service organizations in every part of the country. Select out of these three organizations that belong to any of the following categories: a process industry; a mass production system; a service set-up; a mid-volume, mid-variety manufacturer.

   Visit the selected manufacturing and service organizations, make a formal plant tour of the organization and collect data on various aspects of operations management. After you have recorded all the key observations based on the visit, prepare a list of items on which you would like to collect additional information and obtain them. Also interview the plant manager, the process planning team, and the line supervisor. Note down their key observations about the plant’s functioning. Based on this work, prepare a final report that contains the following information:

   a. The process flow diagram of the plant
   b. The nature of the production system
   c. The key challenges for operations management
   d. Status of current operations management practices in the organization
   e. Specific areas in which improvement potential exist for the organization

2. There are alternative approaches to layout design. The use of software packages for this purpose has increased manifold in recent years. Prepare a project report to answer the following question pertaining to the use of software for layout design:

   a. Scan the Internet and prepare a list of avail-able software solutions for layout design. Briefly explain the salient features of the software.
   b. Develop a classification scheme to list the software that you have identified. Can you recommend a specific set of application domains of the software on the basis of this classification scheme?
   c. Select one software package from each of your classification schemes and critically compare them. Identify the specific advantages and disadvantages of each package.

3. There are several companies that have recently made significant changes in their layout design. Prominent in the list are automobile and auto-components manufacturing firms. Identify one such company in your locality and perform the following studies and submit a report of your findings:

   a. What were the major drivers of the layout change decision in the organization?
   b. Enumerate the salient aspects of the alternative layout design process (methodology used to arrive at the new design, tools and techniques used, scope of the project, organizational aspects of driving the change process etc.)
   c. Understand the implementation aspects of the layout design process (methodology of implementation, time taken, chronology of events leading to completion of the process etc.)
   d. What were the main benefits that accrued to the organization as a result of this layout design change?
   e. How did the layout change affect various people in the system including the production workers, supervisors, managers, customers, and suppliers?

CASE STUDY

Aerospace India Limited

Aerospace India Limited (AIL) has been serving the needs of the Indian defence sector for the past 20 years. The company has four divisions that manufacture various components for the aerospace sector. Unit 1 was established in 1970 to manufacture components for helicopters. The entire machining of about 2,230 components required for various versions of helicopters is done at the machine shop at Unit 1.

The Machine Shop at AIL

The machine shop at AIL is responsible for manufacturing all components required for the helicopters. It consists of more than 100 machine tools, which includes some high- precision machine tools such as an NC jig boring and a CNC gear grinding, besides many conventional lathes, turrets, milling machines, and drilling machines. The machine shop occupies an area of about 6,440 m^2.

The facilities in the machine shop are arranged in a functional fashion. These include a gear unit comprising facilities for gear manufacturing ranging from 50 mm to 600 mm diameter, a lathe unit for rotating parts, a milling unit, a turret unit, a drilling unit, a line spar milling, a grinding unit, CNC machines, a metrology unit, a tool room, an inspection unit, and production tool stores.

Manufacturing Requirements for New Product

With the progressively dwindling production of the existing range of helicopters, AIL was entrusted with the task of designing and manufacturing components in Unit 1 for a newer helicopter design by its customers. Irrespective of the many variations in the new product, most of the subsystems will have a commonality of about 85 per cent from the perspective of manufacturing components at the machine shop. Therefore, the manufacturing requirements of the new product are not much different from that of the existing ones. The existing machining capacity at the machine shop is adequate to handle this additional load. The process plans and time estimates have already been made for the components to be machined at the machine shop in Unit 1.

Typically, the production of machined components for the new product involves the following production planning and control activities: The scheduling department issues route cards and job tickets based on the production target. The progress department collects these and draws the required material from the stores. Based on the scheduling prepared by the machine shop manager, the components are loaded on to different work centres. Components are inspected after the completion of every operation. Stage inspection is mandatory in production. After inspection, the components are loaded to the next operation. Component loading, operation completion, and the inspection cycle are repeated until all operations are completed. All components are subjected to 100 per cent inspection. However, if the components fall under the life-critical category, the inspection records are maintained for lifetime to trace the history in cases of accidents and failures pertaining to the component.

In the existing set-up, the machine shop is headed by a senior manager who is assisted by one manager and one deputy manager. Currently, even though the area of responsibility is clearly defined, interdependency is high due to the functional layout. It warrants frequent meetings between managers. One of the problems with the existing organization structure is the total lack of product focus. Many components that require turning or milling queue up in the respective sections. The supervisors and the section in-charge normally go by convenience and rush requirements. The senior manager is the only person responsible for the products and their sub-assemblies. The rest are more concerned with turning, milling, etc.

Implications of Maintaining the Status QUO

Since the manufacturing requirements for the new product are very similar to that for the existing one, one option to organize manufacture of new components is to maintain the status quo. This appears to be a soft option. It impinges on no one's working style and requirements. However, one of the senior managers was sceptical of this arrangement. "You see, with the existing set-up we will not be able to manage two different projects. It basically deprives us of product focus." This is so for several reasons, some of which are as follows:

1. A functional layout increases the cycle time. Since machine utilization is stressed over the completion of product families in a functional layout, components that do not deserve immediate priority are loaded to avoid idling, which causes bottlenecks for priority items. This leads to an increase in the WIP inventory.
2. Since the facilities are located far apart, the material-handling distance is large. Also, due to the number of operations, the frequency of material handling is high.
3. Given the complexity of scheduling for more than 2,000 components, functional layout often has to rely on the follow-up group, whose job is to "chase" the components.
4. In the absence of product focus, despite more than 80 per cent completion of loaded components, quite a few assemblies cannot be started, as the required items will be still under progress.
5. Both supervisors and operators develop a tendency to reduce set-up time by combining batches whenever possible. This results in increased batch quantity, even though it was not meant to be.
6. Manufacturing errors are not detected at an early stage. Due to an imbalance in the load, the inspection department often authorizes supervisors to carry out inspection, who do a superficial job.
7. Operators make frequent trips to production tool stores, the standard tools crib, the blueprint booth and the inspection department for various reasons. This increases non-value-added activities and lead time considerably.
8. With an increase in the number of batches and WIP, component traceability is lost. It requires some time to locate the batch required, as identification would be very difficult in the absence of route cards which will be either with the operator or with the inspection department.
9. Due to a focus on performance at the work-centre and section level, it appears that the responsibility of completing the component entirely as per the given schedule, cost, and quality is nobody's except that of the top management.
10. Due to lack of knowledge about other machining operations, workers generally do not appreciate another work area. This also creates a mindset against multi-functional skills.
11. Team spirit is absent, since the functional set-up *minimizes* chances of group interaction.

Design of the Manufacturing Process

Efforts were made to investigate alternate ways of organizing manufacturing for production of machined components for the new product. Initially, a meeting was convened to discuss the various possibilities. Mr Prakash, one of the managers from Unit 1, made a presentation based on his analysis of the problem and proposed two new alternatives. He suggested two alternative approaches to redesigning the machine shop for manufacturing machined components required for the new product. In the first approach, known as the assembly-module approach (AM), the entire machining is organized on the basis of modules of sub-assemblies. In the other approach, known as the machining similarity–based approach (MS), the grouping of components is based on the machining requirements.

Assembly-Module-Based Redesign

The manufacture of components required for the new product can be classified under 14 modules. Each module forms a sub-assembly. From the bill of materials, the components required for each sub-assembly have been segregated. There are about 731 components (Table 9.13 has the details). For example, 133 components pertain to the flight control system. Similarly, 25 components are required for the tail gearbox sub-assembly. For each component, the following information was collected: part number, department number, work-centre number, set-up time, unit processing time, and the quantity required. Using this information, the work-centre-wise capacity requirements have been calculated for each module.

Using a minimum utilization value of 30 per cent, it was found that only seven modules could justify dedicating capacity. Hence, the other modules were combined with these to finally form seven modules. Some modules have more than one cell assigned to them. In addition, a separate cell designated as a common cell was formed with equipment that is both costly and has low utilization at the individual module level. Finally, this has resulted in 13 cells. Table 9.14 has the details. In the final design, wherever the required machines were not available, recommendations have been made to procure them.

TABLE 9.13 Sub-assemblies and Machining Requirements for the New Product

Sub-assembly	Number of Components
Flight control system (FCS)	133
Avionics and electrical system	25
Hydraulic system	12
Structures	59
Landing gear	29
Main rotor	76
Tail rotor	21
Power plant	74
Main gear box (MGB)	145
Tail gear box (TGB)	25
Intermediate gear box (IGB)	26
Auxiliary gear box (AGB)	25
Tail drive shaft (TDS)	24
Others	57
Gear components from existing project	41
Total	772

Note: *41 components from the existing project have been added to avoid omission of these during capacity calculations. These components require special purpose machines to be assigned for producing the new product.

Machining Similarity–Based Redesign

In the second approach, the computation of the capacity requirements work-centre-wise, and the number of machines required for each cell are all done in the same way as described above. But there is a fundamental difference in the approach to forming cells. The 772 parts are grouped together based on their similarity in machining requirements. This would mean, for example, that a group of components requiring turning operations might have been grouped together. Similarly, a group of components going through a series of milling and finishing operations from many sub-assemblies might have been put together.

TABLE 9.14 Details of Modules and Cells as Per the AM Approach for Redesign

Sl. No.	Module	Cell Number	Number of Machines	Number of Componets	Number of Exceptions#	Number of Machines to be Procured
1	Flight control system (FCS)					
1(a)	FCS–I	1	7	93	3	1
1(b)	FCS–II	2	6	40	18	2
2	Structures					
2(a)	Avionics and electrical system, structures	3	5	84	20	1
2(b)	Hydraulic system, landing gear	4	4	41	18	1
3	Rotor group					
3(a)	Main and tail rotor	5	7	65	40	–
3(b)	Main and tail rotor	6	4	32	13	–
4	Power plant accessories	7	8	74	37	1
5	Main gear box (MGB)					
5(a)	MGB–I	8	5	78	32	1
5(b)	MGB–II	9	3	67	11	2
6	Gears (TGB, IGB, AGB)	10	15	76	44	1
7	Non-MGB					
7(a)	Others, gear components for existing project	11	7	86	30	3
7(b)	Others, tail drive shaft	12	3	36	9	–
8	Common cell	13	8	*	*	
	Total		82	772	275	13

Note: * Eight machines have been separately located as Cell 13. These machines were highly valued one-off machines and it was not possible to justify either locating them in a particular cell or procuring additional machines. About 79 components from four modules undergo processing in the cell.

Out of the 275 exceptions, only 92 required movement across the modules. In other cases, it involved inter-cellular movement between cells belonging to the same module.

Production flow analysis was initially employed to identify cells. Forty cells were initially formed. However, the demand on many machines in these cells was far less. Moreover, the number of cells was too many. Using the same machine utilization cut-off value of 30 per cent, the 40 cells were merged and finally 8 cells were formed. Table 9.15 presents the summary details for this design. Finally, Mr Prakash presented a comparison of the two approaches based on several criteria (see Table 9.16 for details).

The task before the executives at AIL was to identify an appropriate configuration for the machine shop at Unit 1.

QUESTIONS FOR DISCUSSION

1. Should AIL continue with the current manufacturing set-up? Articulate three reasons in support of your argument.
2. Classify the two alternatives provided by Mr Prakash using your knowledge of process and technology choices for manufacturing organizations.
3. What are the pros and cons of the two alternative designs that Mr Prakash has proposed for changing the manufacturing shop configuration?

TABLE 9.15 Details of Cells as Per the MS Approach for Redesign

Cell number	Number of Machines	Number of Components	Number of Exceptions	Number of Machines to be Procured
1	10	112	29	2
2	6	80	4	1
3	7	127	6	2
4	5	47	–	1
5	10	104	25	1
6	11	122	16	1
7	7	89	39	1
8	22	91	9	–
Total	76	772	128	9

TABLE 9.16 A Comparison of the Two Approaches

Si. No.	Criterion	AM	MS	Remarks
1.	Implementation cost related			
	(a) Number of cells	13	13	More supervisors in AM
	(b) Number of machines to be procured	8	9	More investment in AM
2.	Cell-size variation			
	(a) Components	32–93	47–127	Larger variations in MS
	(b) Machines	3–15	5–22	Larger variations in MS
	(c) Utilization of machines			
	Maximum	84	92	Capacity more balanced in MS
	Minimum	30	42	
	Average	67	84	Better utilization in MS
3.	No. of exceptions	275	128	More exceptions in AM
4.	Product focus	Well focused	Blurred	Simplified production planning in AM
5.	Production control	Satisfactory	Better	More exceptions in AM makes control difficult
6.	Quality control			
	(a) Requirement of inspection equipment and tools	Less	More	
	(b) Technical documents	Unique	Mixed	AM is better because of product focus
	(c) Ability to direct improvement efforts	More	Less	Each group in AM can identify distinctly to an end product/ sub-assembly
7.	Liaison with design	Simple	Complex	Lack of sub-assembly focus in MS makes it difficult
8.	Document control	Easy	Difficult	Standards vary between the modules. Hence it is easy to distribute documents related to these in AM
9.	Skill improvement/training	Focus on modules	Focus on machining processes	In AM, skill improvement with the end product as focus is possible.

Note: AM = assembly-module approach; MS = machining similarity–based redesign

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CHAPTER 10

Design of Service Systems

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- Is process design in service systems any different from that in manufacturing systems?
- What factors significantly determine the design of service systems?
- What do we mean by customer contact in service organizations? How does it affect the design of service systems?
- What do we mean by service positioning? What are the factors that determine service positioning?
- What is the basic structure of a waiting-line model?
- How can one use the principles of queueing theory to analyse capacity-related issues in service and manufacturing firms?
- How do service firms address short-term capacity planning problems?
- How is service quality measured?

The design of a service system and the choice of its layout are closely related to the degree of customer contact in a service system. Blue Ginger, the Vietnamese restaurant at Taj West End, Bangalore, is designed with teak flooring, fire torches, mood lighting, and waterfalls, in addition to several other features. Vietnamese entertainers in a show kitchen in the dining area offer a unique dining experience.

ideas at Work 10.1

Design of Luxur y Services

Designing an operating system for services is a different cup of tea altogether. There are specific issues that need to be factored in when we address the issue of design. Let us try to understand this with an example—that of offering luxury services to high–net worth individuals. According to an estimate by KSA Technopak, nearly 1.8 million Indian households earn more than USD 100,000 or more per year and spend about USD 10,000 or more on luxury or premium goods and services. This amounts to a market potential of USD 18 billion. Only select players in categories such as hotels and jewellery retail are offering such luxury services. What are the requirements for offering such services?

First, companies need to carve out a unique position as customers are very individualistic and conscious about logos and brands. In the case of luxury services (and also in most other services), the shopping experience is very crucial. Once a customer walks through the door, he/she must be convinced to spend on the services and products offered. Raymond claims to have sold 1000 shirts priced at ₹12,000 and 100 suits at over ₹100,000 per piece in its Manzoni range in 2007.

Designing services is also about the tiny details that please the customer. Whether it is buying a very expensive handbag or spending an afternoon in a spa, service excellence is all about the nature and quality of staff interaction with the customers. Therefore, designing services with greater interaction with the customers require that the right people are in place to deliver the experience. This is especially true of a luxury service where experience is at the root of brand building. The Murjani Group, which deals with luxury brands, believes in carefully selecting employees and putting them through an extensive training programme. This educates them about the brand and prepares them for special circumstances such as the arrival of a celebrity at the store. The Indian Hotels Company Limited, better known as Taj Hotels Resorts and Palaces, redesigned its structural appearance and repositioned its brands to achieve service excellence. Furthermore, it also put in place some unique processes and defined service standards. It invested substantially in training its employees.

Another aspect of services is the need to address the issue of personalization. Ferrari, the luxury car-maker, has a personalization programme called “One-to-One” for its top-end model, the 612 Scaglietti. The idea is to let the customers design their own car with the help of a company advisor.

Such service requirements place commensurate demand on the design of the operating system as well. Service systems must allow personalization, customer interaction, and variety. All these add to the complexity of the service offering. The experience of the service delivery process influences the service quality and lets the company build its brand. The design of services must address these issues and provide the operations manager with alternatives. The operations manager must also be aware of the implications of these alternatives. We shall take a closer look at these aspects in the chapter.

Source: Based on P. Singh, "Luxurious Ride," *Business World*, 28 July 2008, pp. 36–48.

10.1 DESIGN OF SERVICE SYSTEMS: CHARACTERISTIC ASPECTS

Designing operations systems typically involves making choices with respect to the location, technology, capacity, and layout of the system. These decisions directly influence other aspects of the operations, such as the people and skills to be deployed and the planning methodology to be put in place. However, designing a service system is vastly different from designing a manufacturing system. In a manufacturing system, the customer is seldom part of the process. He/she merely places an order and awaits the delivery of the product. Issues such as what resources are to be deployed, how they need to be laid out, how to link the successive stages of the conversion process, and what kind of planning and coordination elements to deploy are all made with this basic understanding. In contrast, in most service systems, customer participation in the conversion process is inevitable. Therefore, it poses a different challenge altogether and requires the designer to incorporate the customer as an integral element in the design process.

Consider setting up a restaurant in the city of Hyderabad. Assume that we have been able to secure a 40,000 square feet independent building with some spacious land around it. When we think of a good restaurant, several things come to our mind with respect to the design of the system. Some of these include (a) a well-laid out dining space with tasteful decoration of the surroundings and a good ambience, (b) the nature and breadth of offerings in the menu available to the customer, and (c) the judicious use of technology and human elements so that the system is responsive. From a service design perspective, achieving these outcomes essentially requires us to answer some questions regarding the design of the restaurant. There are several issues that we need to address in this process. Let us list some of them:

> Designing operations systems typically involves making choices with respect to the location, technology, capacity, and layout of the system. However, designing a service system is vastly different from designing a manufacturing system. It requires the designer to incorporate the customer as an integral element in the design process.

a. Are there alternatives available for us to position the service? What factors influence service positioning and what are the implications of this on the overall service delivery design?
b. What is the nature and level of interaction that we must design between the service provider and the customer? What are the implications of this?
c. What is the overall level of technology that we must use? How and where should we deploy the technology?
d. What are the elements of the front office and the back office of this service delivery system? How do we identify these elements?
e. How should we design the dining area and the kitchen area? What are the factors that will influence the choice of the design?
f. How should we lay out the service delivery system? Which are the areas that need greater attention with respect to look and feel?
g. What should be the capacity of the dining area and the kitchen area? How can we estimate this, given a certain

uncertainty in the arrival pattern and the demand for restaurant services?

h. How should we measure and improve the quality of the restaurant?

This list is merely suggestive. It indicates the nature of decisions that one must make in the design of a service system. One can develop similar sets of questions with respect to the design of other service systems such as a hospital, an automobile garage, an after-sales service outlet, a management consulting firm, or a travel agency.

10.2 CUSTOMER CONTACT IN SERVICE SYSTEMS

Of the several factors that may influence our choice of various design elements in a service system, the most fundamental one is the customer contact that we want to provide in the service delivery system. Customer contact signifies the extent to which the customer participates in the preparation and consumption of a service as well as the nature and intensity of interaction that the customer has with the service personnel. It also indicates the level of exposure that the customer has to the various facets of the service system while receiving the service. The degree of **customer contact** relates to varying proportions of customer exposure to all these attributes. Some examples will help clarify these ideas.

> **Customer contact** signifies the extent to which the customer participates in the preparation and consumption of the service as well as the nature and intensity of interaction that the customer has with the entities and service personnel.

Let us consider an automobile garage with two different options with which the service delivery mechanism could be designed. In Design A, the customer is received at the front portion of the garage in a neatly laid out office. The customer assistant interacts with the customer, hears his/her complaints and the issues to be addressed while servicing the car, records them in the work sheet, and takes his/her approval. The customer assistant requests him/her to come back at a particular time to pick up the car after servicing. When the customer comes to pick up the vehicle, he/she meets the service assistant at the same office, makes the payment, and drives the car away after completing the formalities. In Design B, while the elements of the service are the same, the manner in which it is laid out and the extent to which the customer is exposed to various aspects of service delivery is different. For instance, in Design B, the customer is allowed to visit the garage and is allowed to interact with the repairperson and to seek his evaluation of the condition of the car. The customer will also have an opportunity to “see” the manner in which the car is being serviced.

In the example discussed, customer contact is varying. In Design B, the degree of customer contact is high as the customer has greater opportunities to participate in the service delivery process and discover several moments of truth. A similar situation exists in the banking sector where a customer can use either an ATM or a branch office to withdraw or deposit cash/cheques. There are several situations in service systems where the process design enables the customer to either make use of self-service with helplines and menus and technology choices, or get a service agent to co-create the service along with the customer. This includes the use of vending machines instead of a sales agent to deliver a service (such as issuing tickets or vending coffee and beverages), malls and supermarkets versus traditional grocery stores, and Web-based online after-sales service facilities as opposed to on-site visits by service personnel. It is easy to appreciate that in all these situations, the degree of customer contact varies.

The degree of customer contact is a design choice that a service organization has, and different choices would result in different impacts on the design and operation of the service delivery system. At the two extremes of the degree of customer contact, we find certain distinctive characteristics of the service system. When the degree of customer contact is very low, the system could be highly mechanized and firms can pursue efficiency goals very well. On the other hand, when the degree of customer contact is high, it is difficult to pursue efficiency goals. Satisfying the customer requires clear trade-offs between the efficiency and the effectiveness of service delivery. Based on the degree of customer contact, one can visualize three types of designs for service processes:

- *Low degree of customer contact*: quasi-manufacturing
- *Medium degree of customer contact*: mixed service
- *High degree of customer contact*: pure service

> Based on the degree of customer contact, one can visualize three types of designs for service processes:
>
> - Low degree of customer contact: quasi-manufacturing
> - Medium degree of customer contact: mixed service
> - High degree of customer contact: pure service

Therefore, customer contact is an important decision variable in the service process design problem. It affects several aspects of a service system. We shall take a look at some of these aspects.

- *Efficiency of operations:* Customer contact has a direct bearing on the operational efficiency in service systems. When service systems are designed with a high degree of customer contact, pursuing efficiency goals becomes difficult or futile. In a high customer contact system, customers are likely to participate to a greater extent, along with the service personnel in co-creating the service. Therefore, convenience and quick-response requirements need to be met. These will come in the way of organizing the entire operations from a pure efficiency perspective.

  Therefore, we can conclude that in service systems designed with a high degree of customer contact, effectiveness goals are more important to pursue. The effectiveness of a service delivery is a function of how well, in the mind of the customer, the service was delivered. In conclusion, low customer contact may allow a service organization to pursue internally focused measures such as low cost and efficiency. On the other hand, high customer contact may require that the service organization pursues externally focused measures pertaining to customer satisfaction.
- *Capacity choices:* From this discussion, we can easily infer that a service system designed with high customer contact may need to have a capacity in excess of average requirements. The organization will be better off with moderate levels of utilization. We shall see later in the chapter why high utilization levels are undesirable in the case of service systems. Therefore, one can expect higher investments of capacity in high-contact systems, which may marginally increase the cost of the service being provided.
- *Location of facilities:* Service organizations designed with a high degree of customer contact must address the issue of location of facilities very carefully. Since customer participation in the service creation becomes inevitable in high customer contact situations, locating the service delivery system in a convenient place is very crucial. Consider two alternatives for setting up an after-sales service centre for, say, Sony television sets. In one scenario, if the customer

makes a phone call or sends an e-mail, the service personnel will come home, pick up the television set, and deliver it back after repair. This is a low customer contact scenario. In another scenario, the customer is expected to visit the service outlet to leave the TV and take it back after the repair is done from the outlet. Several home-appliance service providers in the country seem to follow this design. This is a high customer contact design compared to the earlier scenario. In this case, the location of the service outlets is very important. The same logic could be extended to home delivery of pizzas as opposed to visiting the nearest pizza corner shop to buy pizzas.

- *Operational control:* The nature and degree of operational control that must be put in place also depends on the degree of customer contact. The variability of the service is likely to be more in a high customer contact system as each customer will bring his/her idiosyncrasy. Therefore, in a service delivery system with high customer contact, operational control is not only important but also difficult. Training and skill development of the service personnel and ensuring a high quality of service are some of the critical aspects of a high customer contact service delivery system.

VIDEO INSIGHTS 10.1

Design of a service delivery system requires that a few operating decisions with respect to resources deployed and the level of access given to the customer are appropriately made. It also requires developing systems and procedures that are customer oriented. For an illustration of these in automobile sales and service, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

10.3 COMPLEXITY AND DIVERGENCE IN SERVICE SYSTEMS

Closely related to customer contact are two other attributes in a service system. These are the degree of complexity and divergence in a service offering. The **degree of complexity** refers to the steps and sequences in the process, measured by the number and intricacy of the steps. Let us consider two identical service settings in, say, offering air services between Mumbai and Bangalore. Let us consider one full-fare airline such as Jet Airways and a no-frills airline such as Spice Jet. The number of steps involved in completing all the processes in one journey between Mumbai and Bangalore is more in Jet Airways compared to Spice Jet. Figure 10.1 is an illustration of the ticketing and the boarding process in the case of these two airlines.

The **degree of complexity** of a service refers to the steps and sequences in the process, measured by the number and intricacy of the steps.

FIGURE 10.1 An illustration of degrees of complexity

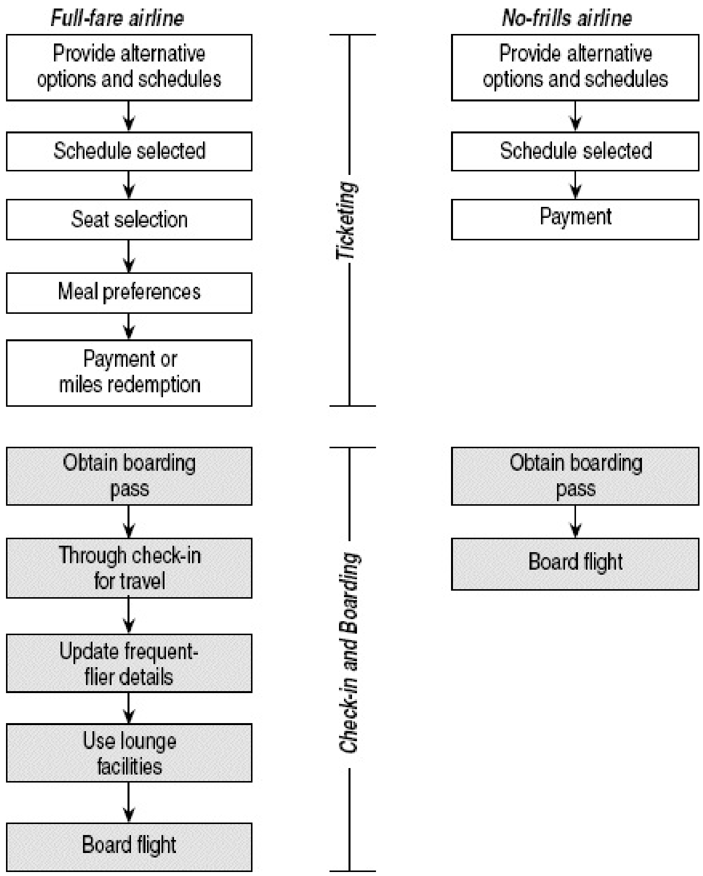


TABLE 10.1 Degree of Divergence: An Illustration

Process Description	Low-cost Airline (Low Divergence)	Full-fare airline (Hhigh Divergence)
Online booking	Air ticket, insurance	Air ticket, insurance, hotel, airport transfer, cab for local travel
Fare options	Low-cost fare	Non-refundable, apex (restricted), apex (normal), economy, full fare
Cabin class	Economy	Economy, club class, first class, business class
Meal preferences	On-board sale of limited snacks	Asian vegetarian meal, non-vegetarian meal, Jain meal, diet meal, fruit platter, choice of beverages
Airport services	None	Valet, lounge, special assistancel

As shown in Figure 10.1, in the case of a full-fare airline such as Jet Airways, there are a total of 10 steps in the ticketing and the boarding process. As opposed to this, in the case of a typical no-frills airline such as Spice Jet, there are only five steps. In Jet Airways, several fare classes, meal preferences, and alternative seating choices are available. In addition, Jet Airways needs to handle multiple frequent-flyer options and associated processes, in addition to addressing the issue of offering lounge facilities. A typical travel process must address all these steps in the ticketing and service delivery aspects. On the other hand, in the case of Spice Jet, these steps are not required in the service delivery process. From our definition, the degree of complexity is greater in the case of Jet Airways. Drawing cash from an ATM has a lesser degree of complexity than using a traditional branch office. Similarly, an automated car washing facility may be a less complex service process than a fully manual car-washing facility. In general, many automation projects may possess greater complexity in terms of technical systems, maintenance, etc. However, from a process design perspective, they may simplify the user interface and the process itself.

Part of the reason for increased complexity may be due to the number of alternative options available at each step in the service delivery process. This aspect can be understood through the concept of process divergence. The variability of the steps and sequences represents the degree of divergence. Process divergence occurs primarily on account of multiple options available at several steps of the process. A standardized process will have a low degree of divergence. At the other extreme, in a process in which every step of the process is unique for each customer, the degree of divergence is high. A psychological counselling service provider will experience a highly divergent process as each arriving patient requires a unique approach for counselling.

Table 10.1 illustrates the divergence in the case of air travel. The table provides a comparison between a typical full-fare airline and a no-frills airline. As evident from the table, each step has more options in the case of a full fare airline (such as Jet Airways or Indian). If you visit the home page of Jet Airways (www.jetairways.com), you find that, in addition to booking air tickets, it is possible to also book hotels and insurance. On the other hand, you may not find these options in the case of Spice Jet. In a full-fare airline, there may be three classes of cabins—Economy, Business, and First. Typically, a no-frills airline such as Spice Jet offers a single class cabin (economy—low fare). In a full-fare airline, the menu on offer is wide and one can indicate one's preferences even at the time of booking the ticket. In contrast, in a no-frills airline, a limited set of snacks is sold on board. From a process design perspective, degree of divergence introduces greater challenges in the service delivery as we saw in the case of degree of complexity.

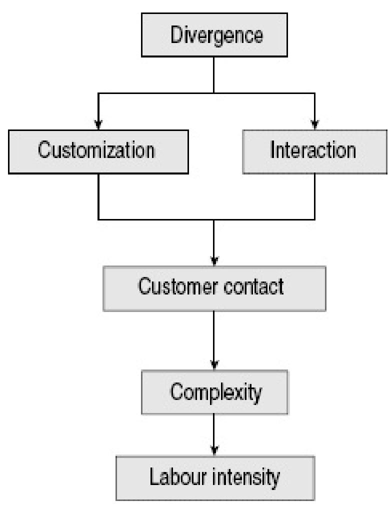
> The executional latitude or variability of the steps and sequences in a process represents the degree of divergence.

10.4 SERVICE POSITIONING

In a service setting, customers are part of the system. Therefore, organizations need to incorporate the nature of interaction and the scope and role of the customer in the overall service consumption as an important element of the design. A simple service scenario of providing a cup of standard coffee/tea in exchange for exact change from a customer can be effectively serviced by a coffee vending machine or a roadside *dhaba*. On the other hand, in a Café Coffee Day outlet, a customer can choose from over 20 different varieties of coffee/tea. In such a service set-up, it is impossible to handle requests using a machine. Moreover, the large number of varieties may require a certain degree of interaction with the customer. The *paanwallah* pre-pares virtually an infinite variety of *paans* because the ingredients he adds to make each *paan* is a function of an individual customer's taste preferences. Because of these considerations, the three parameters of customer contact, degree of divergence, and degree of complexity influence the design of service processes significantly.

Furthermore, each of these parameters has a certain impact on the labour component in a service system design. Customer contact directly influences the nature of interaction in a service system as we have already seen. On the other hand, the degree of divergence signifies the customization in the system. A high degree of divergence, as we saw, results in a high degree of customization. As the degree of customization, the degree of interaction and the complexity of the service increases, the labour intensity required in delivering the service will also go up. Figure 10.2 illustrates the relationship among these factors and how they all eventually affect the labour intensity in a service system.

FIGURE 10.2 Factors affecting design in services



Knowledge of the impact of the labour components of a service design is very important as it helps to develop appropriate systems for service delivery. When the degree of interaction and customization is low, the flow becomes streamlined due to fewer varieties. It is also possible to exploit technology options to provide the service. Therefore, such systems will resemble mass production systems. On the contrary, when the degree of customization and interaction is high, the system resembles a jumbled flow and similar operations management problems will be faced by the service system.

From an operational perspective, when the labour intensity is high, it has certain implications for the service delivery process. Establishing good procedures and practices and focusing on employee welfare are important aspects of managing such service systems. This is because there is likely to be greater interaction between the service provider and the customer in such systems.

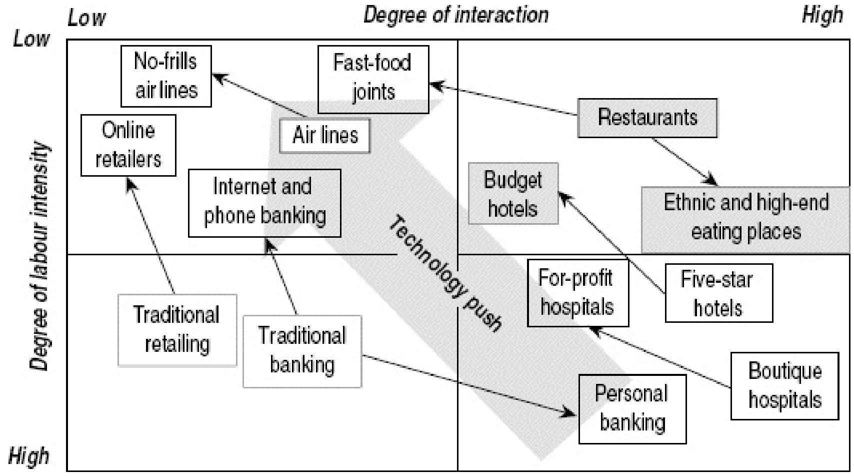
Starting up of new units and managing growth are challenging issues. An example will clarify these aspects of such service systems. Take the case of Aravind Eye Care, Madurai or any other example in the case of health care. Starting another unit cannot happen by franchising the brand name as a fast-food provider such as McDonald’s may do. Another sector is the hospitality industry. In both these cases, you will find that labour intensity is greater. Therefore, these issues are important in the service design process.

VIDEO INSIGHTS 10.2

Service delivery systems are designed with several objectives in mind on account of customer contact and high involvement. Moreover, capacity decisions also need to be made appropriately failing which there could be delays and waiting. These issues are of paramount importance in a healthcare delivery design such as the Medicity facility of Medanta in Gurgaon. To know more about these issues, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

On the other hand, in the case of low interaction and customization, the issues of process design are somewhat different. Since there will be fewer opportunities for interaction, attention to physical surroundings is important. The development of good standard operating procedures, deployment of relevant technological aids, and managing rigid hierarchies are other elements of process design that makes these systems successful. Such firms may also have to spend more on marketing as means of developing loyalty as repeat purchases through personalized service offerings are minimal. An Internet-and ATM-based banking system will be a good example to understand this. If you bank with ICICI Bank you will experience many of these. ATM transactions, phone banking, and Internet banking channels have reduced the customer interaction by substituting standard procedures and technological gadgets in the place of service personnel. They have also invested in greater marketing efforts and better physical surroundings to deliver the service. Another example to think about is the low-budget hotels such as Ginger Hotels. They have also put in place technological gadgets and standard operating procedures in place of service personnel.

FIGURE 10.3 An illustration of service positioning



The culmination of these issues pertaining to service process design is the issue of service positioning. The three parameters—contact, divergence, and complexity—pertaining to the service than an organization offers, determine service process and delivery system design. **Service positioning** is the strategic choice a firm makes on these three parameters. An illustration of service positioning is given in Figure 10.3. Let us look at two examples in the figure. Service positioning in the banking sector has emerged in two different directions. While technology-assisted banking solutions such as Internet banking and phone banking have created a new service positioning with lesser labour intensity and interaction compared to the traditional banking operations, we also witness personal banking solutions that target high–net worth individuals in which the service system is designed with greater labour intensity and interaction. Similarly, we see alternatives emerging in the restaurant business as well. Maiyas, the Bangalore-based restaurant chain, opened a multi-storey service offering in the heart of the city in which customized solutions and menu offerings are made available on one floor of the restaurant. This increases both the interaction and labour intensity of the service offering compared to a typical restaurant business. On the other hand, in a fast-food joint, the service positioning moves towards lesser labour intensity and interaction as we have witnessed. As shown in the figure, the technology solutions help the service designer push the service towards lesser interaction and labour intensity by replacing human elements with technology interfaces through a variety of gadgets and the Internet.

Service positioning is the strategic choice a firm makes on the degree of customer contact, degree of divergence, and degree of complexity pertaining to the service.

ideas at Work 10.2

Blue Ginger: The Vietnamese Restaurant at Taj West End, Bangalore

The design of a service system, choice of the layout, and the elements that are included in the list of customer contact is a crucial exercise. Typically, the restaur ant and the dining space design in a five star hotel have all the complexities of a service system design. Several choices go into this design. These include the extent to which the customer needs to be exposed to the actual act of cooking (in some cases there is a show kitchen which actually demonstrates the cooking process in the dining area itself), the ambient design, layout of food display, the dining space, and the nature and depth of offerings to be made in the food.

Taj West End, Bangalore (one of the Taj chains of luxury hotels), has several dining facilities. Of these, Blue Ginger is special as it is the first Vietnamese restaurant in India. Blue Ginger serves various varieties of Vietnamese cooking prepared by Chef from Vietnam. The restaurant is designed with teak flooring, fire torches, mood lighting, and waterfalls, in addition to several other features. The Vietnamese entertainers in a show kitchen in the dining area offer a unique dining experience.

The restaurant has been refurbished with present day requirements. The salient features are as follows:

1. Show kitchen for a greater interactive experience and an open bar counter
2. Three musicians from Vietnam who perform live
3. Specially designed furniture reflective of the regional style with water-hyacinth fibre chairs, leather ottomans, dark silk furnishing, and natural stone tables

Several choices of dishes are offered in Blue Ginger. Two of the sample menus offered are given in Table 10.2. Although this may increase the diversity and the complexity of the service offering, it provides unique advantages for the service provider.

This example brings out the importance of process design in services systems and the alternatives from which one could choose to design a service system such as hotels and restaurants. It also illustrates the complexity of such design choices and the implications for competitive advantage.

Source: Based on information available on http://www.tajhotels.com/Luxury/THE%20TAJ%20WEST%20END%2CBANGALORE/default.htm, accessed 20 July 2009, www.tajhotels.com/tajluxury/luxury/pdf/HLTBLRWE/essentials/factsheet.pdf accessed on Apr 28, 2014

TABLE 10.2 Sample Menus Offered in Blue Ginger

Sample Menu 1	**Sample Menu 2**
Soup: asparagus and crabmeat soup or spinach and vegetable soup	Soup: asparagus and crabmeat soup or corn and tofu soup
Salad: Chicken and green papaya salad; raw mango salad	Salad: Lotus stem salad with shrimp; raw mango salad
• Shrimp paste with crispy rice coating • Grilled chicken in Saigon marinade • Fresh rice paper roll with tofu and vegetables • Crispy deep fried babycorn	• Crispy fried soft shell crab • Fresh rice paper roll with shrimp and chicken • Tofu and vegetable with dill and turmeric • Fried vegetable rice paper roll

• Sautéed lobster in salt pepper and garlic • Braised lamb shanks with lemon leaves • Stir fried chicken with mushroom in sate sauce • Sautéed spinach and greens with garlic • Sautéed vegetables in chilly plum sauce • Braised mushroom in green peppercorns • Soft noodle with mix vegetables • Egg and crab meat fried rice/vegetable fried rice • Baguette bread • Crème coconut custard with choice of ice cream	• Sautéed lobster in salt pepper and garlic • Stir fried vegetables in chilly bean sauce • Stir fried lamb with snow peas • Sautéed spinach and greens with garlic • Spiced fish cari in clay pot • Spicy vegetable red cari • Soft noodle with mix vegetables • Vegetable fried rice • Baguette bread • Crème coconut custard with choice of ice cream • Fresh fruit platter

10.5 SERVICE BLUEPRINTING

Layout design is a process by which decisions are made about locating various resources in an organization such that the performance of the system is maximized. In a manufacturing organization, layout planning enables the operations manager to conveniently locate the resources in a shop floor so that jobs travel smaller distances, are not handled too frequently and unnecessarily, and spend less time in the system before it is completed. In the case of a service system, these requirements are equally important. For instance, if we visit the local branch of the Life Insurance Corporation (LIC) of India Limited to process a new policy, similar requirements need to be met. We should not be travelling up and down across various departments to complete the task. We may not also like our requirements to be handled multiple times by multiple personnel. For instance, when we make a telephonic contact with a service provider, we find that the call is often transferred to other departments and each time we start narrating the whole story from the beginning. This is reflective of a bad process and system design. Furthermore, we would like the service to be delivered fast. All these point to the possibility of using some of the concepts and tools that manufacturing systems have developed to address layout planning.

However, the major point of departure is with respect to the role of the customer. Since in a service system, the customer often “co-creates” the service along with the service provider, other challenges crop up and need to be addressed over and above the issues mentioned so far. Some of these are as follows:

- In a service system, the customer directly interacts with the service provider. Therefore, appropriate structural mechanisms must be in place to make the process simple, easy to use, and comfortable for the customer.
- The appearance of the place where the service is provided in itself influences the impressions and the service quality aspects. Therefore, paying careful attention to the aesthetics and ambience of the system is very important while doing layout planning.
- Organizations have alternative choices with respect to customer contact and service complexity. These choices reflect in the service positioning. Once the choices are made, it has a bearing on the layout. Certain aspects of the service need not be exposed to the customer; therefore, layout planning for such elements of the service delivery could be very different from those in which there is direct customer contact. An example of this is the restaurant. In a restaurant, the layout for the kitchen and the stores is vastly different from that of the dining area.

The culmination of this ongoing discussion is that the starting point in the layout design of a service system is to map various activities pertaining to the service delivery process and identify specifically how each step of the service delivery process will make an impact with respect to the service positioning strategy. Once this is done, the steps that require direct involvement and interaction of the customers could be isolated for one kind of layout planning and the rest with no direct customer interaction could be considered for an alternative layout planning. The tool used to do this is known as service blueprinting. **Service blueprinting** is a method by which the service delivery process is broken down into individual elements through a step-by-step mapping of the process. Service blueprinting helps organizations design, monitor, control, and improve processes and the service delivery system on an ongoing basis. While this is very similar to a process mapping done in manufacturing systems to analyse processes, we superimpose a few more elements to this to make it relevant for service systems. We shall define these new aspects related to service blueprinting before using an example to understand this.

> **Service blueprinting** is a method by which the service delivery process is broken down into individual elements through a step-by-step mapping of the process.

> All aspects of a service delivery system that are in the line of visibility of a customer will be part of the *front office*. The front office provides the customer with ample opportunities to discover his/her moments of truth about the service delivery process.

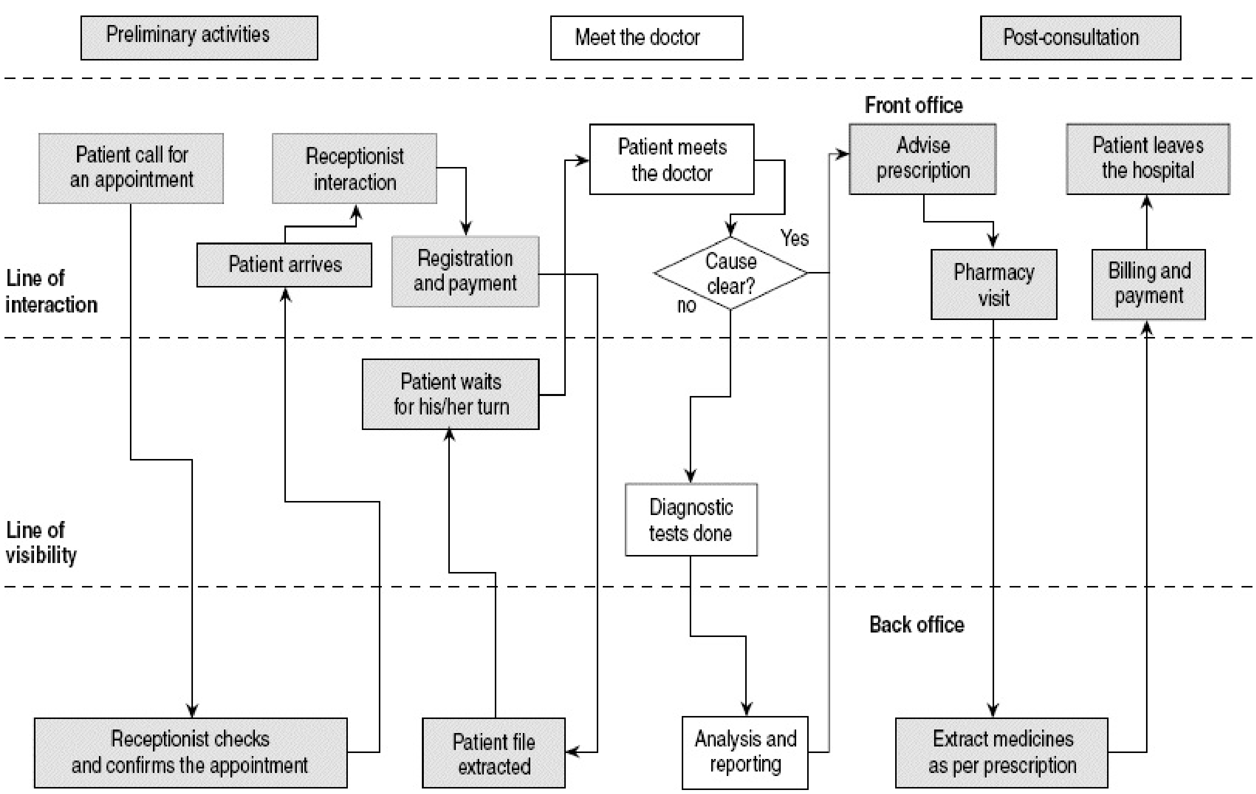
- *Line of interaction:* In a service layout planning exercise we need to draw the line of interaction. This line separates all the activities in which the customer has to have a direct interaction with the service provider as part of the service creation and delivery process.
- *Line of visibility:* This line includes all the structural, planning, and interactional elements of a service delivery process that fall within the eyesight of the customer. For example, in a restaurant, the kitchen is not in the line of visibility. However, the parking lots, the washroom, the eating space, the cash counter, the front lawns, and the food delivery counter are all in the line of visibility.
- *Front office*: All aspects of a service delivery system that are in the line of visibility of a customer will be part of the front office. Essentially, the front office provides the customer with ample opportunities to discover his/her moments of truth about the service delivery process, the quality, the people, and a host of other issues.
- *Back office*: All aspects of a service delivery process that are behind (or beyond) the line of visibility constitute the back office. Customers normally do not have access to these aspects of the service delivery process as these are meant for internal interactions among the service delivery personnel. The back office may operate as a support arm for the front-line staff by providing them with data, information, planning tools, and processing support on several aspects of a service.

> All aspects of a service delivery process that are behind (or beyond) the line of visibility constitute the *back office*.

Let us try to understand these concepts using the example of a hospital. Suppose you want to visit a consultant in the Brain & Spine Department of Fortis Hospitals, Bangalore. First, you call the Brain & Spine Department and ask for an appointment. You follow this up with a visit to the hospital at the appointed time. The receptionist first collects the consulting fee and extracts the file from the records room. If you are a first-time visitor, you also go through a registration process. You wait for your turn to meet the doctor. The doctor interacts with you and gets additional tests done, if required, before prescribing appropriate medicines. Finally, you will visit the pharmacy, buy the prescribed medicines and leave the hospital. This process has been mapped using the concept of service blueprinting. See Figure 10.4 for details. In Figure 10.4, the line of visibility and the line of interaction are shown by dotted lines. Also, zones indicating the front office and back office have been shown.

All structural elements in the line of visibility require a careful approach when it comes to layout planning. Cleanliness, comfort, convenience, proper lighting of the place, provision of adequate spaces, clear signage, and unambiguous instructions are certain aspects of layout design. Also, the employees operating in the front office require superior communication skills, the right attitude and temperament in dealing with the customers. On the other hand, employees in the back office require greater planning and technical skills than interpersonal skills.

FIGURE 10.4 Service blueprinting: An illustration



10.6 CAPACITY PLANNING IN SERVICES USING QUEUEING ANALYSIS

Consider the capacity planning problem in the case of the computerized passenger reservation facility of Indian Railways. In simple terms, the question boils down to deciding the number of booking counters to be made available to the public. It is obvious that if there are fewer booking counters, the queue is likely to build and customers may end up spending more time in the system before they get their tickets booked. We have similar experiences in a banking system or at BSNL's bill payment counters. Capacity decisions in service systems are often made on the basis of the impact on the customers. In service systems, waiting time is an important operational measure that determines service quality. Similar examples exist in manufacturing systems as well. A resource that is fewer in number and highly utilized is likely to be a bottleneck and increase the waiting time of the jobs ahead of it. Due to this, manufacturing lead time will increase and work in progress will pile up in the factory. This will have a cascading effect in terms of missing delivery commitments and shipping delays.

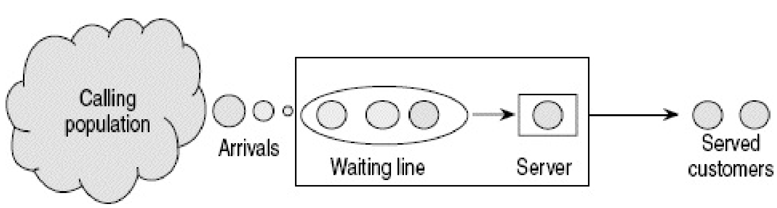
Waiting-line models make use of queueing theory fundamentals such as queue length, waiting time and utilization of resources, to analyse the impact of alternative capacity choices on important operational measures in operating systems. Therefore, the capacity planning problem could be analysed using queueing theory fundamentals. We will now study the basic elements of a queueing system and the alternative scenarios that can be analysed using the waiting-line models developed.

> Waiting-line models make use of queueing theory fundamentals to analyse the impact of alternative capacity choices on important operational measures in operating systems such as queue length, waiting time, and utilization of resources.

The Basic Structure of a Queueing System

Figure 10.5 depicts the basic structure of a queueing system. The demand for the products/ services offered by the operating system originates from a *calling population* or source. In the case of a restaurant, the calling population (source) of demand could be the citizens in the vicinity of the restaurant. The demand manifests in the form of *arrivals* at the system. In the case of service systems, it could be actual customers arriving to experience the service. In the case of a manufacturing system, it could be work orders at a shop or customer orders at a division. The third element is the *waiting line*, which characterizes the provision made for the arrivals to wait for their turn. There are *servers* in the system for service delivery and finally the *served customers* exit the system. We shall understand each element in detail and enumerate alternative representations that exist in real life in each of these. Figure 10.6 provides a concise illustration of the elements of waiting-line models and enumerates the alternatives pertaining to each element.

FIGURE 10.5 Basic structure of a queueing system

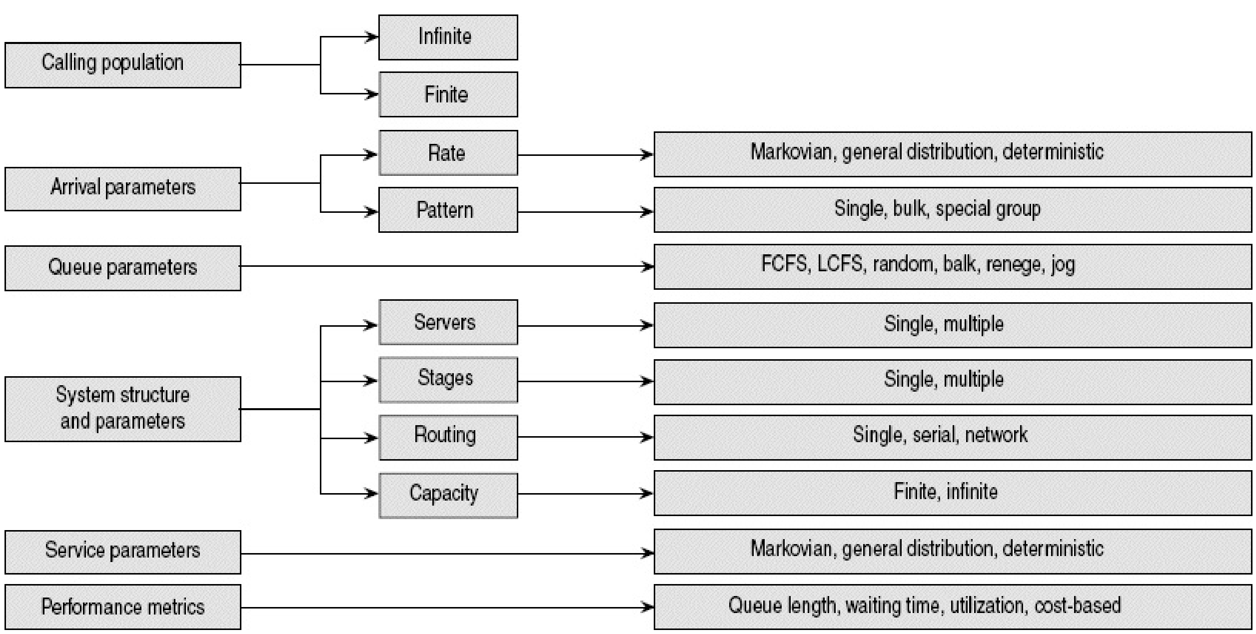


The calling population

It is the calling population in an operating system that places a demand and uses the capacity deployed. In several cases, the calling population is infinite for all practical purposes. For instance, the calling population for a petrol pump in the Greater Kailash locality of New Delhi in the National Capital Region could be the entire set of vehicles running on the roads of the city. Similarly, for a bank in a metropolitan city such as Chennai, the calling population could be the individual and institutional members in the society in the city. These typically amount to an infinite number as far as the operating system is concerned. However, in some cases, the calling population could be finite. Consider the maintenance department in a large manufacturing plant. If there are 300 machine tools in the plant, they form the calling population for the maintenance department in the manufacturing plant. Every machine breakdown corresponds to an arrival at the maintenance shop. In this situation, the calling population is finite. The important difference between an infinite source and a finite one is the manner in which arrival rates are estimated.[1]

> The important difference between an infinite source and a finite one is the manner in which arrival rates are estimated.

FIGURE 10.6 The basic elements of a waiting-line model



Clearly, every arrival from a calling population decreases the probability of the arrival of the remaining machines at the maintenance shop.

Arrival parameters

Customers arrive from the calling population and place a demand on the resources. Therefore, understanding the arrival parameters is critical to capacity analysis using waiting-line models. Two parameters are of paramount importance in understanding the impact of arrivals on the system. The first is the rate at which customers arrive in a service system or work orders arrive in a manufacturing shop. The *arrival rate* could be characterized using a Markovian distribution such as Poisson. Alternatively, the arrival rate could be on the basis of any general stochastic distribution. The third possibility is a deterministic arrival rate. No matter what the exact distribution pertaining to arrivals, the fact remains that they significantly influence the amount of demand placed on the resources and have a bearing on the extent to which capacity should be deployed in the system.

The second parameter pertaining to arrival is the *arrival pattern*. Arrivals can be single or in a batch. People arriving at a restaurant to have dinner or to watch a movie in a theatre, for example, seldom arrive singly. Typically, a number of people arrive in groups. Many manufacturing and service systems exhibit such group arrivals. The other issue is whether the group enjoys any special privileges. Such a group may enter the system and join the queue ahead of other waiting members. Such differentiation of arriving customers or work orders is very common in practice and may have certain implications for operational performance measures and the capacity planning premise. The management of computing and IT facilities is done with different service-level agreements. A platinum-level service may call for a system restoration within minutes as opposed to a silver-level service that may specify restoration within the same business day. These are some examples of the special groups.

Queue parameters

In any operating system, jobs wait on account of resources not being available immediately, inevitably leading to queue build-up. Therefore, waiting-line analysis requires knowledge of exactly how the waiting jobs are handled. Furthermore, in a servicing environment, arriving customers may exhibit different behaviour while waiting in the queue. Some may choose to leave the queue and exit the system, anticipating delays; some may jump from one queue to the other anticipating faster service and so on. All these have a bearing on capacity utilization and the operational performance measures pertaining to the system.

System structure

System structure refers to the manner in which resources are organized in the operating system. It specifies the number of units of resources available for use in the system, as well as the capacity available in each unit of resource. It also specifies how the resources are organized and the order in which the resources will be used by the arriving jobs. Although several variations exist in practice, it is useful to understand them on the basis of the four parameters (see Figure 10.6 for details). The resources can be organized as single sever or multiple servers. Further, in order to complete the requirements, jobs may visit more than one stage. It is also possible that successive stages are visited in a serial or a networked fashion. All these result in varying system configurations and affect the system performance differently. Figure 10.7 graphically depicts all these alternatives.

In this chapter, we will not deal with all the alternatives, as some of them are mathematically too complex to analyse. We will confine ourselves to single-stage queueing systems only. In the case of multiple servers, the number of servers is denoted by S.

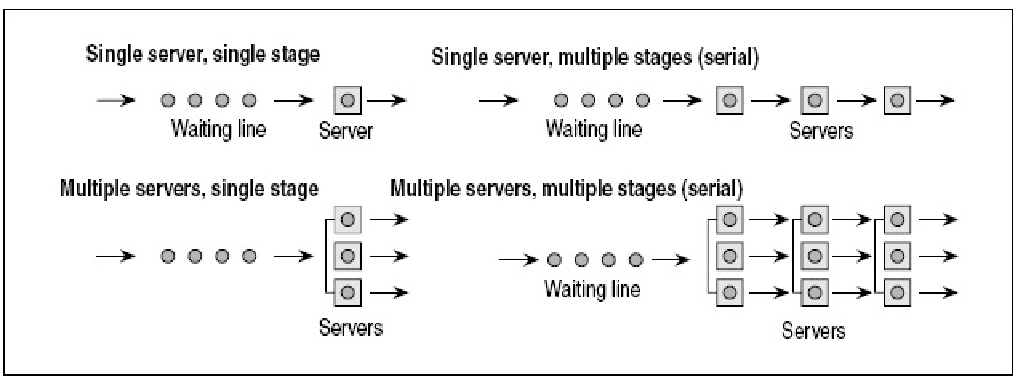
System structure refers to the manner in which the resources are organized in the operating system.

Service parameters

The arrival parameters determine the rate at which demand is placed on the resources by the arriving jobs. Service parameters, on the other hand, determine how resources are likely to be consumed in servicing the arriving jobs. Therefore, the arrival and the service parameters together significantly influence the operational performance measures of the system. The servicing parameters specify the service time, which could follow a Markovian distribution such as exponential distribution, or a general stochastic distribution. In some cases, the service time could be deterministic without any variation (as in the case of a completely automated system).

Service parameters determine the amount of resources likely to be consumed to service the arriving jobs.

FIGURE 10.7 System configuration in queueing systems



The most commonly employed distributions for modelling arrivals in a waiting-line problem are Poisson and exponential distributions. The number of arrivals per unit time is often found to follow a Poisson distribution. On the other hand, the inter-arrival time (between successive arrivals) follows an exponential distribution function. The parameters of these distributions are as follows:[2]

Poisson distribution. The probability of the number of arrivals (n), during T, is given by:

$$P_n = \frac{(\lambda T)^n \times e^{-\lambda T}}{n!} \tag{10.1}$$

Here, λ is the mean number of arrivals per unit time.

Exponential distribution. The probability of an arrival within a specified time can be computed using the probability density function and is given by:

$$f(t) = \lambda e^{-\lambda T} \tag{10.2}$$

The mean and variance of a Poisson distribution is the same and is equal to λ. On the other hand, the mean of an exponential distribution is $1/\lambda$ and the variance is $1/\lambda^2$.

When service times are random, it can often be approximated to an exponential distribution. Therefore, we can use Eq. 10.2 to compute service completions if we know the mean number of services completed per unit time (service rate). The service rate is denoted by μ. If the mean servicing time is found to be three minutes in an operating system, then μ = 20 per hour. Similarly, if customers arrive at the system on an average of once in four minutes, then λ = 15 per hour. The arrival rate (λ) and the service rate (μ) have a significant bearing on the operational performance of the system, as we shall soon see.

Performance metrics

Waiting-line models analyse the adequacy of the capacity to serve the arriving jobs on the basis of certain operational performance measures, as discussed earlier. These include waiting time distribution and queue statistics such as the length of the queue and resource utilization measures. It is also possible to assess the queueing system using some cost parameters. For example, the length of the queue in a manufacturing system corresponds to the work-in-progress (WIP) inventory. Similarly, the cost of the resources can be included in the analysis and some form of cost–benefit analysis could be done to determine the usefulness of adding more capacity in the system.

The following measures are very useful in assessing the adequacy of capacity in waiting-line models:

L_s = Average number of customers in the system

L_q = Average number of customers in the waiting line

W_s = Average time a customer spends in the system

W_q = Average time a customer spends waiting in line

EXAMPLE 10.1

Consider a banking system in which customers arrive for service. After data collection about the number of arrivals in the bank, it has been found that customers arrive at the bank once every three minutes. What is the probability of exactly 10 customers arriving at the bank within a time period of half an hour?

Solution
Let us assume the unit time to be an hour.

Therefore, the arrival rate for the bank (λ) = 20. Now, n = 10 and T = 0.5 for the problem. Substituting these in Eq. 10.1, we can compute the probability of exactly 10 arrivals in the bank as follows:

$$P_n = \frac{(\lambda T)^n \times e^{-\lambda T}}{n!} = \frac{(20 \times 0.5)^{10} \times e^{-20 \times 0.5}}{10!} = 0.125$$

There is a 12.5 per cent probability that exactly 10 customers arrive at the bank during a half-hour interval.

The system measures include statistics pertaining to waiting in the queue as well as while getting served at the servers. There is a generalized relationship between these performance measures, which is known as *Little's formula*. It can be stated using the following set of equations:

$$W_s = \frac{L_s}{\lambda} \tag{10.3}$$

$$W_q = \frac{L_q}{\lambda} \tag{10.4}$$

Further, we also know that the time spent in the system is nothing but the sum of the time spent in waiting in the queue and the service time. Therefore, we can further state:

$$W_s = W_q + \frac{1}{\mu}$$

$$\Rightarrow W_s = \frac{L_q}{\lambda} + \frac{1}{\mu} \tag{10.5}$$

Multiplying both sides by λ and using Eq. 10.3, we derive the following equation:

$$L_s = L_q + \frac{\lambda}{\mu} \tag{10.6}$$

Another useful measure is the utilization of servers in a queueing system. The utilization of servers is denoted by r. The relationship between arrival and service rates and the number of servers in a single stage queueing system is depicted by the following equations:

$$\text{Server utilization in the case of single server: } \rho = \frac{\lambda}{\mu} \tag{10.7}$$

$$\text{Server utilization in the case of multiple servers: } \rho = \frac{\lambda}{S\mu} \tag{10.8}$$

Little's formula provides a generalized relationship between performance measures in a queueing system.

Single-server queues with exponential service times and Poisson arrivals

Let us consider the performance characteristics of a single-server queue whose arrivals are characterized by Poisson distribution. Furthermore, the service time follows exponential distribution. We use the notations for the arrival rate, service rate and server utilization as defined earlier. Some of the measures of interest are given by the following set of equations:

$$\text{Probability that the system is empty } = P_0 = \left(1 - \frac{\lambda}{\mu}\right) = (1 - \rho) \tag{10.9}$$

$$\text{Probability that there are } n \text{ customers in the system } P_n = \left(1 - \frac{\lambda}{\mu}\right) \times \left(\frac{\lambda}{\mu}\right)^n = (1 - \rho) \times \rho^n \tag{10.10}$$

$$\text{Average number of customers in the waiting line } = L_q = \frac{\lambda^2}{2\mu(\mu - \lambda)} \tag{10.11}$$

Using Eqs. 10.3–10.5, one can calculate all other measures of interest.

When the utilization of the server approaches 100 per cent, the number waiting in the queue increases exponentially and approaches infinity asymptotically.

Table 10.3 shows relevant formulae for computing L_q for other types of queueing systems that we may like to analyse. Once L_q is known, other measures of interest could be computed using Little's formula (Eqs. 10.3–10.5).

TABLE 10.3 Formula for Computing L_q for Different Queueing Systems*

Description of Queueing System	Formula for Computing L_q
Single-server queue with exponential service time	$L_q = \dfrac{\lambda^2}{\mu(\mu-\lambda)}$
Single-server queue with general service time whose mean is μ and variance is σ^2	$L_q = \dfrac{\lambda^2\sigma^2 + \left(\dfrac{\lambda}{\mu}\right)^2}{2\times\left(1-\dfrac{\lambda}{\mu}\right)}$
Single-server queue with constant service time (this is obtained by placing $\sigma = 0$ in the above case)	$= L_q = \dfrac{\lambda^2}{2\mu(\mu-\lambda)}$
Multiple-server queue with exponential service time, where S is the number of servers, $\rho = \dfrac{\lambda}{S\mu}$	$P_0 = \left[\sum_{n=0}^{S-1}\dfrac{(\lambda/\mu)^n}{n!} + \dfrac{(\lambda/\mu)^S}{S!}\left(\dfrac{1}{1-\rho}\right)\right]^{-1}$ $L_q = \dfrac{P_0(\lambda/\mu)^S\rho}{S!(1-\rho)^2}$
Multiple-server queue with service time and arrival rate computed from actual data**	$L_q = \dfrac{\rho^{\sqrt{2(S+1)}}}{(1-\rho)}\times\left(\dfrac{C_a^2+C_S^2}{2}\right)$
$\overline{X_a}$ is the mean inter-arrival time (*IAT*) $\overline{X_S}$ is the mean service time (*ST*) S_a is the standard deviation of inter-arrival time S_S is the standard deviation of service time C_a, or the coefficient of variation of *IAT* $= S_a/\overline{X_a}$ C_S, or the coefficient of variation of *ST* $= S_s/\overline{X_S}$ λ, or the mean arrival rate $= 1/\overline{X_a}$ μ, or the mean service rate $= 1/\overline{X_S}$ ρ, or the utilization of the S servers $= \dfrac{\lambda}{S\mu}$	

Notes:

* In all the above cases, arrivals are assumed to follow Poisson distribution. Interested readers can consult any standard book on Markov processes for derivation of these formulae.

** Based on R. B. Chase, R. Shankar, F. R. Jacobs, and N. J. Aquilano, *Operations Supply Management* 12th edition (New Delhi: McGraw-Hill, Education (India) pvt ltd. 2010), pp 341–342.

It is evident from the formulae in Table 10.3 that operational performance measures (L_q in this case) deteriorate on account of several factors:

> When the utilization of the server approaches 100 per cent, the numbers waiting in the queue increase exponentially and approach infinity asymptotically.

EXAMPLE 10.2

The teller facility of a bank has a one-man operation at present. Customers arrive at the bank at the rate of one every four minutes to use the teller facility. The service time varies randomly across customers on account of some parameters. However, based on the observations in the past, it has been found that the teller takes on an average three minutes to serve an arriving customer. The arrivals follow Poisson distribution and the service times follow exponential distribution.

a. What is the probability that there are three customers in front of the teller counter at most?
b. Assess the various operational performance measures for the teller facility.
c. Of late, the bank officials notice that the arrival rate has increased to one every three and a half minutes. What is the impact of this change in the arrival rate? Do you have any observation to make?

Solution

(a) Estimating probability

Arrival rate at the bank = λ = 15 per hour

Service rate at the teller = μ = 20 per hour

Utilization of teller facility = $\rho = \frac{\lambda}{\mu} = \frac{15}{20} = 0.75$

Probability of at the most three customers in the system

$$= \sum_{n=0}^{n=3} P_n$$

Using Eq. 10.10, we compute P_n for values of n ranging from 0 to 3.

$P_0 = (1 - r) = 0.25$

$P_1 = 0.25 \times 0.75^1 = 0.1875$

$P_2 = 0.25 \times 0.75^2 = 0.1406$

$P_3 = 0.25 \times 0.75^3 = 0.1055$

The probability of at the most three customers = 0.25 + 0.1875 + 0.1406 + 0.1055 = 0.6836

(b) Operational performance measures

Average number of customers in the waiting line

$$= L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{15^2}{20(20-15)} = 2.25$$

Average number of customers in the system

$$= L_s = L_q + \frac{\lambda}{\mu} = 2.25 + \frac{15}{20} = 3.00$$

Average number of customers in the waiting line

$$= W_q = \frac{L_q}{\lambda} = \frac{2.25}{15} = 0.15 \text{ hour} = 9 \text{ minutes}$$

Average number of customers in the waiting line

$$= W_S = \frac{L_S}{\lambda} = \frac{3.00}{15} = 0.20 \text{ hour} = 12 \text{ minutes}$$

(c) Impact of arrival rate increase

New arrival rate = 60/3.5 = 17.143 per hour. Based on this, all computations are revised as shown in Table 10.4.

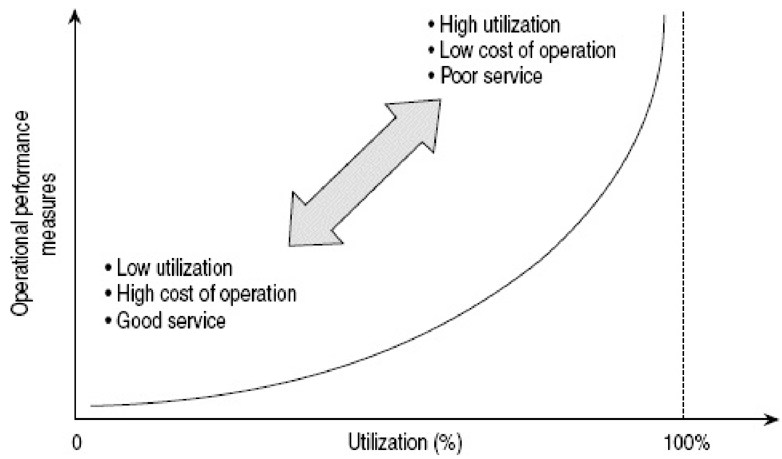
Key Inferences

The computations point to an interesting trend in the operational performance measures and show the linkages between these measures and the arrival and service rates. We note that when the utilization of the teller facility increased from 75 per cent to 86 per cent, there was a marked increase in the waiting time. Further, the number of customers in the system also doubled.

TABLE 10.4 The Impact of Arrival Rate Changes

	Description of Queueing System	**Formula for Computing L_q**
Utilization of the teller facility	75%	85.7%
Average number of customers in waiting line	2.25	5.14
Average number of customers in the system	3.00	6.00
Average time a customer spends waiting in line	9 minutes	18 minutes
Average time a customer spends in the system	12 minutes	21 minutes

FIGURE 10.8 Utilization trade-off in queueing systems



- When the variation in the service times is high, it leads to poor operating per-formance.
- From Little's formula (Eqs. 10.3–10.5), we note that an increase in L_q results in increase in all other operational performance measures.

Utilization trade-off in queueing systems

One of the fundamental results obtained from the analysis of a waiting-line model is the impact of utilization on operational performance measures that are of interest to the management. It can be analytically shown in the case of simple queueing systems, as we have seen in Example 10.2, as well as computationally in other complex queueing systems that as server utilization increases the performance of the system begins to deteriorate. At the limiting case of 100 per cent utilization, the waiting time in the system as well as the queue length increases exponentially and approaches infinity. Figure 10.8 shows this phenomenon graphically.

> Arriving at an optimum level of utilization is an important design issue, especially when capacity planning decisions are made.

This has important implications for operations managers. A low level of utilization of resources results in lesser waiting time and faster turnaround for customers. Therefore, customers may perceive better service quality in the system. Furthermore, operations managers will have greater flexibility in scheduling operations as excess capacity is available. They will be in a position to handle sudden surges in demand and have greater flexibility in operations. On the other hand, due to low utilization, the operating costs of the system will go up. In contrast, operating the system at high levels of utilization will help the firm economize the cost of operations but will result in greater dissatisfaction among customers. Therefore, arriving at an optimum level of utilization is an important design issue, especially when capacity planning decisions are made. In practice, it has been found that manufacturing systems can work with relatively higher levels of utilization as compared to service systems. In service systems, utilization levels more than 85 per cent may not be desirable. These are only simple rules of thumb that could be used at the time of addressing the capacity requirements of the system in question.

10.7 OTHER ASPECTS OF ADDRESSING CAPACITY ISSUES IN SERVICES

The waiting-line models discussed earlier underscore the need to address capacity planning issues in a service system carefully. Any improper or inadequate build-up of capacity in the system may lead to poor operational performance measures. In a manufacturing organization, customers do not experience delays directly. It is the work order, which is substituted by customers, that is delayed on account of bad capacity management. On the other hand, in a service system, customers may not want to wait for a long time in the system to get their turn for service. Therefore, service firms need to address capacity issues more seriously than manufacturing firms, failing which it will directly affect the profitability of the firm and even its long-term viability.

Two issues merit attention in the case of capacity planning in a service firm. The first is the responsiveness of the service system. Capacity planning must ensure that service firms deliver reasonable responsiveness to waiting customers. It does not make sense to make a hungry customer wait at a restaurant for over 30 minutes to serve food. From the earlier discussion on waiting-line models, we can infer that service systems cannot work with high utilization. Building excess capacity is more of a business requirement than a norm in service firms.

> Capacity planning must ensure that service firms deliver reasonable responsiveness to waiting customers.

The second issue is one of high demand volatility, characteristic of service firms. Since in several service firms inventorying services is not possible, capacity planning in services should also be able to handle fluctuations in demand. Typically, peak-hour and non-peak hour conditions occur in several service firms and capacity planning must take into account the complexities arising out of this. It is not prudent to simply build capacity that will meet the peak hour requirement. Such an approach will result in very poor utilization of the available resources. Instead of that, the capacity planning exercise should provide alternatives that can handle issues peculiar to service firms.

It is possible to use several alternatives to handle peak versus non-peak requirements while planning for capacity in service firms. Some of these pertain to operational decisions and the rest pertain to the resource usage in the system. Table 10.5 summarizes some of these alternatives. In several service firms, any of the problems pertaining to capacity are solved through varying the strategy of operations. During the non-peak hour period, capacity constraints are often non-existent or very minimal. Therefore, the strategy is to offer customized services. Moreover, in several service firms involving some inventory (such as food items in a restaurant) some processes are completed during the non-peak hour by making use of the available slack capacity. However, when the peak hour approaches, the operations strategy changes to meet the demand. First, variety is cut to a minimum. This is very helpful because as we introduce variety some capacity loss becomes inevitable due to changeovers. The second strategy is to offer a “configure to order” proposition instead of “provide to order”. This is viable in several cases because some processes would have already been completed in the non-peak hours.

It is evident from this discussion that during peak hours, the service offerings will be narrow; and during non-peak hours, the service offering will be sufficiently wide. These principles can be seen in operation at fast-food joints in any of the metros. It is not uncommon that during the early morning hours, South Indian fast food joints typically offer only *idly*, *vada*, and one or two more items. After the peak hour is over, more varieties are made available in the fast-food joint. The other approach to addressing capacity issues is to manage the demand itself. Capacity reservation methods are provided during the peak hours to minimize disappointments. During non-peak hours, demand could be induced by providing alternative tariff plans and discounts. The two sets of strategies are complementary to each other, working towards shifting peak-hour demand to non-peak hours and providing a reasonably level load on the existing capacity.[3]

TABLE 10.5 Capacity Planning Alternatives for Service Firms

Issue for Consideration	Peak Hour	Non-peak Hour
Operations strategy	Standard offering, configure to order	Customized order
Service portfolio	Narrow	Wide
Demand management	Reservations	Special tariffs, offers
Resources management	Multi-skilled labour, adding temporary workforce, increased working time	Dedicated tasks, training and development, reduced working time

Differences in resource management between peak hours and non-peak hours is another aspect of capacity planning in service organizations. During non-peak hours, the workforce focus is on a single skill and the performance of dedicated tasks assigned to them. The slack in capacity is also utilized for multi-skilling, providing training and development of the workforce in certain cases. In the long run, a multi-skilled workforce is a source of additional capacity in the system. During peak hours, the workforce is not focused on a single task. Due to higher levels of multi-skilling, workers perform a variety of tasks and thereby make up for some additional capacity. Moreover, additional capacity is added to the system in the form of semi-skilled and low-skilled labour as these inputs are available in plenty and rather easily. During non-peak hours, the workforce could be trimmed by laying off these temporary workers.

> Differences in resources management between peak hours and non-peak hours is another aspect of capacity planning in service organizations.

10.8 SERVICE QUALITY

Measuring quality in a service set-up is inherently complex since the characteristics of services are different from those of a manufacturing set-up. Services are often performances involving customers as opposed to dealing with objects, as in the case of manufacturing. Most services cannot be counted, stocked, and verified. Furthermore, with the high degree of labour content and the personal involvement of both the service provider and receiver, a high degree of heterogeneity in the process is inevitable. The challenges pertaining to service quality indeed arise from the unique features of services. Some of them are as follows:

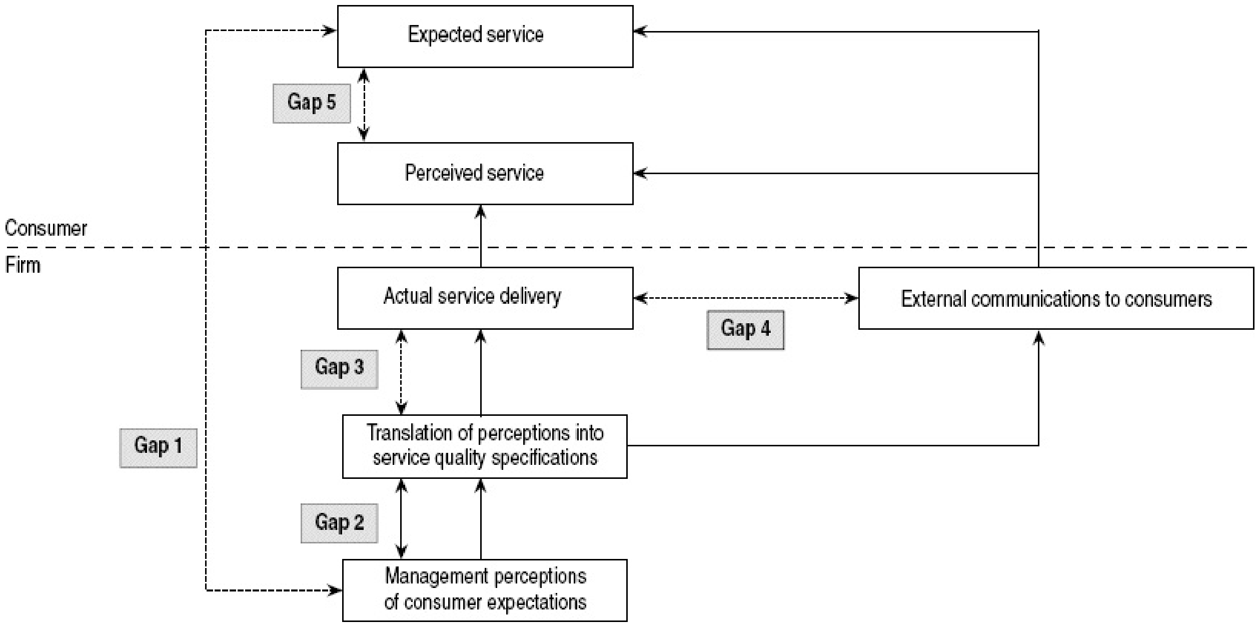
- *Intangibility:* Services are intangible because:
    - they are performances rather than objects, therefore, precise specifications can rarely be set and met.
    - they cannot be counted, measured, inventoried, tested, and verified in advance to assure quality.
    - it is difficult to understand how consumers perceive and evaluate services.
- *Heterogeneity:* Services are heterogeneous because:
    - performances vary from producer to producer, consumer to consumer, day to day.
    - consistency of behaviour in service personnel is difficult to assure.
    - what firms intend to deliver may be different from what the consumer receives.
- *Simultaneity:* Services have an element of simultaneity because:
    - unlike a product, services are not engineered in a plant and then delivered intact to the consumer.
    - quality occurs during service delivery while the consumer interacts with the service personnel.
    - consumers' inputs may be critical to quality.
    - the service firm may have less managerial control in real time.

Because of these inherent qualities of services, it is difficult to set up precise parameters and measuring performance on their basis. Clearly, the measure of service quality involves the perceptions of the customers, the service provider (employee in contact with the customer), and the management. In this sense, it is a measure of how well the delivered service matches with expectations. One popular model that takes several of these into consideration is the SERVQUAL model.

> The evaluation of service quality is not made solely on the outcome of the service. It also involves evaluation of the process of service delivery.

Figure 10.9 shows the **SERVQUAL model** developed by Parasuraman, Zeithhaml, and Berry for measuring service quality.[4] According to them, five potential gaps exist in any service system, which influence the service quality. The first gap occurs when the customers' perception about the quality of the service that he/she has received is different from his/her expectations. This gap occurs partly on account of the other four gaps. When the management's understanding of its customers' expectations is at variance with the reality, another gap is created. Moreover, with this imperfect understanding, the management proceeds with the process of arriving at the specifications for the service that it proposes to deliver, designs the service delivery system, trains its employees, sends out communication about the nature of the service provided and so on. As shown in the figure, at every stage, potential mismatches happen, increasing the gap, and thereby significantly influencing the final quality of the service offered.

FIGURE 10.9 The SERVQUAL model for service quality



Source: Adapted from A. Parasuraman, V. A. Zeithhaml and L. L. Berry, “A Conceptual Model of Service Quality and its Implications for Future Research,” *Journal of Marketing*, no. 49 (Fall 1985): 41–50. Reproduced with permission.

Understanding why these gaps exist in service quality is the first step in addressing them. Some of the reasons for the existence of gaps are as follows:

According to **SERVQUAL**, five potential gaps exist in any service system that influence the service quality.

- *Gap* 1: Service-firm executives may not always understand:
  - what the consumer wants.
  - what features a service must have.
  - what levels of performance should be delivered.
- *Gap* 2: The means to meet the expectations are absent because:
  - knowledge of consumer expectations exists but not the perceived means to deliver.
  - the means are known but they are too expensive to implement.
  - management is not committed to quality.
- *Gap* 3: There is variability in employee performance because:
  - standard operating procedures and policies are not in place.
  - employees are not trained periodically, leading to skill variance.
  - behavioural and attitudinal differences exist among the employees.
- *Gap* 4: There are problems arising out of communication:
  - Firms tend to promise more in communications than what they deliver in reality.
  - Firms tend to neglect to inform consumers of special efforts to assure quality that are not visible to consumers.
- *Gap* 5: Gap 5 is a function of Gaps 1, 2, 3 and 4. Therefore, Gap 5 = f (Gap 1, Gap 2, Gap 3, Gap 4).

Firms need to address these issues in a sustained manner to improve quality. Obtaining customer feedback frequently may help the service provider address Gap 1. In every room in a five-star hotel, guest feedback forms are always kept so that management can tap this information and act on certain areas to reduce Gap 1. We see similar practices in air travel, hospitals, and other service outlets as well. Gap 4 is a common problem that we witness. Service firms prepare brochures without thinking about these issues and present a rosy picture of the service offering. Since brochures play a crucial role in shaping the expectations of the customers of the service, more care needs to be exercised to avoid or reduce the gap. Similarly, employee training programmes that cover not only technical skills, but also behavioural and communication skills, need to be periodically offered to customer facing service personnel. This may to a large extent address Gap 3.

ideas at Work 10.3

mproving Service Quality Through Better Communication: The Case of Aravind Eye Hospitals

Service quality is much harder to measure and improve as services are experiences and not objects as in the case of a manufacturing organization. However it does not mean that it is impossible. The SERVQUAL model has identified five gaps between perceived and actual quality. One of the frequently cited reasons for poor service quality is that customers' perceptions of quality are different from what they experience while consuming the service. One way to address this problem is the use of brochures that provide useful information about the service so that expectations could be set at reasonable and realistic levels a *priori*.

Aravind Eye Hospitals has utilized this approach to educate their patients about the steps in the process that they are likely to go through and the likely time for each of these steps. A brochure entitled "Your Guide to Quality Eye Care," printed both in English and the vernacular language, is given to the patients so that they are aware of the steps and the time taken. According to this brochure, it may take up to two hours to complete the process. The various processes and the time taken for each of them is listed:

1. Registration: 5 minutes
2. Vision test: 10 minutes
3. Refraction check: 10 minutes
4. Preliminary examination: 20 minutes
5. Blood pressure/eye tension/sugar test: 30 minutes
6. Final examination: 5 minutes

The brochure makes an attempt to briefly describe the process in each of the listed stages and explains why a particular test is done in that stage of the process. Further, it provides a schematic block diagram of the process flow and the location of various facilities including the pharmacy, the information centre and the cash counter. The brochure also has a detailed layout plan of the building. Through this information, the brochure ensures that an arriving patient will have a fair idea of what to expect and where to go.

The Aravind Eye Hospitals brochure educates us about some important aspects of designing a brochure for a service offering. It reminds us that care must be taken while designing a brochure. Committing to more than one can deliver or painting a rosy picture of the reality in the brochure might backfire. Instead of improving the service quality, it may indeed deteriorate it by creating false expectations when the operations cannot deliver the same.

Source: Based on "Your Guide to Quality Eye Care," the brochure of Aravind Eye Hospitals & Post Graduate Institute of Ophthalmology, Madurai.

SUMMARY

- Process design of service systems differs vastly from that of manufacturing systems.
- The degree of customer contact, the degree of complexity and the degree of diversity of service offerings have a significant bearing on process design in service systems.
- *Service positioning* is the strategic choice a firm makes on the three parameters of customer contact, degree of complexity and degree of diversity in the offerings.
- *Service blueprinting* helps organizations to design, monitor, control and improve processes and the service delivery system on an ongoing basis.
- *Waiting-line models* make use of queueing theory to analyse the impact of alternative capacity choice on operational performance measures such as waiting time, resource utilization and queue length.
- Waiting-line models indicate that as resource utilization approaches 100 per cent, queue length and waiting time become very large. At low levels of utilization, costs of operations shoot up. Therefore, organizations face a critical trade-off between cost and utilization.
- Service systems tend to have plans for lesser resource utilization compared to manufacturing systems. Moreover, service systems use alternative strategies for managing capacity during peak and non-peak hours.
- Service quality is hard to measure. Various gaps exist between the delivered service and the expectations of the service receiver. This provides a measure of the *service quality*.

FORMULA REVIEW

The probability of the number of arrivals '*n*', during *T*, $P_n = \frac{(\lambda T)^n \times e^{-\lambda T}}{n!}$

The probability of an arrival within a specified time $f(t) = \lambda e^{-\lambda t}$

Average time a customer spends in the system, $W_s = \frac{L_s}{\lambda}$

Alos, $W_s = W_q + \frac{1}{\mu} \Rightarrow W_s = \frac{L_q}{\lambda} + \frac{1}{\mu}$

Average time a customer spends waiting in line, $W_q = \frac{L_q}{\lambda}$

Average number of customers in the system, $L_s = L_q + \frac{\lambda}{\mu}$

Server utilization in the case of single server, $\rho = \frac{\lambda}{\mu}$

Server utilization in the case of multiple servers, In the case of a single server queue, $\rho = \frac{\lambda}{s\mu}$

Probability that the system is empty, $P_0 = \left(1 - \frac{\lambda}{\mu}\right) = (1 - \rho)$

Probability that there are '*n*' customers in the system, $P_n = \left(1 - \frac{\lambda}{\mu}\right) \times \left(\frac{\lambda}{\mu}\right)^n = (1 - \rho) \times \rho^n$

Average number of customers in the waiting line in a single server queue

1. With Exponential Service Time, $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$

2. With general service time, $L_q = \frac{\lambda^2\sigma^2 + \left(\frac{\lambda}{\mu}\right)^2}{2 \times \left(1 - \frac{\lambda}{\mu}\right)}$

3. With constant service time, $L_q = \frac{\lambda^2}{2\mu(\mu - \lambda)}$

Average number of customers in the waiting line in a multiple server queue

$$L_q = \frac{\rho^{\sqrt{2(s+1)}}}{(1-\rho)} \times \left(\frac{C_a^2 + C_s^2}{2}\right)$$

REVIEW QUESTIONS

1. What are the key aspects of service process design? How is it different from manufacturing process design?
2. Give one example of low-degree customer contact and high-degree customer contact in each of the following service settings:

   a. Travel agency
   b. DVD rental services
   c. Courier services
   d. Computer facilities management services
   e. Investment consulting services
   f. Sweets and savouries shop

3. Why should we understand the notion of customer contact in service design?
4. Suppose your friend has decided to set up a travel agency service. Explain the principles of service complexity and service divergence and help him make an appropriate positioning of the travel agency service.
5. Visit your hostel mess and prepare a service blueprinting of the service offered. Based on the service blueprint that you have developed can you comment on the existing layout of the hostel mess and provide recommendations for improvement?
6. What are the basic elements of a waiting-line model? How does waiting-line modelling help an operations manager to address capacity issues in an operating system?
7. Identify three performance metrics for an operating system and explain the impact of each of the following on the system:

   a. The mean inter-arrival time has decreased in the system recently
   b. The variability in the service time has increased due to malfunctioning of one workstation in the assembly shop
   c. The number of servers in the system has gone up by one unit due to the recent addition of a new computer and a clerk in the railway reservation office
   d. The hostel block, that has a common dining facility, is augmented with 300 more rooms recently
   e. The bank has installed an ATM in its branch office

8. Are capacity management issues in a service system different from those in a manufacturing system?
9. The manager of an automobile garage in the heart of the city of Delhi has built such a good reputation for himself that more and more customers throng to his garage for getting their cars serviced. The utilization of the facility is now about 88 per cent. He has been getting more and more requests for automobile servicing. What will be your advice to the manager? Prepare a one-page report for him.
10. Compare the issues pertaining to measuring service quality with that of product quality. Which one is easier to assess? Why?
11. Consider any one service system which you are familiar with. Can you identify one instance for each of the five gaps as per the SERVQUAL model?
12. What are the challenges in assessing the quality of services? How can an organization mitigate some of these challenges?

PROBLEMS

1. Consider a single-server queue with Poisson arrivals and negative exponential service times. The arrival rate is 10 per hour and the service rate is 15 per hour. Compute the following:

   a. What is the probability that exactly 5 will arrive in a 30-minute interval?
   b. What is the expected utilization of the server?

2. In a single-server system with Poisson arrival rate and exponential service time distribution, the arrival and service parameters are as follows:

Arrival rate: 10 per hour; Service time: 5 minutes

Compute the following:

   a. The probability that nobody will be in the system
   b. The probability that at least 3 will be in the system
   c. The probability that not more than 5 will be in the system
   d. The average length of the queue

Use Little's formula and compute other relevant performance measures for the system.

3. In a single-server system with Poisson arrival rate and exponential service time distribution the arrival and service parameters are as follows. Arrival rate: 12 per hour; Service time: 4 minutes. Compute the following:

   a. How long will the customers wait in the queue to get their turn for the service?
   b. If the waiting time in the queue needs to be brought down by 10 per cent, by how much should the service be speeded up?
   c. If the arrival rate comes down by 10 per cent, what will be the impact on the waiting time in the system if the service characteristics remain unchanged in the system?

Use Little's formula and compute other relevant performance measures for the system in each of the given scenarios.

4. Consider a single-server queue with Poisson arrivals and exponential service time distributions. The arrival rate is 5 per hour and the service time is 8 minutes. Compute the following operational measures of performance for the system:

   a. The probability that the system is empty
   b. The probability that there will be at least two customers in the system
   c. The utilization of the system
   d. The waiting time for the customers before they get their turn of service and the average queue length

What will be the threshold arrival rate so that the total time spent in the system is greater than or equal to 15 minutes?

5. Consider a queuing system with a poisson arrival and negative exponential service time distributions. If the arrival rate is 15 per hour and the service time is 3 minutes, compute the following:

   a. The average number of customers waiting for service
   b. The average time a customer waits
   c. The average time the customer spends in the system
   d. The idle time of the server

6. There is a repair shop in a residential locality attending to TV repairs. Failed TVs arrive at the repair shop in a Poisson fashion at the rate of 7.5 per day. It takes on an average about 45 minutes to restore the TVs. Service times are exponentially distributed. The TV shop is open daily between 10.30 am and 6 pm.

   a. What is the utilization of the TV repair shop?
   b. What is the expected waiting time in TV shop before a TV is taken up for servicing?
   c. If the arrival rate of failed TVs at the repair shop increases to 8 per day, by how much the waiting time will increase?
   d. For the increased arrival, by how much the service time needs to be speeded up to restore the waiting time to the old value?

7. A university campus has a students' coffee shop, which the students normally visit during their short breaks to have coffee and other beverages. Arrivals at the coffee shop follow a poisson distribution on an average at the rate of 3 per minute. The service counter takes about 18 seconds on an average to attend to a student. The service times are found to be exponentially distributed.

   a. What is the expected idle time of the service counter?
   b. What is the probability that not more than 3 students will be in the coffee counter?
   c. The students complain that often they need to wait an excess of 5 minutes to get their turn for service. Do you agree with their claim?
   d. It is possible to install a vending machine that can serve a request exactly in 18 seconds. Will this arrangement address the student expectations with respect to the waiting time?

8. There is a hairdressing saloon in a locality of a town. The saloon operator has a single chair facility and 3 waiting spaces for the arriving customers. Arrivals are 3 per hour and they follow a Poisson distribution. On an average, each customer requires 15 minutes to get the service done. Answer the following questions with respect to the saloon:

   a. How long will an arriving customer wait for his turn?
   b. What is the probability that there will be at most two customers in the system?
   c. Suppose an arriving customer may go away if there are no waiting spaces, what is the probability that this can happen?

9. In a telephone booth, the arrivals of customers wanting to use the phone follows Poisson distribution and the duration of the calls placed follows exponential distribution. On an average, 15 customers arrive in an hour and end up using the phone for 180 seconds. The charges are ₹2 per minute. The booth owner has invested ₹27,000 on the whole set-up and pays a monthly tariff depending on the usage. Every call leaves him with a 10 per cent margin to cover his initial cost after paying for tariffs and meeting other expenses of running the booth. He keeps the booth open for 10 hours every day from Monday to Friday. Compute the following:

   a. How many waiting spaces should he provide for the arriving customers?
   b. How long will the customers spend ever since he/she arrived to complete his/her call?
   c. What is the utilization of his facility?
   d. When can he recover the cost of his investment?

10. The ATM centre for ICICI Bank in a certain locality of Lucknow currently has one ATM. Customers arrive at the ATM centre at the rate of one in every two minutes. Although the nature of transactions may vary with every customer, it has been found that on average, the service time for a customer is 90 seconds. The arrivals follow Poisson distribution and the service time follows negative exponential distribution. The bank officials would like to know the impact of adding another ATM machine in the same premises. Prepare relevant data for the bank officials.

11. Customers arrive at a car washing facility at the rate of one in every 6 minutes. The car washing facility is at present a manual process that takes a variable time, whose mean and standard deviation are estimated to be 4 minutes and 2 minutes respectively. A company has offered to install an automated system, which will eliminate the variability of the facility. Furthermore, it will bring down the service time to 2.5 minutes. The system will cost ₹500,000. The company expects that if the waiting time for the customers comes down by at least 15 per cent, the number of customers arriving at the station will increase by 50 per cent of the current level. Servicing each customer will mean a contribution of ₹100 to the firm. The facility works for 8 hours per day for 25 days a month. Should the firm go for the new system? What will be the payback for the investment?

12. Prolonged observation of a multi-server facility in a supermarket resulted in the collection of some data with respect to customer arrivals at the supermarket and the service time at the check out counter. Table 10.6 has the data based on 100 observations made in the last two months. The data is representative of the situation prevailing in the supermarket. Currently, there are five checkout counters in the supermarket. The supermarket wants to know if reducing the variability of the service process by 25 per cent is better than adding one more counter at the shop. Use the data given in Table 10.6, compute the relevant operational performance measures for the supermarket, and advise.

TABLE 10.6 Arrival and Service Parameters

	Inter-arrival Time (Minutes)	**Service Times (Minutes)**
Mean	0.75	3.25
Standard deviation	0.25	2.25

NET-WISE EXCERCISES

1. ITC forayed into the Hotel business to support the national priority of developing new avenues of foreign exchange earnings and boosting tourism. Beginning with the Sheraton Chola, Chennai in 1975, ITC's journey in this business has redefined the face of Indian hospitality. ITC Hotels is one of largest hotel chains in India with over 90 hotels in more than 70 destinations. ITC Hotels pioneered the concepts of branded accommodation, branded cuisine, environment, and guest safety. ITC Hotels is an exemplar in sustainable hospitality with all its premium hotels being LEED® Platinum certified. Visit the URL http://www.itchotels.in/Index.aspx to know more about the services offered.

   The Indian Hotels Company Limited (IHCL) and its subsidiaries are collectively known as Taj Hotels Resorts and Palaces. Taj Hotels Resorts and Palaces comprises 93 hotels in 55 locations across India with an additional 16 international hotels in Maldives, Malaysia, Australia, UK, USA, Bhutan, Sri Lanka, Africa, and the Middle East. Visit the URL http://www.tajhotels.com to know more about the services offered.

   a. Select one hotel each from the list available in the URLs and pursue it by visiting all relevant links. Assess various elements of service design, service complexity, and divergence. Also try to understand the layout of different areas of the hotel. Visit the photo galleries and take virtual tours wherever available to get a feel of the place.
   b. Prepare a report highlighting the various aspects of process design as discussed in this chapter. Prepare a subjective assessment of the complexity of the service design and its implications for the hotels. Also make a comparative analysis of the two hotels.

2. The Housing Development Finance Corporation Limited (HDFC) was amongst the first to receive an 'in principle' approval from the Reserve Bank of India (RBI) to set up a bank in the private sector, as part of the RBI's liberalization of the Indian Banking Industry in 1994. HDFC Bank is headquartered in Mumbai. HDFC Bank has a nationwide network of 3,403 Branches and 11,256 ATM's in 2,171 Indian towns and cities. Moreover, HDFC Bank's ATM network can be accessed by all domestic and international Visa/MasterCard, Visa Electron/Maestro, Plus/Cirrus, and American Express Credit/Charge cardholders.

   Visit the URL of the bank at http://www.hdfcbank.com. Pursue the link related to Personal Banking and go through the links in that page. Study in detail the Imperia/Classic/Preferred, and Private Banking options by clicking the menu 'Products' and then 'Premium Banking' links there under.

   After going through the pages, prepare a report on the service offerings of HDFC bank from the perspective of service process design and its implications. In the chapter, there is a discussion on service positioning. Use the framework given in that section (see Figure 10.3 in the chapter also) and show how it applies in the case of HDFC Bank.

MINI PROJECTS

1. Visit the local branch of a bank and perform the tasks listed here. Based on your analysis and major findings, prepare a final report of recommendations to the bank manager.

   a. Study the working of the bank, collect data on working times, types of customers, nature of transactions, waiting times, capacity of resources, waiting space etc. Understand from the manager the key operational performance measures of interest to the bank branch, elicit the problems that need to be addressed.
   b. Estimate the key parameters of the waiting-line model to be constructed to assess the current working of the branch. The parameters include number of arrivals (or mean-inter arrival times), mean service times and the number of servers.
   c. Build a waiting-line model and compute the measures of performance. Is there adequate capacity in the system to serve the arriving customers? If not, what are the alternatives the bank branch has to improve the capacity (and thereby the performance)?
   d. If there is adequate capacity at present, identify methods to improve the performance by 10 per cent over the next 6 months.

2. Perform a similar exercise as described in Mini Project 1 by studying the student hostel mess in your college and prepare a report for the mess manager.

CASE STUDY

Waiting Times at Post Offices

The customers at the post office in a busy locality of Bangalore were getting restless. Most of them were unanimous in saying, "Do something about the agents, it's because of them that we have such long queues." A few others had come to the post office multiple times for their work as a particular "software wasn't working." Another common grouse of the people was that different kinds of transactions had been combined in the same queue and due to this, one had to go through a long wait to get even a small transaction such as a passbook entry done. However, there were a few people, who seemed to be "seasoned customers," who would manage to jump the queue and discreetly carry out small transactions. When it was suggested to the customers that they could avoid facing long queues by going through agents, a few said that they had already tried that route, but gave up after the agents made a large number of mistakes. The issue was about reducing the waiting time of the customers and thereby improving the overall service quality.

Post Office Operations

Post offices in India undertake a large number of operations in addition to their routine operations of delivering mail. Some of these include:

- Sale of stamps, envelopes, etc.
- Savings bank accounts
- Monthly income schemes offering higher rates of interest
- Senior-citizen deposit schemes
- Payment of bills for utilities such as electricity, telephones, water, etc.
- Money order, speed post, etc.
- Sale of brochures for competitive examinations
- Public provident fund services

Let us concentrate on the services pertaining to savings bank accounts, monthly income schemes, savings certificates (such as Kisan Vikas Patra) and public provident funds, since these have been having problems with long queue lengths in several post offices in the country.

- It is generally observed that the queue is more on Saturdays and Mondays than on other days.
- Another problem is that the monthly income interest for senior-citizen schemes accrues on a certain day in the month and there is generally a huge crowd on the following few days.
- A large number of people who transact at the counters related to savings bank and monthly income schemes are agents representing other people. These agents get a small proportion of the money involved in the transaction as "incentive". They indirectly operate as salespeople for the post office's savings and monthly income facilities.

Agents

The Government of India, in association with India Post, has formed a network of authorized agents in order to promote small savings through the National Savings Certificate, National Savings Scheme, Indira Vikas Patra and Kisan Vikas Patra schemes. These agents are like "marketing executives" for the post office and are responsible for getting new customers for the different schemes.

One can identify agents as they usually carry large bags with papers of a large number of clients. They also seem to perform multiple transactions at counters. They do not get any preferential treatment at the post offices. They have to stand in the common queue along with the general public. However, given that they are familiar with the people behind the counter, they can push in multiple applications at once. They perform a variety of transactions that are available at the post office. They need to deliver a full range of services (post office, bank deposits, etc.) to their clients in order to maintain the relationship. Most of the clients stay with their agents for a longer term. The agents need to provide proper incentives to their clients and maintain a high quality of service.

There is quite a bit of queue jumping that happens. Agents stand in a particular queue for a couple of minutes, tell the person behind them that they will be right back, and then go and stand in another queue. This way, they manage to "parallel process" two queues and manage to get their job done faster. In addition, since the people behind the counters are familiar with the agents, no one (except for the odd customer) seems to mind.

As told by one postmaster, there is a large number of agents. These people come with huge sheets of papers to be processed, spend a long time at the counters and repeatedly stand in queues till all their clients' work is done. There is not enough space (physically) in the post offices in order to form the queues. Hence, queues tend to form horizontally in front of the counters and end up obstructing other counters.

A few counters seem to be doing "batch processing". They collect papers from a group of people (all of whom are crowding the counter and also the neighbouring counters), process all of them together, and then finally complete all the processes together.

Typical Services Offered

A description of the services offered by a regular urban post office in Bangalore is a good example of the typical services offered by a post office with respect to the investment opportunities mentioned earlier. There are three counters in the City Post Office (CPO) that render these services.

- Counter 1
    - National Savings Certificate
    - Kisan Vikas Patra
- Counter 2
    - Post office savings bank account
    - Public provident fund
    - Recurring deposit
- Counter 3
    - Monthly income schemes
    - Senior-citizen schemes

Arrival and Service Rates

The arrival rates and service rates at different counters at different times were assumed to follow the average rates observed over the six-day period during that time slot. For example, the arrival rate used at Counter 2 in the 11:15– 11:30 a.m. period corresponded to the average arrival rate in the same period over the six days during which data was collected. The arrivals fit to Poisson distribution, *albeit* with a low level of confidence and the service time the negative exponential distribution.

The mean arrival and service rates (in minutes) per customer at each counter as observed are given in Table 10.7. Agents and non-agents have been separated to show their respective arrival rates. A general trend across counters is that arrivals decline towards the end of the morning session, which may be indicative of people not being confident of being serviced if they come around the time of the lunch break.

TABLE 10.7 Arrival Rates

Counter	Mean Number of Arrivals in a 15 Minute interval			Mean Service Time (Minutes)
	Agents	Non-agents	Total	
1	3.20	0.65	3.85	4.08
2	3.10	0.15	3.25	2.48
3	2.65	0.40	3.05	3.16

Capacity Issues and Alternatives

After having collected 70 data points, a study team simulated the existing model at CPO for a period of 1000 days where each day was defined to be of duration 9:30 a.m. –1 p.m. Apart from the existing model, the team also looked at alternative ways of setting up the counters in an effort to minimize the average waiting of a customer at CPO.

Three proposals were studied as an alternative to the existing scenario. In Option 1, the idea was to have a single queue that would feed all four counters (as in the case of railway reservation counters). It was noticed that the waiting time for Counters 2 and 3 reduced while that for Counter 1 increased when all the counters were merged. Thus, an alternate model was examined where only queues for Counters 2 and 3 were merged (earmarked as a non-agents' queue) while the queue for Counter 1 was still maintained separate (designated as an agents' queue). After each service completion in any of the three counters, one from the agent queue and one from the non-agent queue would alternately go to the freed counter for service. A third option was to have a separate counter for agents (and therefore a separate queue as well). A simulation analysis of these proposals gave the results shown in Tables 10.8 and 10.9.

TABLE 10.8 Total Residence Time in the System (Minutes) for Alternative Proposals

	Existing Process: Anybody Can Join any of the Three Queues	Proposal 1: Form a Single Queue	Proposal 2: Separate Queue for Agents	Proposal 3: Separate Counters for Agents
1	49.01	39.55	Agents: 43.82	Agents: 62.23
2	34.75		Non-agents: 34.54	Non-agents: 4.83
3	40.31			

TABLE 10.9 Utilization and Average Service Times for Proposal 3

	Utilization	Average Service Time (min)
Non-agents	37.8%	2.53
Agents	89.8%	22.69

QUESTIONS FOR DISCUSSION

1. Enumerate the reasons for excessive waiting time at the City Post Office in Bangalore. Identify some countermeasures to solve the problem.

2. What is your recommendation to the postmaster for solving the problem? Would you recommend any of the three proposals? Justify your recommendations with suitable arguments.

3. What are the other steps that the postmaster can take to solve the problem at CPO?

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Simulation as a Modelling Tool

Consider a branch of the State Bank of India in a centrally located place such as the Nariman point in Mumbai. Let us assume that the branch manager has observed an increase in the waiting time of the customers. This problem requires some immediate attention, failing which dissatisfied customers may close the account and switch to a competition bank. The bank manager would want to understand the impact of the alternative operational choices that he/she has to address this problem. This, for example, may include adding two more counters, increasing the service rate by deploying some technology choices, adding some waiting spaces and resorting to other mechanisms of reducing the demand placed on the servers. In order to analyse these alternatives, the bank manager needs to build a model of the system and study its behaviour with respect to key performance metrics such as waiting time.

In reality, the bank will cater to a variety of customers, including retail customers who have a personal savings account in the branch, small and medium business customers, and large industrial clients. Further, there will be multiple counters with random fluctuations in arrival and service patterns. Due to these, the operation system is likely to be much more complex than what the available queuing models can solve. The behavioural patterns of the service providers in the branch and significant variations in the arrival patterns of the customers at the branch, not only during the working hours on a particular day but also across calendar days, makes it very difficult to analyse the problem realistically, using the available mathematical models. Therefore, alternative solution methodologies are required to understand the impact of several operational choices that the bank manager may have in front of him/her.

Like the bank manager’s problem, several operations management problems do not lend themselves to modelling and analysis using the available simple mathematical models. For example, if we analyse the traffic and capacity problem in a supermarket, we will find that using the simple single-server queue with the steady-state condition may not truly reflect the working conditions of the supermarket. The study of realistic situations requires complex modelling techniques, which not only makes the modelling effort difficult but also results in intractable solutions many a time. In operations management, we face such situations quite often and therefore require alternate mechanisms which will enable us to analyse the problems and obtain some insights about possible solutions that could be implemented. Simulation is a well-known method developed during the Second World War period. It enables an operations manager to model complex real-life situations and obtain some insights into the problem.

Simulation, in simple terms, is a mechanism in which a numerical model is built in which the reality is mimicked. By repeated use of the numerical model, it is possible to obtain some insights about the behaviour of the system and to use this information to make certain choices about the operating system. A simulation model is often resorted to under the following conditions:

- When the system to be studied does not lend itself to any readily available mathematical model.
- When mathematical models are available to study the system, but there are no known solution methodologies to derive

some insights into the problem.

- When a complex set of random events tend to affect the behaviour of the system and therefore it requires some stochastic analysis of the problem.
- When the existing solution methodologies are too expensive.
- When it is prohibitively costly or unadvisable to tamper the operating system to study the impact of the alternatives to be considered.

The following elements will invariably be required to build a simulation model:

- A clock to keep track of the passage of time in which the behaviour of the system is observed. On several occasions, the clock is used to stop or terminate the simulation. Simulations are normally terminated by either the number of arrivals or the absolute value of the clock.
- A random number generator to sample random numbers and use them to incorporate certain stochastic elements of the system being studied.
- Mechanisms to collect data of interest as the clock advances from time zero to the end time.

We shall understand these aspects of building a simulation model and using the model to obtain data as simulation proceeds in order to gain some insights about the system being studied.

The Use of Random Numbers

Central to the simulation methodology is the use of random numbers to model the stochastic behaviour that we face in real life in several operations systems. Let us use a simple example to understand the logic of using the available random number generators and mimic the behaviour of the system that we want to study by incorporating some of the random behaviours. Let us model a simple queuing system with the random behaviour shown in Table 10A with respect to the inter-arrival times (IAT) at the service counter.

TABLE 10A Inter-arrival Time Distribution

Inter-arrival Time (minutes);	Probability	Cumulative Probability
3	10%	10%
4	22%	32%
5	11%	43%
6	12%	55%
7	15%	70%
8	12%	82%
9	11%	93%
10	7%	100%

All simulation models use the inbuilt random number generator available with software applications such as Microsoft Excel to model the arrival pattern. In order to do that, the procedure followed is to sample a random number [in the case of a computer software, the random number generator is invoked by using the RAND() function] and map it to the corresponding cumulative probability value in the table and read the corresponding inter-arrival time. If the first random number that we obtain is .09, from the cumulative probability value in Table 10A, we will sample an inter-arrival time of three minutes. Similarly, if the second random number obtained is 0.61 then the corresponding inter-arrival time will be seven minutes. This is demonstrated for a set of 20 arrivals in Table 10B.

Building the Model and Collecting Relevant Data for Analysis

If we know the service times taken by each of the arrivals at the counter, it is possible for us to compute statistics of interest to us, such as the utilization of the server and the waiting time of arrivals. In Table 10C, the result of the simulation for 20 arrivals in a single server queue has been tabulated. We make the following observations based on this simulation study:

- In all, the total time of simulation for the 20 arrivals is 120 minutes, as evident from the clock time of the exit of the last arrival.
- The cumulative waiting time in the system is 5 minutes.
- The 20 arrivals together have spent 68 minutes in the system in order to get their service.
- The total idle time of the service provider at the service counter is 57 minutes.

TABLE 10B SImulation of Arrivals Using Random Numbers

Customer	Random Number Sampled	Time Between Arrivals	Clock Number (Arrival)
1			0
2	0.09	3	3
3	0.61	7	10
4	0.03	3	13
5	0.87	9	22
6	0.96	10	32
7	0.51	6	38
8	0.81	8	46
9	0.72	8	54
10	0.77	8	62
11	0.56	7	69
12	0.04	3	72
13	0.74	8	80
14	0.26	4	84
15	0.12	4	88
16	0.60	7	95
17	0.39	5	100
18	0.54	6	106
19	0.64	7	113
20	0.36	5	118

In this simple example based on the present data, one can compute relevant performance measures such as the utilization of the server, the average waiting time of the customer, the average time spent by a customer in the system, and the average idle time of the server. Since this is a step-by-step enumeration of the processes that govern this queuing system, the modeller can choose the data to be captured for analysis. Further, each random event in the system could be modelled in a very similar fashion by using random number generators, sampling random numbers, and relating it to the cumulative probability of the respective stochastic behaviour that we want to incorporate in the model, as we have done for the inter-arrival pattern in this example.

TABLE 10C Simulation of a Single Server Queue for 20 Arrivals

Customer Number	Random Number	Time Between Arrivals (Minutes)	Clock (Arrival)	Service Time	Waiting Time	Service Beginning	Service Duration	Service End	Time in System	Clerk Idle
1			0	1	0	0	1	1	1	0
2	0.09	3	3	4	0	3	4	7	4	2
3	0.61	7	10	4	0	10	4	14	4	3
4	0.03	3	13	2	1	14	2	16	3	0
5	0.87	9	22	1	0	22	1	23	1	6
6	0.96	10	32	5	0	32	5	37	5	9
7	0.51	6	38	4	0	38	4	42	4	1
8	0.81	8	46	6	0	46	6	52	6	4
9	0.72	8	54	1	0	54	1	55	1	2
10	0.77	8	62	3	0	62	3	65	3	7
11	0.56	7	69	5	0	69	5	74	5	4
12	0.04	3	72	5	2	74	5	79	7	0
13	0.74	8	80	3	0	80	3	83	3	1
14	0.26	4	84	6	0	84	6	90	6	1
15	0.12	4	88	1	2	90	1	91	3	0
16	0.60	7	95	1	0	95	1	96	1	4
17	0.39	5	100	6	0	100	6	106	6	4
18	0.54	6	106	1	0	106	1	107	1	0
19	0.64	7	113	2	0	113	2	115	2	6
20	0.36	5	118	2	0	118	2	120	2	3
Total					5				68	57

EXAMPLE 10A

Consider the problem that a newspaper vendor faces on a day-to-day basis. The newspaper vendor buys a copy at the rate of ₹0.33 and sells it at ₹0.50. If the vendor is unable to sell the paper, it fetches a salvage value of ₹0.05. The decision the newspaper boy faces is the number of papers that he needs to buy daily. The following random events complicate his decision making:

- On 20 per cent of the occasions, the demand is likely to be low. There is, however, a chance that the demand is likely to be very good on 35 per cent of the occasions. At other times, the demand is likely to be moderate.
- Likely demand on a particular day depends on whether it is low, moderate, or good. The pattern of demand observed in the past is shown in Table 10D.

TABLE 10D The Pattern of Demand Observed in the Past

Demand	Good	Moderate	Low
40	3%	10%	44%
50	5%	18%	22%
60	15%	40%	16%
70	20%	20%	12%
80	35%	8%	6%
90	15%	4%	
100	7%		

Build a simulation model for the above problem, run it for 20 days, and provide a framework for the newspaper vendor to decide on the number of papers that he needs to order on a daily basis.

Solution

In this example, we notice two random events affecting the decision. So, let us first prepare the cumulative probability distribution for these random events. Based on the given information, Tables 10E and 10F depict the cumulative probability distribution for the respective random events.

Simulation models belong to the category of descriptive modelling in which the impact of a particular decision is analysed, given the conditions under which the model behaves. Therefore, in this example, we need to decide on the alternative for which we would like to study the behaviour of the system. The alternative to be studied is nothing but the decision variable for the newspaper vendor, that is, the number of papers that he needs to order daily. The steps in the simulation are as follows:

TABLE 10E Cumulative Distribution of the Type of Day

Type of the day	Cumulative Probability	
Good	35%	0.35
Fair	45%	0.80
Poor	20%	1.00

1. Fix the decision variable whose effect on the system needs to be studied. In Table 10G, the effect of buying 60 newspapers every day is being studied.
2. Sample a random number from the random number generator and use it for deciding the type of the day using their cumulative distribution table for the type of the day (Table 10E).
3. Sample another random number from the random number generator and use it for deciding the demand expected using the cumulative distribution of demand for the type of the day (Table 10F).
4. Since the number of copies bought as well as the demand is known, calculate the revenue for the day, lost profit (if any), salvage (if any) and daily profit (if any).

5. This completes one day of simulation. Repeat the above steps until the terminating condition for the simulation is achieved. In our example, the above steps are performed 20 times and the statistics is used to assess their impact on the system.

Proceeding in this manner, the relevant data for the system has been captured in Table 10G. The table shows the behaviour of the system with respect to a decision variable of the vendor buying 60 newspapers every day.

TABLE 10F Cumulative Distribution of the Demand Related to the Type of Day

TABLE 10G Simulation of the Newspaper Vendor Problem for a Daily Purchase of 60 Papers

Day	Random Numbers	Day Type	Random Numbers	Demand	Revenue	Lost Profit	Salvage	Daily Profit
1	0.94	Poor	0.80	60	30.00	0.00	0.00	10.20
2	0.77	Fair	0.20	50	25.00	0.00	0.50	5.70
3	0.49	Fair	0.15	50	25.00	0.00	0.50	5.70
4	0.45	Fair	0.88	70	30.00	1.70	0.00	8.50
5	0.43	Fair	0.98	90	30.00	5.10	0.00	5.10
6	0.32	Good	0.65	80	30.00	3.40	0.00	6.80
7	0.49	Fair	0.86	70	30.00	1.70	0.00	8.50
8	0.00	Poor	0.73	60	30.00	0.00	0.00	10.20
9	0.16	Good	0.24	70	30.00	1.70	0.00	8.50
10	0.24	Good	0.60	80	30.00	3.40	0.00	6.80
11	0.31	Good	0.60	80	30.00	3.40	0.00	6.80
12	0.14	Good	0.29	70	30.00	1.70	0.00	8.50
13	0.41	Fair	0.18	50	25.00	0.00	0.50	5.70
14	0.61	Fair	0.90	80	30.00	3.40	0.00	6.80
15	0.85	Poor	0.93	70	30.00	1.70	0.00	8.50
16	0.08	Good	0.73	80	30.00	3.40	0.00	6.80
17	0.15	Good	0.21	60	30.00	0.00	0.00	10.20
18	0.97	Poor	0.45	50	25.00	0.00	0.50	5.70
19	0.52	Fair	0.76	70	30.00	1.70	0.00	8.50
20	0.78	Fair	0.96	80	30.00	3.40	0.00	6.80
Total					**580.00**	**35.70**	**2.00**	**150.30**
Average					**29.00**	**1.79**	**0.10**	**7.52**

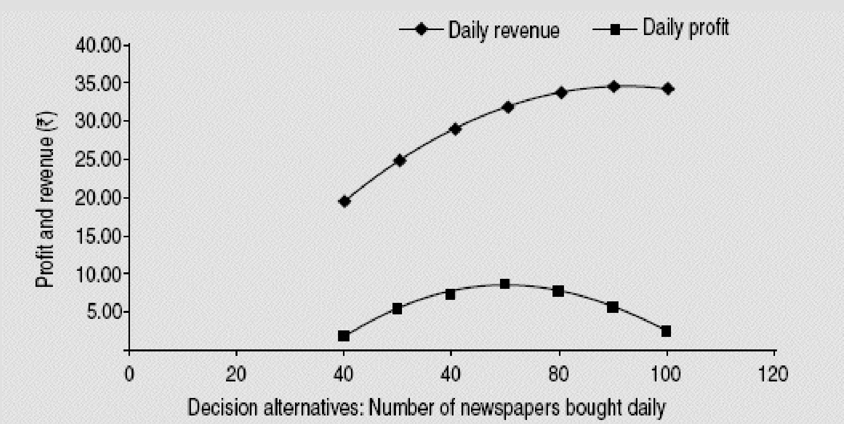
The results indicate that the news vendor would have made an average daily revenue of ₹29 and an average daily profit of ₹7.52. In a similar fashion, one can compute the average daily profit for alternate values of the number of newspapers bought daily and use this scenario analysis to arrive at an optimum decision.

TABLE 10H The Simulation Results for Various Values of the Number of Newspapers Bought Daily

Number of Newspapers Bought	Average Daily Revenue (₹)	Average Daily Profit (₹)
40	20.00	1.96
50	25.00	5.36
60	29.00	7.52
70	**32.25**	**8.75**
80	34.00	8.12
90	34.25	5.63
100	34.25	2.83

Table 10H shows the simulation results for various values of the number of newspapers bought daily. From the table and the chart beginning for that, by buying 70 news-papers daily, the news vendor can maximize his/her daily profit. On the other hand, by buying 90 or more number of newspapers, that daily revenue flattens at ₹34.25 while the daily profit deteriorates. Figure 10A pictorially demonstrates this.

FIGURE 10A Simulation analysis of the new vendor problem



Steps in Simulation Modelling

So far, we have merely demonstrated how to set up a simple simulation model and use it for analysing alternative decision choices. There are several other issues which we need to take care of when a simulation study is undertaken. These are summarized here:

- The issue of random numbers and the variance introduced on account of using one set of random number needs to be eliminated before the results of a simulation study are used for meaningful interpretation. Therefore, several replications of the model need to be done and the results must be averaged out before any interpretation could be done. This is known as *tactical planning* of a simulation experiment.
- Similarly, the number of variables and the number of levels in which each of the variables must be altered for the purpose of analysing the behaviour needs to be decided before a simulation experiment is conducted. For example,

in a manufacturing system, if a detailed simulation is performed to identify the number of storage locations to be provided in front of each machine as well as the number of common storages to be provided for the entire shop floor, there are two levels of decision variables: the central buffer and the local buffer. For each of these, the range of alternatives to be considered needs to be decided before simulation is done. Once this is decided for each combination of values of the central buffer and the local buffer, a separate simulation needs to be performed. This is known as *strategic planning* of a simulation experiment.

- Simulation modelling requires a good understanding of the system to be studied, translating it into logical building blocks of interconnections, preparation of data for the study and validation of the logic of the simulation model built. These steps need to be completed before tactical and strategic planning of simulation experiments are done.
- Finally, a good documentation of the study and the results will be very valuable.

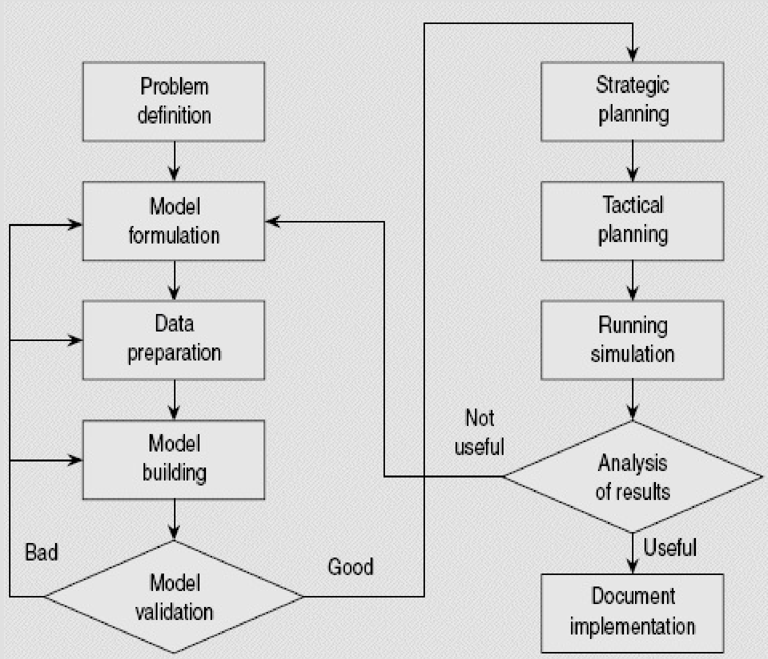
Figure 10B outlines the steps in a simulation experiment before results are drawn from the simulation model and useful interpretations are made for management decision making.

Computer Software for Simulation Modelling

Simulation modelling is often used in practice because of its ability to model real-life situations and provide useful statistics for the operations manager. Over the years, with advances in computing technology, several interesting simulation packages have been made available. One of the earliest packages available for simulation modelling was the General Purpose Simulation System (GPSS). GPSS uses several basic building blocks of logic with which alternate operations systems could be modelled. There are provisions available for:

- creating entities that will place demand on various elements of an operation system,
- moving the entity logically through the operation system,
- maintaining a clock for monitoring this simulation,
- alternate random number generators and built-in probability distributions for modelling the stochastic behaviour of the system, and
- a host of data-capturing mechanisms and report-generating facilities.

FIGURE 10B Steps in a simulation experiment before results and interpretation are drawn



Using the software, a modeller can quickly replicate any real operation system and use the model for analysing the performance and the behaviour of the system under study. Owing to its popularity, a number of computer packages are available for simulation study of operations systems. The popular among them include ARENA, PROMODEL, @RISK, WITNESS, and GPSS/H The recent versions of the software provided 3-D animation facilities, debugging facilities, and alternatives for interfacing the input and the output with other software. With these improvements in the development of simulation software, it is possible to link a simulation study with several other aspects of management decision making today. For example, when the design of a new factory is being attempted, it is possible to link the 3-D CAD/CAM software to the 3-D animation simulation software and simultaneously study not only the physical and geometric properties related to locating machines on the shop floor and their relationship with material handling systems and other system components, but also its impact on waiting time, congestion, and inventory build-up using a simulation software.

Applications of Simulation

Simulation modelling finds a host of applications in operations management. Some of them are listed here:

- *Capacity analysis:* Capacity decisions are often expensive and require some detailed analysis before investments are made. Further, the use of capacity in operations often involves complex networks of queues and several random behaviours of system entities. Therefore, capacity analysis is often done using a simulation model.
- *Layout design:* Designing of manufacturing systems with respect to new product lines requires some analysis about the number of resources to be deployed, utilisation of the resources and their impact on waiting time, and inventory build-up and congestion in the shop floor. It also requires some understanding of the material-handling complexities arising out of material flow patterns on the shop floor. Such situations are often analysed using a simulation model.

- *Operational performance of service systems:* Service systems are characterized by high levels of heterogeneity and complexity due to the presence of the human element in the process. Service systems often present a complex network of queues. Moreover, they are transient in nature, making mathematical modelling of such systems almost impossible. Several operational details with respect to the number of servers to be provided, the waiting space to be provided, the scheduling practices to be adopted, and the investments to be made in various other secondary resources are to be analyzed in greater detail in a service system. Simulation modelling is a valuable tool to address these issues in a service system.
- *Traffic management systems:* Study of traffic management systems often involve real-time and dynamic aspects of congestion, queuing and waiting time. These aspects are easily studied using a simulation model. Therefore, modelling of large-scale public systems such as public transport, railway networks and airline systems could be done using simulation modelling.
- *Supply chain management:* Similar to the traffic system, several aspects of supply chains also require an understanding of dynamic situations in order to address fleet management and logistics and distribution systems. Inventory management systems involving random demand and multiple demand points are difficult to study mathematically. Under these conditions, a simulation model would be very useful.

SUMMARY

- *Simulation* is a mechanism in which a numerical model mimics reality. A simulation model is often resorted to when the system to be studied does not lend itself to any readily available mathematical model or when a complex set of random events tend to affect the behaviour of the system.
- Simulation models belong to the category of descriptive modelling in which the impact of a particular decision is analysed, given the conditions under which the model behaves.
- To build a simulation model, use of the following is inevitable: a clock to keep track of the passage of time in which the behavior of the system is observed, a random number generator to sample random numbers, and mechanisms to collect data of interest as the clock advances from time zero to the end time.
- Central to the simulation methodology is the use of random numbers to model the stochastic behaviour that we face in real life in several operations systems.
- The variance introduced on account of using one set of random number needs to be eliminated before the results of a simulation study are used for meaningful interpretation. This is known as *tactical planning* of a simulation experiment.
- Owing to its popularity, a number of computer packages are available for simulation study of operations systems. The popular ones among them include ARENA, PROMODEL, @RISK, WITNESS and GPSS/H.
- Simulation modelling finds a host of applications in operations management. Some of them are capacity analysis, layout design, operational performance of service systems, traffic management systems and supply chain management.

REVIEW QUESTIONS

1. What is the relevance of simulation as a modelling tool in operations management?
2. Suppose a factory manager approaches you with a dilemma. He is not sure if he must use simulation for a problem he faces on the shop floor. On what basis will you advise him to use the simulation model or some other mathematical model to solve his problem?
3. Identify three situations in each of the following places where simulation could be a useful tool to study the problem:

    a. A five-star hotel
    b. The Bangalore Dairy (that processes and packages milk and milk products)
    c. Chennai Central Railway Station
    d. The student recreation centre in your college
    e. The final assembly plant of Suzuki Motors Limited
    f. A multi-specialty hospital

4. How are random behaviours studied in a simulation modelling exercise? Take the example of the number of students arriving at the hostel mess for lunch as an example to illustrate this.
5. What are the steps in carrying out a simulation experiment? Which of these steps are critical and why?

PROBLEMS

1. An ophthalmologic clinic has patients arriving at the clinic in a certain pattern. Based on a one-month observation, the following data (see Table 10I) is obtained with respect to arrival:

TABLE 10I Data with Respect to Arrival

Inter-arrival Time	Number of Cases
5 minutes	20
10 minutes	32
15 minutes	54

   a. Simulate the system for 20 arrivals. When did the last patient arrive if the clinic opened at 8.00 a.m.?
   b. Simulate the system for 3 hours. How many patients have arrived so far?
   c. Compute the average waiting time of the patients under the following conditions:
      - Each arrival spends approximately 9 minutes for service.
      - The service time is distributed in the following fashion: 20 per cent spend 13 minutes, 45 per cent spend 10 minutes, and the rest spend 6 minutes.

When will the clinic complete the servicing of the last arrival if the doors are closed after three hours?

2. A bakery owner sells three types of specialty cakes: honeycomb, butterfly, and whole nut. The demand for these is random and based on his experience in the past, the bakery owner found that 45 per cent prefer honeycomb, 37 per cent prefer butterfly, and the rest prefer whole-nut. The other uncertainty is the order size. In 25 per cent of the cases, the order size is for half a dozen, and in 47 per cent cases, the order is for a dozen. The remaining orders are for 2 dozens. The bakery owner wants to know what should be the optimum daily production run that he must schedule for the three varieties. Due to cost sharing, technology constraints, and other considerations, the production is always to be maintained in the ratio 5:3:2 for the three varieties. The cost, price, and salvage value of unsold cakes per dozen cakes are given in Table 10J. Simulate the problem.

TABLE 10J The Cost, Price, and Salvage Value of Unsold Cakes per Dozen

Variety of Cake	Cost (₹)	Price (₹)	Salvage (₹)
Honeycomb	20	45	12
Butterfly	34	70	20
Whole-nut	52	120	30

SUGGESTED READINGS

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CHAPTER 11

Product Development Process

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What are the strategic benefits of a good product development process?
- What are the stages of the product development process?
- What does concurrent engineering mean? Why should organizations make use of this concept?
- What are the tools and techniques used by organizations in a product development process?
- What does design for manufacturability (DFM) mean?
- How do organizations handle mass customization requirements?
- What are the performance measures used to assess the effectiveness of a product development initiative?
- How does management accounting help the product development process?
- What are the steps in a software product development process?

The Airblade Tap hand dryer is Dyson’s newest creation, taking what the company has learned about touchless hand drying, and packing it into a sleek faucet you can install in your own home. The Dyson Airblade Tap hand dryer won the gold in the Best in Biz Awards 2013.

Source: http://airblade.dyson.com/hand-dryers/airblade-tap/ airblade-tap/gallery.aspx

ideas at Work 11.1

Development of AEH by Philips: A New Approach to R&D

New Product development is all about bringing innovations in product and service offerings. While the common approach is to look for newer technology that can substitute an older one to address customer's existing needs, there is a possibility of developing new products and services that customers may find more meaningful and at times they don't even know. The design arm of Philips conducted more than 20 projects to explore how emerging technologies could be used to create new products. One result is the Ambient Experience for Healthcare (AEH). The development of AEH by Philips Electronics is an example that points to newer dimensions to the product and service development process. AEH was a new product developed by Philips to reduce the anxiety that patients often experience when they undergo a CT scan or a MRI scan.

The Philips team studied how people experience the environment in which they live and the emerging technologies might give rise to new experiences as part of the R&D process that led to the development of AEH. The first step in creating the product was to come up with new ideas. To identify appropriate but unusual domains, Philips adopted a few steps. Initially, it broadened the scope of analysis to include the user's whole experience rather than focusing just on what happens when the patient is undergoing a CT or MRI scan. In this process it identified factors related to the whole experience that they normally wouldn't think about during product development. The next step was to identify a battery of experts as interpreters on these factors. Typically, the experts had conducted research on user's experiences and have interpretations that challenge the dominant assumptions.

The experts have studied the users of the product from multiple perspectives. These include organizational insiders, scholars, researchers, designers, and people from other industries. The Philips team assembled a young team of such people with expertise in design, architecture, interior design, sociology, and anthropology. One internal interpreter provided significant insights into how the layout of rooms could help to relax patients and staff members. Another expert group pointed to the value of storytelling, which led the design team to incorporate videos in AEH.

Philips conducted workshops in which a number of interpreters discussed how healthcare experiences were changing and brainstormed about enabling new experiences through technology. Their conclusions were used to redesign the user experience. Finally, Philips built a full-scale prototype of the entire AEH system which allowed the potential customers to experience the new product themselves.

AEH has cut the time required to conduct CT scans by 15 – 20% and reduced the number of children under the age of three who need to be sedated for a CT scan by 30 – 40%. Consequently, it also slashed the amount of radiations that they were exposed in the whole process. On account of several such initiatives, the development of AEH eventually strengthened Philips imaging business worldwide and allowed it to realize higher prices and improve its profitability.

Philips approach to product development at one level seemed to have all the ingredients of a typical product development – idea generation, concept development proto-typing, use of multiple skills and expertise, and a time bound approach. We shall see these aspects in some detail in this chapter. However, it also points to certain aspects of a successful product development process. Two ideas stand out. First is their understanding that new product development is more about creating better customer experiences that existing application do than using new technology for marginal improvements in the products and services offered. The other is the value of involving experts from diverse fields during ideation and concept generation stage of new product/ service development.

Source: Adopted from Verganti, R. (2011), 'Designing breakthrough products', Harvard Business Review, Vol. 89 (10), 114 – 120.

11.1 INDIA'S ROLE IN RESEARCH AND DEVELOPMENT

India is fast emerging as the global research and development (R&D) hub of the world. In 2006 alone, for example, 100 of the world's top R&D companies employed more than 15,000 scientists in India. Many multinational corporations are setting up their R&D labs in India. For instance, Sony Ericsson has established an R&D unit for mobile phones in Chennai. Dell has established its biggest research and development centre outside the United States in Bangalore. British aerospace major Rolls-Royce has tied up with the Indian Institute of Science (IISc), Bangalore, and Imperial College, London to work together on a new research project to develop alloys for use in “greener” aircraft engines.

The DaimlerChrysler Research Centre in Bangalore is involved with fundamental and applied research in avionics, simulation, and software development. Boeing is working with HCL Technologies to co-develop software for everything from navigation systems and landing gear to the cockpit controls for its 7E7 Dreamliner jet. Microsoft has built its largest development centre outside the United States in India. The University of Oxford is to set up its first research centre outside the United Kingdom in association with the Confederation of Indian Industry (CII) with a focus on issues related to India’s rapidly expanding economy, such as infrastructure, education, social entrepreneurship and business taxation.

The reasons for this interest in India by global majors are obvious: its rich talent pool of technical know-how comes at a very competitive cost. India produces a huge pool of graduates—2.5 million per year in IT, engineering, and the life sciences. With 4,000 doctorates and 35,000 postgraduate degrees awarded by 162 universities, India has the third largest scientific and technical human-resource base in the world.

India’s R&D capability spans a wide spectrum of industries: agriculture, biotechnology, energy, nanotechnology, information technology, space, defence, automobiles, aviation, pharmaceuticals, theoretical physics, and statistics, among others. India is the only developing country and the sixth country in the world to manufacture and launch its own satellites in a geo-stationary orbit. Moreover, it has also launched satellites for foreign customers such as Germany and Korea. In October 2008, India successfully embarked on its moon mission when the Indian Space Research Organisation (ISRO) launched Chandrayaan I in a bid to expand knowledge about the moon.

India is one of the few countries that have developed stem cell lines as part of the stem cell network worldwide (at Reliance Life Sciences and the National Centre for Biological Sciences). In the pharmaceutical sector, India has the largest number of FDA-approved plants after the United States. Indian Institute of Technology (IIT) Madras has developed the world’s first nanomaterial-based water purifier. With initiatives in so many fields, India’s role in research and development is undeniable.

11.2 PRODUCT DEVELOPMENT: THE KEY TO COMPETITIVE ADVANTAGE

To be successful, businesses need to engage constantly in value creation for shareholders as well as customers. Innovation has been recognized as a potential lever for value creation. Innovation can enhance the value and applicability of the organization’s existing competence. Organizations in a sector of an industry that offer a homogenous set of products and services have very little opportunity for value creation. The notion of creating value through innovation has been well articulated by researchers and demonstrated by successful companies. It is based on the premise that innovation creates disequilibrium in the market, paving the way for new value-creation opportunities. The heterogeneity in the offerings of an organization is likely to delay the appropriation of profits in competitive markets by the competitors.

Operations management addresses the issue of innovation by enabling organizations to bring in some distinctiveness in their offerings. The distinctiveness may be on account of the product or service it offers, the technology and channel it employs, or the processes it uses to provide the product/service to the customer. For example, when Amazon offered 1.5 million titles of books through a virtual bookstore in 1995, customers experienced a high degree of differentiation. Similarly, Dell’s direct selling model had a high degree of differentiation. The product development process provides a broad set of tools, techniques, and concepts that enable an organization to provide distinctiveness in its offerings by rolling out new products and services faster and at a lower cost.

In recent years, we have witnessed a rise in customer expectations with respect to the products and services offered. Organizations can benefit in this scenario, either by offering highly differentiated products and services or by offering very cost-effective products. Furthermore, organizations can also benefit by bringing these products and services much faster than the competition and gain from early-mover advantages. In order to achieve this, organizations need to have a robust mechanism to understand customers’ expectations. They must also have the capability to react faster once they understand these expectations. In the 1950s and 1960s, Hindustan Motors introduced variations of its Ambassador (the Mark 2, the Mark 3, and so on) roughly once in ten years. Today, no automobile manufacturer can afford to take that much time to introduce new products and variations of the existing ones. A good product development process addresses these issues and provides a set of tools, techniques and concepts that an organization needs to bring products into the market more quickly and cheaply, in order to realize the associated gains.

Organizations have experienced several tangible benefits from a good product development process. For instance, the International Motor Vehicles Programme showed that while Japanese manufacturers such as Honda and Toyota introduced as many as 85 models between 1982 and 1989, their American counterparts were able to introduce only 49 models. This significantly affected the competitive positioning of these organizations.[1] Another study analysed the market impact of new-product introduction and showed that, by introducing products six months ahead of the competitors, an organization can gain as much as three times the cumulative profit earned over the life of the product.[2]

It is clear that product development is an important aspect of the operations management function in every organization, be it services or manufacturing. An organization armed with a good **product development process** will be in a better position to bring new products and services to the market ahead of the competition and will be able to retain customers and its market share in the sector. Repeat performances in the future will reward the organization with an increasing share of the market in the long run. Before we discuss the product development process in detail, it will be helpful to understand the expected outcomes of a good development process. Table 11.1 lists the outcomes that one can normally expect from a good product development process.

The **product development process** provides a broad set of tools, techniques, and concepts that enable an organization to provide distinctiveness in its offerings by rolling out new products and services faster and at a lower cost.

As we see from the table, four sets of benefits are likely to accrue to an organization from a sound product development process. The first set of benefits—*customer dimensions*—relate to attributes that have a positive and significant impact on the customer for whom the products/services are designed. These include perceived quality, better fit with requirements, and a sense of novelty. The second set of benefits pertains to *performance over a sustained period.* Addressing environmental issues, reduced life-cycle costs, and user-friendliness belong to this category. The third set of benefits accrues to the organization through *operational advantages* gained in the product development process. Typically, ease of manufacture and assembly, along with minimization of the need for going back to the drawing board are some examples of this category. All these benefits will lead to strategic improvements in cost, flexibility, and the development of new and unique capabilities.

An organization armed with a good product development process will be in a better position to bring new products and services to the market ahead of the competition.

TABLE 11.1 The Expected Outcomes of a Sound Product Development Process

Dimensions	Potential benefits/outcomes
Customer dimensions	• Provides unique benefits and features to the customers
	• Meets customer expectations better than existing products/services
	• Provides better quality as perceived by customers
	• Results in innovative offerings to the customers
Sustained performance	• Simplifies product use and maintenance
	• Reduces the cost of use over product lifetime
	• Addresses environmental issues pertaining to manufacture, use, and disposal
Operational advantages	• Simplifies the manufacturing process/service delivery process
	• Simplifies the assembly process
	• Minimizes the need for revisions and changes after introduction

Strategic advantages	• Enables faster new-product/service introduction
	• Reduces the cost of the product/service
	• Provides capabilities for mass customization

11.3 THE PRODUCT DEVELOPMENT PROCESS

The product development process consists of a structured and orderly set of activities. These activities are repeated at periodic intervals when the organization feels the need for bringing out new products. Let us take the example of the development of the Tata Nano to understand the process. The car initially had three concepts. The design team picked the one that they thought looked best, and from that they made a full-scale model. In mid-2005, one model was completed, which then went through a stage of refinement. At this stage, the initial volume of the car was defined. The design team then worked on details like lamps and doors. From that point onwards, the design team actually developed another model, which was a second-stage model. Eventually, IDEA, the design house involved in this project, came up with the final refined model. The style for the Nano was frozen in mid-2006—exactly a year after the first model was completed. Understandably, this stage was important since it had to meet the cost targets. Once the style was frozen, efforts were directed towards engineering development.[3]

Stages in the Product Development Process

Figure 11.1 shows a typical product development process that is found in most organizations. Broadly, the product development process consists of four stages: (i) concept generation, (ii) design, (iii) development, and (iv) production.

ideas at Work 11.2

Cross-badging: A Tool for New Rapid and New Product Introduction

New product development is both a time consuming and a costly process. Take the case of automobiles in India. It may require anywhere between 3 – 6 years to develop and commercially launch a new car model. According to Frost and Sullivan it costs at least ₹3 billion to develop a car in India. Therefore, in order to bring new products rapidly, global manufacturers resort to cross-badging. In simple terms, cross-badging refers to selling the same product with cosmetic changes under different brand names. Cross-badging uses common platforms of some major elements such as engines and power trains, and brings some minor changes in the product as it is finally offered to the customers.

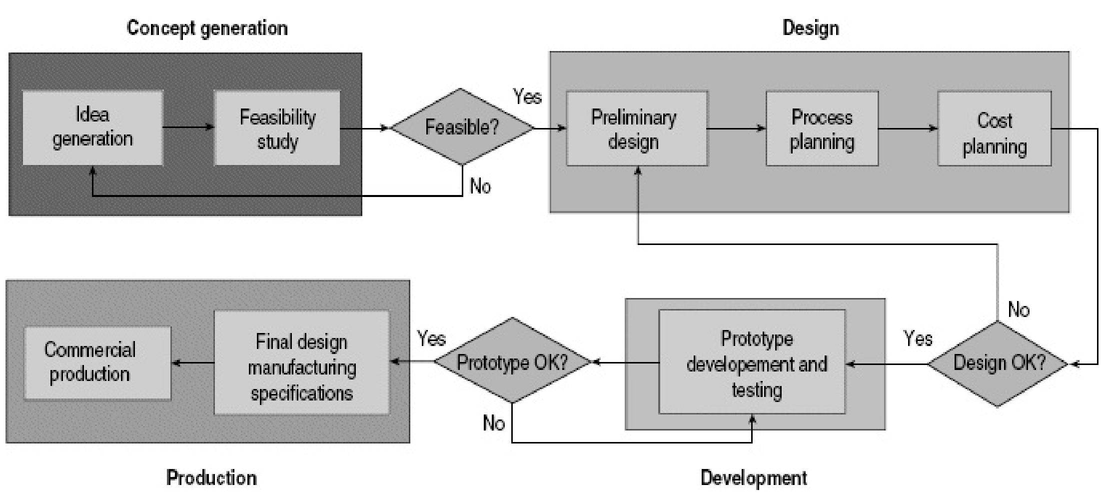
Cross-badging results in numerous benefits for the auto makers. They save on engineering, design and product development costs, and reduce the lead time to bring the new product to the market. For example, cross-badging a car may require some tooling changes which would entail an investment of less than ₹200 million. Therefore, it provides an attractive opportunity to widen the portfolio and get better returns on incremental investment.

Cross-badging has been practiced in the US and Europe for several decades successfully to boost sales. In 2013, Subaru BRZ and Toyota Scion FR-S were both launched in the US in a cross-badging arrangement. This sports car was jointly developed by Subaru and Toyota Motor Company, thereby producing a better vehicle than either could have done individually. Subaru took care of engineering chassis and power train, and Toyota handled the design.

Cross-badging of automobiles has been a failure in India so far. After cross-badging, the combined sales of Renault's sedan Scala and Nissan's sedan Sunny in February 2013 was 1,811 units, whereas Sunny alone sold 2,757 units before Scala was launched. Similarly, in the compact car segment the sales of Nissan's Micra was 1,855 units in January 2012 and the combined sales of cross-badged compact cars Micra and Pulse in February 2012 was 1,028. In order for cross-badging to succeed, manufacturers first need to establish their brands well in the market. In an evolving market, there are no shortcuts like cross-badging to brand building and large investments are essential.

Source: Based on Madhavan, N. (2013), '*Double trouble*', Business Today, April 28, 2014, pp 66 – 72.

FIGURE 11.1 A typical product development process



Concept generation

The first stage in a product development cycle is concept generation. New products and services are the outcome of the need to close the gap that exists in the market with respect to the customers' needs. Therefore, understanding customer needs, how exactly the existing portfolio of products and services fulfils this, and the areas that need greater application and attention are critical. Once there is some clarity on this aspect, the next step is to translate the need into products and services. This activity requires good innovation skills to develop unique products and services. Several alternative methods of fulfilling the identified need can be identified, but the feasibility and novelty of each of these approaches need to be carefully established.

Feasibility includes several dimensions: the technological feasibility to manufacture and deliver products according to the design marketing feasibility to create a market, distribute, and sustain maintenance; cost feasibility; and the feasibility of customer acceptance, to name a few. At this stage, feasibility is not evaluated in a strict and detailed manner. Instead, expert judgement is used to validate the specifications, numbers and assumptions behind the concept. This is a crucial step in the product development process.

VIDEO INSIGHTS 11.1

Research & Development (R&D) involves several steps. Among these, the preliminary concept generation is a crucial step as it shapes all the future activities with respect to the new product that is being brought out into the market. Maruti Suzuki Limited's video brings out the various steps in the early stages in the making of a new model of a car. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Let us consider a simple example; that of providing good-quality music to customers at an affordable cost. This need could be fulfilled in several ways. One method is to work on the quality and cost of sound reproduction devices such as CD players and bring a product that offers value along this dimension. The other option is to work on alternative technology such as MPEG devices and software and provide the same music in a downloadable format. The third option is to provide the mechanism of a digital cupboard in which every customer can store his/her favourite albums online. As and when a music album is pulled out of the digital cupboard and listened to, a small micro-payment (of a rupee or so) can be charged to his/her account (or to his/her credit card). Each of these alternatives results in different feasibilities, cost, quality, and other dimensions pertaining to the fulfilment of the need for high-quality music. At the concept generation phase, such alternative ideas need to be explored and the feasibility of these options evaluated.

Design

Once product feasibility is established, it is likely that the choice among several promising ideas will be narrowed down to a few potential ones. The next step in the process is to incorporate more details into the concept. Potentially useful ideas need to be analysed from the perspective of physical attributes such as shapes, sizes, and material. Moreover, costs, manufacturing processes, and specifications are the other aspects of the concept that require detailed consideration before the decision to go ahead can be taken. The design phase of the product development process focuses on these aspects.

During the design stage, detailed specifications are first drawn about the product. For instance, if we are designing a new pen, it is important to fix the weight, the material, the surface finish, and the tolerances required. Once these details are arrived at, they provide the necessary inputs to explore how exactly these requirements could be met using the available production resources in the organization. The process planning activity provides these details of the product being designed. Product specifications and process planning decisions are required for cost estimation of the proposed design of the process. At the end of these three steps, it is possible to assess the feasibility of the design.

An initial design may not be feasible for several reasons. For instance, the capability of the existing resources may not be enough to manufacture the product as per the required specifications. In some cases, although capability exists, the cost of the design could appear to be prohibitive, making it infeasible to find a good market. It is also possible that even when the cost and the process feasibility are there, the product will turn out to be uninteresting from a customer perspective. Finally, the availability of raw material or skilled labour may be doubtful in certain cases. Therefore, during the design phase, the product goes through several iterations before the design is approved. Several entities are involved in the decision making at this stage. These include the design department, the finance department, the production planning department, the marketing department, and the procurement department.

At the end of this exercise, a few ideas having potential are thoroughly analysed with a greater level of detail provided by the design team, and one alternative is selected for commercial production. In some cases, a certain amount of flexibility is still incorporated in the design, in which case two or three versions of the product are developed further before the final choice is made.

Development

The third stage of the product development process is the physical **development** of the product itself. During this stage, the details arrived at on the drawing board are translated into reality. Usually, a prototype is built for extensive testing and fine-tuning of design specifications. Moreover, detailed manufacturing specifications and specific methods of manufacture, assembly, and testing are established during this phase. Just as design specifications undergo a few iterations before the specifications are firmed up, similar efforts are required at this stage to iterate and firm up the manufacturing specifications. Design changes are made on the basis of findings from multiple controlled experiments and product usage.

> **Development** refers to the stage of the physical development of the product. During this stage, the details arrived at on the drawing board are translated into reality.

Production

The last stage of the product development process pertains to the transfer of know-how to the production personnel and establishing the system for volume production. Typically, during the development phase, a few pieces of the product are manufactured for testing purposes. The efficiency and effectiveness of the manufacturing process are not of concern at that point in time. Moreover, dedicated equipment and assured sources of supply are not established at that stage. Therefore, in production, the last phase, these aspects are addressed in a detailed fashion. Moreover, systems are established to translate the initial learning-curve advantages into the production, thereby improving productivity and bringing down the cost.

> **Production** involves the transfer of knowhow to the production personnel and the establishment of a system for volume production.

The product development cycle described in this section is fairly representative of a vast majority of situations faced in practice. These steps are normally found even in the case of the development of software products and services. In the case of the development of software products and services, however, the specific set of activities undertaken at each stage will be different from the ones discussed here. It is interesting to note that each stage in Figure 11.1 is separated by a decision box. In reality, these could be considered to be the review points in the product development cycle for the top management. Top management can measure the progress of the product development process and take some “go–no-go” decisions based on additional information available both within the organization and in the external environment.

While a number of creative ideas need to be generated during the initial stages of the product development process, as the process continues, these alternative choices need to be narrowed down to either one or a few variations of a basic version. The decision boxes shown in Figure 11.1 enable the management to achieve this objective.

The Stage–Gate Approach: An Alternative Representation of the Product Development Process

An alternative representation of the product development process is the *product development funnel with stages and gates*. Figure 11.2 depicts such a representation for a hypothetical product development process that is scheduled to launch the commercial version of the product 24 months from the start of the process. In this example, concept generation is expected to take 7 months. The other stages of the product development process take 5 months, 8 months and 4 months, respectively.[4] It is useful to have a considerable amount of flexibility at the beginning of the process. However, as the project evolves, it is inevitable that certain commitments are made with respect to specific concepts, product design, and certain design parameters. The number of ideas gets reduced progressively as we move from left to right. A stage–gate approach helps the management to address various issues in this process in a structured manner.

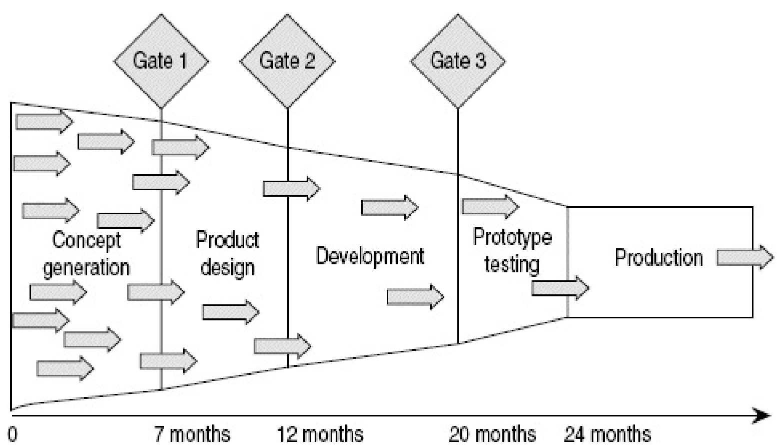
- *Stages:* Stages are the intermediate time-points between two gates. The new-product development team performs various activities to advance the project to the next gate or decision point. Stages are cross-functional because a set of parallel activities are performed by team members from different functional areas in the organization, led by a project team leader. To manage risk using a stage–gate method, parallel activities must be designed at a certain stage to gather vital information pertaining to technical, financial, operational and market-related aspects in order to drive down the technical and business risks.

- *Gates:* Gates are definite milestones in a new-product development project. The gates serve as the entry points where a continue/abandon decision is taken with respect to the project. Effective gates are central to the success of a fast-paced new-product process. In addition to helping the management decide on the fate of the project, gates also enable the top management to decide on the commitment of resources for continuation of the project. The gates have clearly laid out criteria for evaluation of the project as well as deliverables expected at the time of review at the gate.

> An alternative representation of the product development process is the product development funnel with stages and gates.

The entire process could be thought of as a funnel filtering ideas as time goes by. Similarly, the completion of each stage is a milestone that could potentially trigger the management to filter the available ideas, assess the suitability of current efforts and make necessary modifications. Therefore, each gate represents an opportunity for review and mid-course correction.

FIGURE 11.2 A product development funnel with stages and gates



11.4 ORGANIZATION FOR PRODUCT DEVELOPMENT

Product development is an interdisciplinary effort, as we saw from the previous section. Several functional areas are directly involved in the process. Marketing plays a crucial role in the process by providing information on customer needs that are otherwise unaddressed. Moreover, as the concept is established and design and manufacturing specifications are finalized, there is a frequent need for interacting with customers for useful feedback regarding the process. Finance, design, and production planning functions also play a major role in translating the concept to meaningful products that can be manufactured at an attractive cost. Profit planning over the lifetime of the product is also essential. Therefore, there is constant interaction between the various functional areas in an organization for product development.

Currently, most of the development does not happen in a purely in-house fashion. Identifying component suppliers fairly early in the process, involving them in the process from the beginning, and ramping up their capacities and capabilities are important aspects of a faster and more efficient new-product development process. For instance, an alternator manufacturer such as Lucas TVS procures complete information on the developments in bearing design before designing its next generation of alternators or starter motors. Since bearings form an important component of its product, interfacing with bearing manufacturers and getting information on new developments makes its product development process not only faster but also superior. Therefore, the material procurement function is also involved in the process.

In view of the interdisciplinary nature of these entities and the intensity of interaction required among them, an appropriate organization structure is vital for a good product development process. Traditionally, the organizational structure for the product development process was one of functional silos. In this approach, each functional area addressed its part in the product development process in isolation. Moreover, the functional areas addressed the product development process one at a time. After one group completed its part, it was passed on to another group for further processing. If there were infeasibilities, the process was reversed and the part was sent back to the earlier department. Figure 11.3(a) depicts this arrangement.

It is obvious that such an approach is time consuming. There are excessive delays and the process results in poor productivity. A long lead time for product development creates several problems for organizations, especially in the context of heightened competition from global players. Most prominent among the problems is that several assumptions about the market, pricing, and competing products may have been wrong. For instance, if an organization takes 48 months to develop and bring a product to the market, by the time the product is introduced its assumptions about the competition might have changed substantially. The second issue is the cost of development. A longer process would clearly mean greater development costs. Since these costs are sunk even before the first commercial version of the product rolls out of the manufacturing plant, it puts enormous pressure on the marketing and production functions.

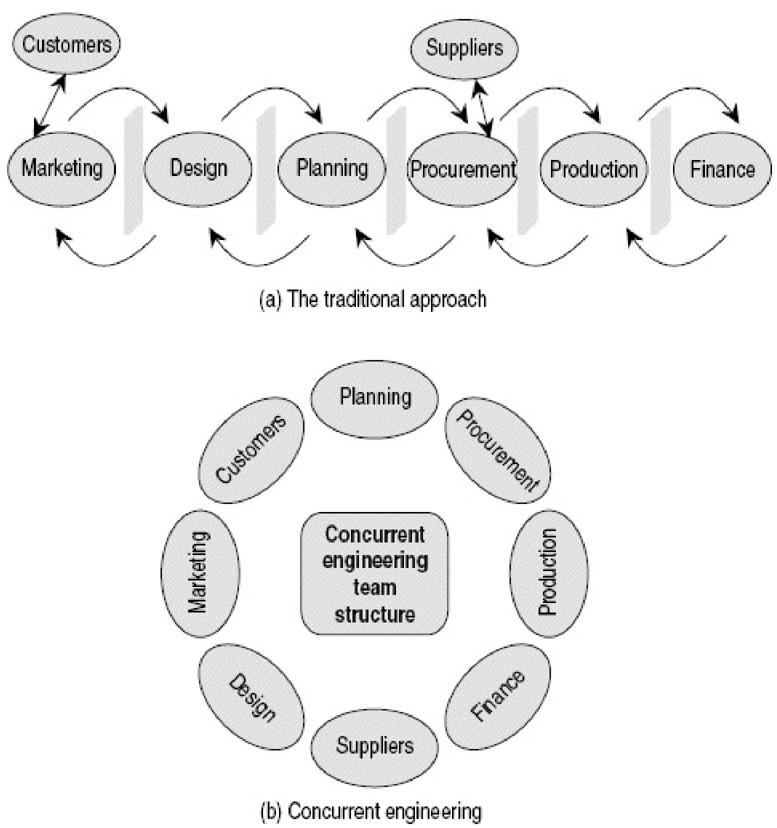
However, in recent times, significant changes have been introduced in the organizational structure for creating a product development process that promises a dramatic improvement in the development lead time. Figure 11.3(b) shows an alternative approach known as **concurrent engineering**. The basic idea behind this is to put together a team of cross-functional professionals and provide them with the necessary resources and mandate for the product development process. The cross-functional team works in project mode. Once the process is over, the team is dismantled and the members return to their parent functional units. By co-locating various functional requirements for the product development process, organizations could benefit in several ways:

> **Concurrent engineering** is the process of putting together a team of cross-functional professionals and providing them with the required resources and mandate for the product development process.

- The development lead time could be more than halved in this process, enabling the organization to bring new products into the market faster. In the long run, this would help the organization capture a greater market share.

- Since various functional requirements are simultaneously available, the number of design changes after the product is introduced into the market will come down. This is because the team members would have had more opportunities to analyse the impact of the design from multiple perspectives before approval. Therefore, design productivity also improves.
- A concurrent approach enables organizations to involve its suppliers early on in the product development process. Therefore, suppliers are able to cut lead time for capacity augmentation and capability building with respect to the new product being developed.
- A team structure promotes consensus-based decision making and increases the propensity for collective risk-taking. These attributes are very valuable for a product development process, especially in the early stages. In the absence of this, important decisions for resolving trade-offs between one design choice and another will not be made efficiently, and the process will be time consuming.

FIGURE 11.3 An organizational structure for a product development process



11.5 TOOLS FOR EFFICIENT PRODUCT DEVELOPMENT

Several tools and techniques can be used for efficient new-product development. These tools address various stages of the product development process that we discussed earlier. In this section, we shall look at some of the tools that are available for product designers to understand customer needs and translate them into meaningful design and manufacturing specifications, and also at some guidelines for incorporating the manufacturing requirements at the design stage.

Understanding Customer Needs

The first step in a product development process is to know what exactly the new product is going to be. The concept generation phase of the product development process addresses this. There are various methods by which organizations can arrive at an appropriate concept for the new product that it intends to develop. Irrespective of the method used, understanding customer needs is an important input to this process.

Market research

Organizations use a set of known tools for soliciting information. For instance, they could commission a market research organization for this purpose. In a market research, a target group is identified and appropriate sampling is done within the target group. Using a structured data collection method such as questionnaire surveys and interviews, information is solicited from the sample. This information is subjected to statistical and other kinds of analytical reasoning before arriving at customers' preferences and needs.

An alternative method is to use *focus groups*. Unlike the earlier method, in a focus group several individuals from the target group are simultaneously met and interviewed together. The additional advantage is the reinforcement of certain ideas and needs through collective reasoning and group-behaviour norms. Suppose an organization is developing a new beverage and its target market for this product is youngsters in the age group of 15–25. One way to get useful inputs for product design is to have a detailed and continuous interaction with a group of 25 to 50 youngsters in the target age group. As various aspects of the product are being designed, this small group of youngsters will act as a sounding board.

The other option is to conduct an *in-depth qualitative interview* with a selected set of potential customers on an individual basis. In this approach, rather than collecting some quantitative data from a large number of respondents, a considerable amount of qualitative information is collected from a chosen few. The data collected in the above manner is subjected to extensive analysis.

In the case of in-depth interviews and focus group meetings, it is possible to analyse the qualitative statements elaborately for identifying possible missing links in the existing offerings in the market. Efforts are often made to exactly reproduce the customers' own words and alternative ways of translating them are attempted. In the case of market research using a questionnaire survey, several statistical tests are performed. The testing of hypotheses pertaining to customers' likes and dislikes and the performance of existing offerings in the market is also done. Irrespective of the method adopted, the exercise must eventually lead to creating a bundle of attributes that customers are looking for in the product and identifying the hierarchies, if any, among them. This forms a critical piece of input to the product design process. Figure 11.4 shows the various steps in the process explained here.

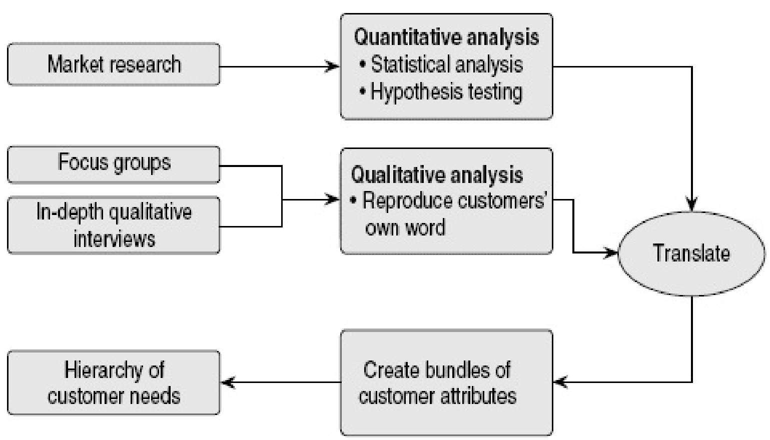
Competitor analysis

An understanding of what the existing offerings are and how the gaps and problems identified can be eliminated can offer valuable inputs to concept generation. This method is a proxy for understanding customers' needs. It is useful in situations where it is either difficult or costly to reach the customer directly. Moreover, this process could also supplement other methods of arriving at a good concept of the product that needs to be developed.

> An understanding of what the existing offerings are and how the gaps and problems identified can be eliminated can sometimes offer valuable inputs to concept generation.

One method of competitor analysis is *reverse engineering* the product. In reverse engineering, the competitors' products are dismantled down to the level of individual components and some detailed studies are conducted on them. These may sometimes reveal the probable processes utilized in their manufacture, the choice of materials and their specifications, and the relationship between these parameters and performance. In some cases, the competitors' products are also subjected to alternative working conditions to understand the latitude the products provide with respect to performance. Whether reverse engineering is ethical is not an easy question to answer, as some critics opine that a violation of professional ethics is involved in this process. There are arguments for and against it. In the case of services, reverse engineering is not possible in most situations.

FIGURE 11.4 Understanding customer needs



ideas at Work 11.3

Getting Together to Know What the Customer Wants

Getting to know what the customer wants is not always easy, nor do many organizations know how to get this information. Breaking away from old procedures and systems and creating an interdisciplinary team within the organization can sometimes offer invaluable help.

Bharat Electronics Ltd (BEL) was to manufacture outstation broadcasting (OB) vans during the Eighth Five-Year Plan period. It had already manufactured eight such vans in the past and the chief engineer approved the design for manufacturing. However, the project chief wanted to know whether the OB vans required any further improvement. Contrary to the contemporary wisdom prevailing at that time, the project chief insisted that the R&D personnel should be involved (along with marketing) in this exercise of getting to know what the customer wanted.

The unorthodox suggestion paid rich dividends. Typical problems encountered by users included the prospect of hitting one's head on the van roof when negotiating rough terrain, and two springs breaking down almost every time when the vans completed a trip to villages, to name just a few. Despite their initial reluctance, the satisfaction level of the R&D team was worth more than the effort in spending time with the user.

About 100 changes were made in the design, nearly half of them at no significant cost. It also brought into focus the fact that it is sometimes not possible for marketing personnel to appreciate, understand, and articulate the design problem.

Source: B. Mahadevan, *The New Manufacturing Architecture* (New Delhi: Tata McGraw-Hill, 1999), p. 16.

VIDEO INSIGHTS 11.2

Development of a new service has similar steps to that of development of a product. However, there are several unique aspects that a service provider goes through before commercially launching a new service. HIFI, a new service in the health and fitness sector by Talwalkars is a case in point. To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

Reverse engineering is one crude method within the larger issue of *benchmarking*. In the case of benchmarking, the competitive product offerings are chosen for a detailed analysis. Specific parameters are chosen for the benchmarking exercise. For example, cost, features, performance, ease of maintenance, ease of manufacture, assembly, and distribution are some of the issues on which a comparative study may be possible. Once the parameters are identified, data collection and analysis will reveal the positioning of one's own product vis-à-vis the competitors' offerings (for an example, see Ideas at Work 12.3 in Chapter 12).

Another method for competitor analysis is to develop *perceptual maps*. **Perceptual maps** are graphical representations of the various competitor offerings and that of the proposed product/service. Although it is similar in approach to the benchmarking exercise, the graphical display makes it easier for managers to understand the implication of the proposed positioning of the product for which the development processes are undertaken. However, the major disadvantage of this approach is the limitation on the number of dimensions on which competitive offerings can be compared and maps generated. While a two- dimensional plot is easy to comprehend, a three-dimensional plot is somewhat manageable. It is not possible to visualize beyond this. However, in reality, there could be more than three dimensions on which competitive offerings can differ significantly.[5]

> **Perceptual maps** are graphical representations of the various competitor offerings and that of one's own proposed product/service.

Quality Function Deployment

The goal of a good product development process is to bring out products that satisfy customers' needs better than those of the competition. However, the attributes of customer satisfaction are often qualitative in nature. On the other hand, the product development process must result in a bundle of quantitative attributes pertaining to the product. The quantitative attributes are nothing but detailed and unambiguous design, process planning, and manufacturing specifications. Therefore, the challenge for a product development team is to ensure that the transition from qualitative attributes to quantitative ones is smooth and complete. **Quality function deployment (QFD)** is a Japanese tool that helps organizations achieve this transition in a systematic and progressive manner.

> **Quality function deployment (QFD)** is a tool that helps organizations translate customer requirements into design, process planning, and manufacturing specifications using a four-stage process.

Quality function deployment achieves this transition in four stages. In each stage, certain inputs are considered, and based on these inputs certain specifications are arrived at. The specifications arrived at in the previous stage form the input to the next stage. Proceeding in this manner, customer requirements are converted into design, process planning and manufacturing specifications.

The first stage links customer needs to the design attributes required. In the second stage, the design attributes form the basis for actions that the organization needs to take to achieve these attributes. The actions identified at this stage are the basis of the third stage in arriving at the specific decisions to be implemented. Finally, in the fourth stage, the implementation decisions drive the process plans to be deployed. Each stage is known as the "house of quality." Figure 11.5 is an illustration of the house of quality pertaining to the first stage. Figure 11.5(a) illustrates its use in the case of a restaurant. Figure 11.5(b) is representative of the structure of a house of quality and the type of data used for analysis and decision making.

Seven types of data are used in this house of quality. The first type is the customer requirement. For example, in the case of the restaurant, the fact that the customer would like to spend less time during peak hours is an important requirement. When several such requirements are identified, it is important to also know if some are more important than others. The important data is captured such that it helps the design team prioritize its efforts.

The next kinds of information required are the product characteristics and the relationship between customer requirements and product characteristics. This information is also captured in the house of quality [see Items 3 and 5 in Figure 11.5(b)]. For example, "less time during peak hours" clearly relate to the number of service counters during peak hours. The more the number of counters, the less is the time spent by the customer during peak hours. It is obvious from this example that some of these service characteristics are inter-related. Order-processing time and the number of service counters during peak hours are strongly and negatively correlated. In certain other cases, the correlation can be either weak or zero. It can also be positive or negative. These trade-offs are also captured in the house of quality [see Item 4 in Figure 11.5(b)].

Finally, before focusing on the design effort, it is also important to benchmark one's own product or proposed specifications with that of the competition. The right side of the house of quality provides inputs from the benchmarking exercise. Once the above information is collected and analysed, it is possible to fill in the lower portion of the house of quality [Item 7 of Figure 11.5(b)]. While doing this exercise, it is again useful to know how important the changes are vis-à-vis the competition and make appropriate recommendations. The lower portion of the house of quality is the output of this stage of the exercise and this is taken to the next stage as input. Proceeding in this manner, all the four stages of the house of quality can be constructed.[6]

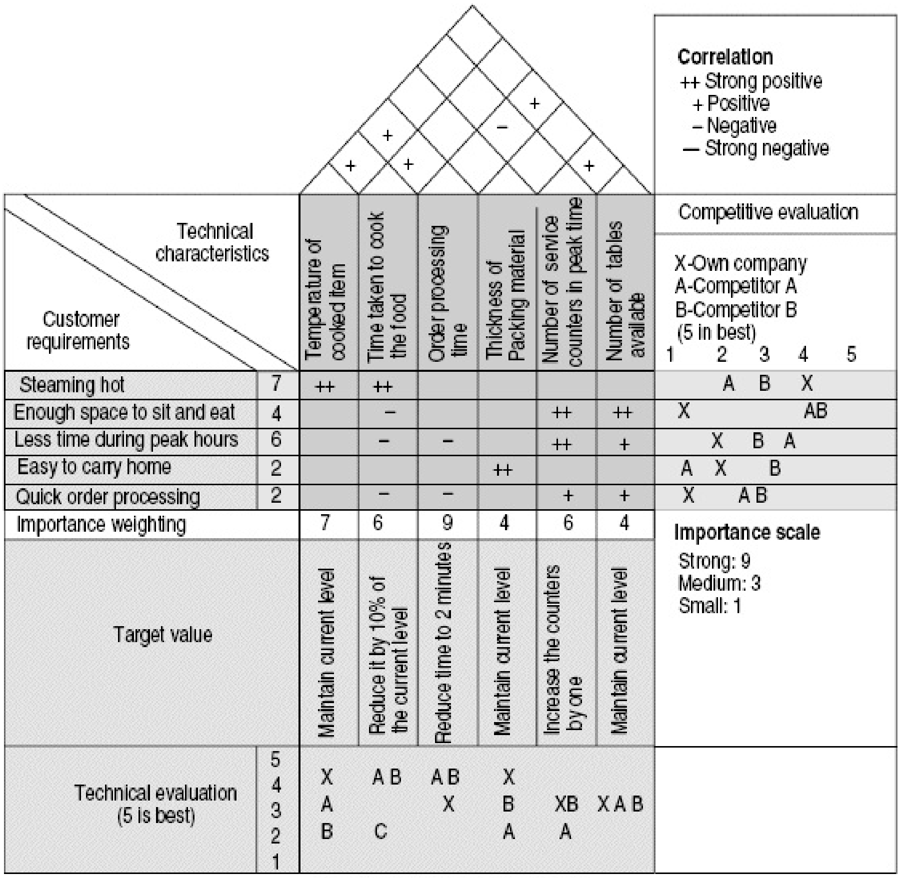
Value Engineering

During the early stages of design, it is important to question several assumptions pertaining to design, process planning, and the manufacture of components in a product development process. Since the specifications are not frozen at that stage, investigating alternative methods can potentially yield better products at a lower cost. **Value engineering** is a set of activities undertaken to investigate the design of components in a product development process strictly from a cost–value perspective and alert the product development team to alternatives that could either bring down the cost, or increase the value by improving the functionality and performance without increasing the cost.

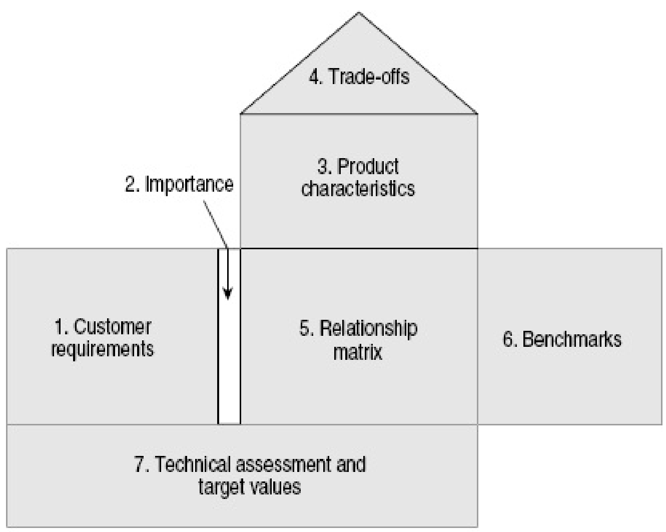
> **Value engineering** is a set of activities undertaken to investigate the design of components in a product development process strictly from a cost–value perspective.

The Tata Nano project had ambitious cost targets to bring to the market an ₹100,000 car. Expectedly, the suppliers had to make use of value engineering efforts. The components in the Nano have been studied from the points of view of functionality, cost and performance. Rane Group, which makes a rack-and-pinion steering system, focused on reducing the weight of the materials used, replacing the steel rod of the steering with a steel tube, which turned out to be a major cost reducer. The product is typically made of two pieces, but it was redesigned into one to save on machining and assembling costs. GKN Driveline India, a subsidiary of global auto parts leader GKN, designed a shaft of a smaller diameter, which made it lighter and saved on material costs.[7]

FIGURE 11.5 The house of quality



(a) An illustration for a restaurant*



(b) A generic representation of the house of quality

Source: Based on J. R. Hauser and D. Clausing, "The House of Quality," *Harvard Business Review*, May–June 1988.

Typically, design professionals brainstorm various options in conjunction with procurement personnel, suppliers, and production personnel with respect to the value–cost dimensions of the product being developed. Usually, several questions are raised, which include the following:

- Can we eliminate certain features from the design?
- Are there instances of over-design in certain components, increasing the cost? If so, how can these aspects be rationalized?
- Are there certain features of design that cost more than they are worth?
- Is it possible to replace the proposed method of manufacture with a less costly one?
- Is it possible for someone else (suppliers) to produce certain components cheaper, faster and better?
- Can we eliminate some parts and replace them with more universal parts?
- Are there opportunities for cost cutting by development of import substitution methods?

Through a series of such brainstorming exercises, some cost reduction opportunities are identified and necessary steps are taken to incorporate them in the design. A good value engineering exercise results in a cost-effective design that maximizes value for target customers. Value engineering exercises succeed only when the top management provides a mandate for such exercises and demands better performance. In the absence of this, the complexity and long-drawn nature of the product development process may result in the product development team pushing this to the background.

Design for Manufacturability

Design efforts can sometimes lead to loss of productivity, increase in cost and further delay before commercially manufactured. One frequently encountered reason for this is that while design engineers may have come up with some design specifications that meet the objectives of the product concept, it may not be easy on the part of manufacturing or assembly to fulfil the requirements of the design specifications. Some useful guidelines might have evolved in the domains of manufacturing and assembly that could be shared with design engineers so that unwarranted complications could be avoided. A simple example would be useful to explain this point.

Let us consider the use of mirror-image components (symmetrically shaped right-hand and left-hand components) in a piece of equipment. From the designer's perspective, it increases the aesthetics of the product and even gives a sense of satisfaction upon creating an appealing product. The cost of making these two components and the technology and expertise required for manufacture are also identical. Therefore, from the designer's perspective, there is no problem in such a design. However, if you look at it from the operations perspective, such a design may not be preferred. The biggest problem is the increase in the number of unique parts and the need to have tighter inventory control on these. Otherwise, the number of right-hand components may exceed that of the left-hand components, leading to assembly delays. Similar problems may exist in the case of spare-parts management also.

Design for manufacturability (DFM)[8] is a structured approach to ensure that manufacturing requirements and preferences are considered fairly early in the design process without the need for extensive coordination between the two. DFM guidelines address three sets of generic requirements: reducing variety, considering operational convenience, and reducing cost. The following are some of the guidelines pertaining to DFM.

> **Design for manufacturability (DFM)** is a structured approach to ensure that manufacturing requirements and preferences are considered fairly early in the design process without the need for extensive coordination between the two.

- *Reducing the variety*: The following guidelines can be followed for reducing the variety:
  - Minimize the number of parts
  - Minimize sub-assemblies
  - Avoid separate fasteners
  - Use standard parts when possible
  - Design parts for multi-use
  - Develop modular design
  - Use repeatable and understood processes
- *Reducing cost*: The following guidelines can be followed to reduce costs:
  - Analyse failures
  - Assess value rigorously
- *Considering operational convenience*: The following are some guidelines for operational convenience:
  - Simplify operations
  - Eliminate adjustments
  - Avoid tools
  - Design for minimum handling
  - Design for top-down assembly
  - Design for efficient and adequate testing

DFM guidelines provide several advantages to an organization. They provide a methodology to identify product characteristics that are easy for manufacture and assembly to follow and highlight them to the design team. Further, as the requirements are considered early in the design process, design productivity improves. In addition, development time and costs also come down in the process. Finally, if these guidelines are followed, it will necessitate less coordination between the two functional areas.

The underlying philosophy of DFM is sound and intuitively appealing. One can extend this idea to several other situations as well. Therefore, it is possible to have design for assembly (DFA) and design for environment (DFE). Design for localization (DFL) is another useful extension of the DFM concept in the case of multilingual and multi-standard products in a global market.[9]

Tools for Mass Customization

One of the fallouts of increased competition is the need to be more customer-focused. Many organizations endeavour to meet this requirement. However, in this process they end up creating several varieties of their products. This increases the complexity of production planning and control and also increases investment in inventory. Therefore, it is important to have a mechanism to provide high levels of customization without increasing the complexity of planning and control of operations. **Mass customization** provides a structured set of ideas and tools to meet this requirement. Customization can happen at the design stage itself, which requires some collaborative effort with customers. In some cases, the customization happens post-design. In this approach, from a set of components, a variety of mix and match combinations can be arrived at.[10] From a product development process perspective, some techniques are available for mass customization. We discuss some of them here.

> **Mass customization** provides a structured set of ideas and tools to provide high levels of customization without increasing the complexity of planning and control of operations.

One of the useful techniques for mass customization is to employ variety-reduction techniques. A careful examination of the portfolio of products may often reveal considerable scope for variety reduction without compromising on customer requirements. The use of a standard set of fasteners is a commonly recommended practice for variety reduction. Instead of using 200 different fasteners, it will be useful to reduce it to, say, 50 varieties. In the process, it may be inevitable to have over designed components. However, the benefits will be far more than the added costs due to overdesign (see Ideas at Work 11.4 for an illustration of this).

The second approach is to promote modular design. The advantage of modular design is that with relatively fewer sub-assemblies (or modules) it will be possible to create a very large number of final products. Modular design enables an organization to provide adaptive mass customization opportunities to its customers. This is possible because customers can mix and match the available modules that suit their individual tastes and preferences. The computer hardware industry provides an ideal example of modular design.[11] The other example is in the area of software development. By having standard modules of applications, it is possible to reuse the same module in a vast number of different applications according to customer preference. Numerous other applications are possible for mass customization by adopting a modular design.

The third, and a more recent, approach is to make use of the concept of product platforms. Traditionally, the product development process has been more focused on *one* product at a time. While such an approach may have resulted in good design productivity, it missed opportunities for faster new-product introduction in a successive manner. Automobile manufacturing giants such as Honda and Ford and inkjet printer manufacturer Hewlett-Packard direct design efforts towards a family of products as opposed to the traditional “one at a time” approach. This is the basic premise behind the product-platform approach to product development. Product platforms form an important aspect of mass customization, as organizations are likely to be in a better position to introduce several variants of the generic concept to suit the varied interests and requirements of their customers.

A **product platform** is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and manufactured. In essence, a platform is a collection of assets that are shared by a set of products. These assets could be components—including parts, designs, fixtures, and tool or manufacturing processes for manufacturing and assembly. Further, a platform also includes a collection of knowledge consisting of techniques, methods, people, and relationships, such as design teams and suppliers.[12]

A **product platform** is a collection of assets that are shared by a set of products.

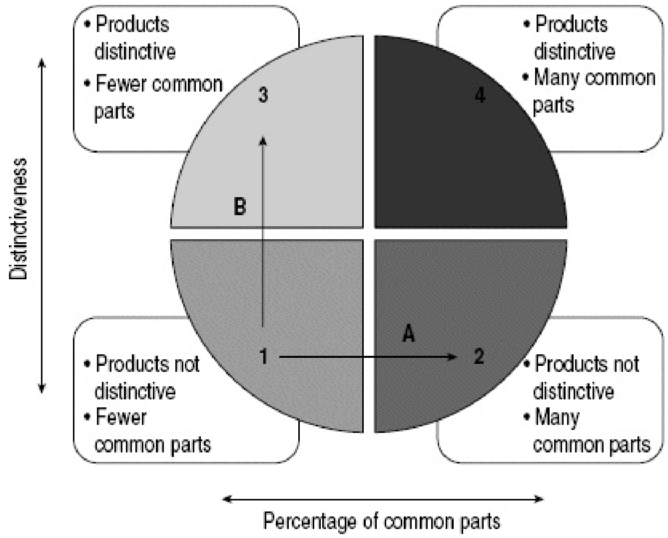
The product-platform concept is built on two basic premises. The first one is the notion of *distinctiveness* and the second is the *degree of commonality*. Let us consider a passenger car. In their choice of one brand of car over the other, customers care for a few features. These include aspects such as the noise level inside the car, the upholstery design, the choice of colour options available, and ease of steering. **Distinctiveness**, therefore, refers to the set of differentiating attributes between one variant and the other in a family of similar products, both within an organization and outside (competitors). On the other hand, consider the engine compartment or various subsystems mounted inside the front hood of the car bonnet. Even a technically inclined customer is less likely to open the bonnet and closely inspect or touch and feel these components before making a choice among competing variations. These are known as "chunks."

Distinctiveness refers to the set of differentiating attributes between one variant and the other in a family of similar products.

While differentiating attributes provide a clear advantage to a product and position it strongly among competing products, this also calls for adding more varieties. Therefore, there will be an increase in the design effort to create these attributes uniquely. Ultimately, it will result in an increase in both the cost of the design and the product. In contrast, chunks influence costs favourably and help an organization use these across a family of offerings, compensating for the increased cost of the differentiating attributes. Therefore, the objective of a product-platform exercise is to critically arrive at a tradeoff between the extent of usage of differentiating attributes and chunks in the design of a family of products. Figure 11.6 graphically depicts the trade-offs involved in this process.

Typically, organizations practicing the traditional product development process will be in Stage 1 of the trade-off process, as depicted in Figure 11.6. In this scenario, even when organizations have fewer common parts, the products may be less distinctive. Such a situation shows that organizations have not been able to benefit from some of the advantages of a good product development process. However, there are other coordinates in the trade-off map that organizations can hope to achieve. For instance, even if the organization is not able to increase the distinctiveness of its product offerings, it can make an effort towards increasing the number of common parts in the existing portfolio of the products. This is indicated by the Trajectory A in the figure. Greater emphasis on the use of variety reduction techniques may achieve this goal and the organization will reach Stage 2 in the product development process.

FIGURE 11.6 Trade-offs in a product-platform exercise



B indicates the second trajectory in the figure. In this approach, organizations try to increase their product distinctiveness without any increase in unique parts. Therefore, while the degree of commonality of parts does not change, the number of offerings increases significantly. One can achieve this by taking a conscious decision to change the design philosophy to a modular approach. By a careful design of the module with the existing components, the organization will be able to offer a wide range of distinctive products to its customer base. Such an approach requires an intensive design effort, compared to the variety reduction drive. This will take the organization to the third stage of its product development process. The final stage is the judicious combination of both the approaches using the principle of product platform. In reality, there could be more trajectories available to reach the fourth stage than those indicated here.

> The objective of a product-platform exercise is to critically arrive at a trade-off between the extent of usage of differentiating attributes and chunks in the design of a family of products.

ideas at Work 11.4

Variety Reduction Exercise: Opportunities for Cost Cutting

A manufacturer of industrial equipment operating in South India was facing stiff competition from new entrants, mainly from Japan, for a product that it had developed just a few years ago. The Japanese competition was offering a similar product, but at a lower price. Therefore, despite having a product with good technology and quality, the company was finding it difficult to compete in the market.

After initial studies, it was found that one promising opportunity for cost cutting was to revisit its design philosophy. There was a widespread feeling that opportunities for using several of the existing components in the new product may have been missed. Moreover, it was also felt that unnecessary variations had been introduced in the product design, thereby increasing the number of unique components used in the product. Based on these initial inputs, the components used for the manufacture of the product were studied. In a cursory analysis, the study concluded that there were significant opportunities for reducing part variety, thereby bringing down the cost. Table 11.2 shows a partial list of 15 components used in the product.

The study pointed to several shortcomings in design. It showed that use of mirror-image components added no substantial value to the operation of the product but to the variety (as in the case of cornet teeth design). The organization failed to recognize the need for using universal components even at the expense of overdesign.

This example underscores the need for the design team to have an appropriate design philosophy. In the absence of this, even with a resourceful and productive design team, the organization can introduce products that are not competitive at the market place.

Source: Unpublished report submitted for "*Management Programme for Technologists*" at *IIM* Bangalore.

TABLE 11.2 Analysis of a Partial List of Components Used in the Product

Parts	Part No.	Description	Remarks
1	375 PH 02321	Hose	These hoses can be substituted with one variety after careful
2	CHH 18 01615	Hose	examination of the assemblies
3	CHH 18 01616	Hose	
4	375 PH 02046	Hose	These hoses can be substituted with one variety after careful
5	CHH 04 00805	Hose	examination of the assemblies
6	375 PH 02184	Tube string (LH)	LH and RH parts can be avoided after suitable redesign
7	375 PH 02281	Tube string (RH)	
8	375 PH 02176	Tube string (LH)	LH and RH parts can be avoided after suitable redesign
9	375 PH 02168	Tube string (RH)	
10	375 PH 02208	Tube string (LH)	LH and RH parts can be avoided after suitable redesign
11	375 PH 02257	Tube string (RH)	
12	375 PH 02216	Tube string (LH)	LH and RH parts can be avoided after suitable redesign
13	375 PH 02265	Tube string (RH)	
14	375 LL 31583	Cornet tooth (LH)	Both these teeth can be substituted with straight teeth
15	375 LL 31575	Cornet tooth (RH)	

11.6 PERFORMANCE MEASURES FOR THE PRODUCT DEVELOPMENT PROCESS

From the foregoing analysis of the product development process, it is possible to enumerate a set of measures to judge the performance of the product development process. Table 11.3 presents a representative list of possible measures that an organization could use for this purpose. Four sets of measures are proposed. Cost-based measures seek to relate the design effort to the cost incurred during the design stage and the cost after the design is utilized for production. The first two items in this list assess the cost impact during the design process, and the next two assess the impact after the design is approved.

Another set of measures pertains to the effectiveness of the design effort. There are several measures that an organization could use for assessing design effectiveness. Of particular interest are the measures “time to return to normal quality” and “the number of revisions in the design”. It is common that once the design is approved and the actual production begins, organizations experience certain difficulties and make revisions in the product design. Usually, a document known as the engineering-change notice (ECN) is generated for this purpose. Therefore, the number of ECNs is indicative of the design effectiveness. Depending on the effectiveness of the initial design effort, it takes more or less time for the ECNs to taper down to very few. Once it reaches this stage, it is reasonable to assume that the product has returned to normal quality requirements of an established product. It was found that in Japanese organizations such as Toyota, the time to return to normal quality was much less compared to their American counterparts during the early 1990s. This shows the effectiveness of the product development process in Japan.

TABLE 11.3 Performance Measures for the Product Development Process

Cost-based measures	• Target cost achievement status
	• Quantum of value engineering efforts
	• Cost of first production run
	• Cost overrun of product development project
Design effectiveness	• Percentage of standard parts and processes
	• Time to return to normal quality
	• Number of revisions in the product design
	• Cost of field repair/service during first year after introduction
	• Time overrun of product development project
Strategic measures	• Time to market
	• Concept to market
	• Number (or rate) of new products introduced
	• Percentage of new products in the overall product portfolio

Market impact	• Total product cost
	• Market share of the new product
	• Total product sales in the first two years after introduction

Strategic measures are also available for assessing the performance of a product development process. Popular among them are the “time to market” and the “number of new products introduced in the market”. You may recall that at the beginning of the chapter we showed how these measures are important and what benefits organizations get from these. The final set of measures pertains to the nature of the impact a product development process can create in the market. Product development efforts are primarily undertaken to improve an organization’s market share and overall positioning. Therefore, using some relevant measure to assess the product development process is a worthwhile effort.

11.7 MANAGEMENT ACCOUNTING TOOLS FOR PRODUCT DEVELOPMENT

Recent developments in the field of management accounting have helped the product development process in more ways than one. Researchers in the management accounting domain have shown that the final cost of products and services offered to customers is to a large extent determined at the design stage. Therefore, they have advocated ways and means of controlling them at that stage itself. Two concepts that management accountants have proposed are of great relevance to the product development process. These are life-cycle costing and target costing.

Traditional cost accounting and control concepts focus on the cost of products and services at the manufacturing stage. As opposed to this, **life-cycle costing** is a methodology that focuses on the cost and control aspects of a product or service throughout its life cycle. The life-cycle approach clearly means that the concept generation and design stage are also to be analysed for cost control purposes.

> **Life-cycle costing** is a methodology that focuses on the cost and control aspects of a product or a service throughout its life cycle.

Life-cycle costing studies point to an important aspect pertaining to controlling product costs. Figure 11.7 depicts this graphically. It is important to understand two types of costs over the life cycle of a product. The first one is the *committed cost* of the product. By *committed*, we mean that no matter when we incur the cost, the amount that we incur is fixed much earlier. For instance, the moment we finalize a design for a product, we will be able to estimate how much the cost of the product will be once manufacturing commences. This is simply because, at the time of design we fix all the required specifications with respect to the type and amount of material, labour, machines, and other resources to be used to manufacture one unit of the product. The second type of cost, *incurred cost*, denotes the actual cash outflow with respect to manufacturing the product. As shown in the figure, 95 per cent of the cost of the product is committed even before the first unit rolls out of the manufacturing facility. On the other hand, only one-third of the cost is actually incurred (in terms of the overheads pertaining to product development) before commercial production begins. This clearly brings out the importance of the product development process and the need to have a good monitoring and review mechanism during the early stages of product development.

FIGURE 11.7 Life-cycle costing: committed and incurred product costs

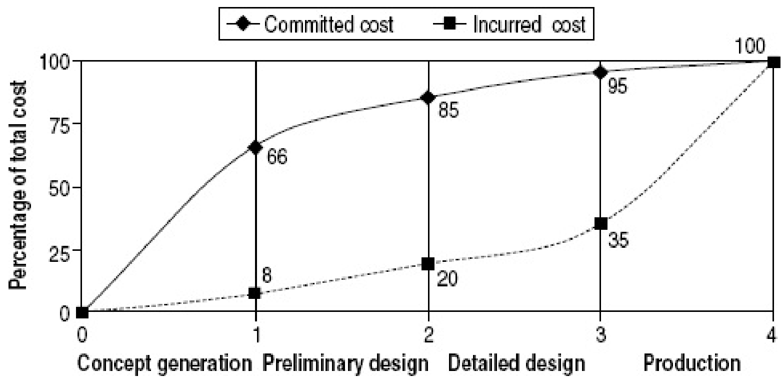
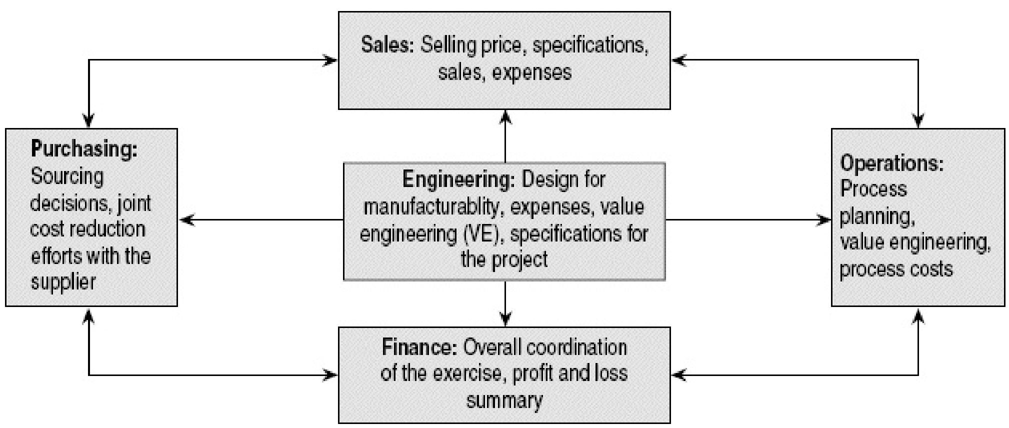


FIGURE 11.8 Target costing: role of different functional areas



Target costing is another useful concept for the product development process. Traditionally, organizations have been managing the cost of the products and services with a broad philosophy known as *cost-plus*. In a cost-plus approach to cost management, organizations incur certain costs for manufacturing a product or for providing a service. They add a desired margin to this to arrive at the price. In simple terms, Price = Cost + Margin. However, in recent times, as competition has intensified, organizations realize that market forces increasingly dictate the price a product or a service may fetch. Moreover, organizations require a certain margin to remain in business and continue to invest in new technology. Therefore, the equation is reversed in this scenario as Cost = Price − Margin. This would mean that in order to remain competitive in the market and continue to earn some margin; an organization has to keep its costs on target, as specified by the equation.

> **Target costing** is a methodology to identify cost reduction methods and pursue them relentlessly so that as the product is designed and manufactured, it is within the target set.

Target costing is a methodology and an organizational mechanism to identify cost reduction methods and pursue them relentlessly so that as the product or service is designed and offered, it is within the set target. Target costing promotes an interdisciplinary approach to product design as the inputs required to arrive at the target cost come from different functional areas. Further, the cost-cutting opportunities and methods by which this could be done also involve more than one functional area. Figure 11.8 shows the various functional areas involved in the process and the nature of efforts required to meet the target cost.

11.8 SOFTWARE PRODUCT DEVELOPMENT

The process followed to design, develop, code, test, and deliver a software product, from the inception of an idea to the delivery of the final software to the customer, is called software product development. Typically, a software development process consists of four stages: requirement analysis, design, development (coding), and testing.

> A software development process consists of four stages: *requirement analysis, design, development (coding)*, and *testing*.

Requirements analysis is the process of specifying requirements by studying user needs and systematically analyzing and refining the specifications. A specification, the primary result of requirements analysis, is a concise statement of the requirements that the software must satisfy. It has often been reported that deficient requirements analysis is a major cause of software project failure. On the other hand, identifying the exact requirements is the most difficult part of a software product development process. Traditionally, requirements analysis is done using a set of techniques such as interviewing, questionnaire surveys, and document searching, to elicit requirements from the customer.

After the requirements have been defined, the software development process involves various levels of design. *Design* produces a complete and precise specification of the software to be developed. The specifications define the principal parts of a software package, describe how these parts interact, and specify how they are integrated to produce the final software. A common problem in designing large software systems is the need to define the overall system structure before the team can specify other details. A principal benefit of teams is their potentially wide range of skills and knowledge. Another issue in the software design stage concerns the effective use of all team members' ideas.

During the *development* stage, the actual code is delivered to the customer as the running system is developed. In this stage, actual programs are written using programming languages. The output of this phase is an implemented and tested collection of modules. Coding is subjected to company-wide standards, which defines the entire layout of programs, such as headers for comments in every unit, naming conventions for variables and sub-programs, the maximum number of lines in each component and other aspects that the company deems worthy of standardization. Further, in the context of software development projects, there are standard methods of development available in manuals. Some of the development codes can also be referred from the organization's databases.

In the final stage of the software development process, all the modules that have been developed and tested individually are integrated and tested as a whole system. As *testing* is the last stage of the software development process, the team needs to ensure that the quality of the product is as per the customer's requirements. Thus, during this stage, the team needs to be focused and should have the goal of delivering a high-quality software product with minimum errors or problems. It should also ensure that the product is delivered to the customer on time.

Various software development process models are available. This includes the linear sequential model or waterfall model, the prototyping model, the rapid application development (RAD) model, the incremental model, the spiral model, the component model, and the concurrent development model.[14] From the description given here, it is clear that several similarities exist between the product development process and the software development process. For example, the major steps in product development are concept generation, design, development, and manufacturing (commercialization), while the steps in software development usually include system conceptualization and project definition, requirement analysis, design, programming, testing, and implementation. Thus, both new-product development and software development go through similar development stages and usually involve cross-functional teams. Moreover, similar external and internal factors influence the development process in both domains.

SUMMARY

- Operations management addresses the issue of innovation through the product development process. An organization armed with a good product development process can bring better products and services into the market ahead of the competition.
- The product development process consists of a structured and orderly set of activities including concept generation, design, development, and production.
- *Concurrent engineering* is an approach to build a cross-functional team of professionals cutting across various departments within an organization as well as the suppliers to accelerate the new-product development process.
- *Quality function deployment (QFD)* is a process by which the qualitative attributes of customer needs are translated into a bundle of quantitative attributes pertaining to design, process planning, and manufacturing specifications for products in an organization.

- *Design for manufacturability (DFM)* principles outline a set of guidelines that help organizations reduce variety and cost and improve the operational convenience of manufacturing while designing new products.
- Variety reduction through standardization, modular design and product platforms are the tools of mass customization.
- Management accounting provides tools such as target costing and life cycle costing for efficient new-product development.
- A software development process consists of four stages: requirements analysis, design, development (coding), and testing and delivery.

REVIEW QUESTIONS

1. How important is it to have a good product development process? What do organizations gain from this?
2. How will you determine if an organization does or does not have a good product development process in place?
3. Briefly sketch the product development process.
4. Is it prudent to exercise the same type of management control and evaluation for all the stages of a product development process? Explain and justify your answer.
5. Given below are three attributes of the management team working in a product development project. Explain which of these are appropriate at different stages of the project:

    a. Establishing norms for efficiency and productivity
    b. Promoting and nurturing creativity
    c. Encouraging speed of operations and demanding output

6. Why is a product development process analogously linked to a funnel with stages and gates?
7. Does the organization structure influence the product development process any way? Explain.
8. What, in your opinion, is the most appropriate organization structure for a product development process?
9. What are the alternative methods available to a product development team for generation of the concept for a new product?
10. What do you mean by quality function deployment? Of what use is it to the product development process?
11. How does the use of DFM guidelines help a product development process?
12. What is the relevance of mass customization principles to the product development process? What are the alternatives available to an organization to enable itself with mass customization?
13. How can the effectiveness of the product development process be measured?
14. Does management accounting play any role in the product development process? If so, how?
15. Compare and contrast the traditional product development process with the software product development process.

NET-WISE EXERCISES

1. Headquartered in Seoul, South Korea, Hyundai operates the world's largest integrated automobile manufacturing facility in Ulsan, which is capable of producing 1.6 million units annually. The company employs about 75,000 people around the world. Hyundai vehicles are sold in 193 countries through about 6,000 dealerships and showrooms worldwide.

    Visit their worldwide website at http://worldwide.hyundai.com/WW/Main/index.html. In the lower part of the page there is a header on innovation with three sub-links – Design, Technology, and Eco. Visit each of these links to get to know the context for Hyundai for new product development.

    Prepare a report on the context and business issues that Hyundai faces in the new product development process. Can you identify some broad directions in which Hyundai is taking forward its new product development process?

2. LG Electronics was established in 1958 and has since led the way into the advanced digital era thanks to the technological expertise acquired by manufacturing many home appliances such as radios and TVs. LG Electronics has unveiled many new products, applied new technologies in the form of mobile devices and digital TVs in the 21st century, and continues to reinforce its status as a global company. Visit their website at http://www.lg.com/in/design to understand their approach in bringing new products to the customers. Also visit their page on innovation by clicking on the web page http://www.lg.com/in/innovation.

   Prepare a two-page report on the overall approach of LG in bringing new innovations into the market. What are the various organizational mechanisms they have in place in order to fruitfully bring new products to the market? Have they been successful in their innovation efforts?

CASE STUDY

The New-Product Development Process at Energex

Energex is one of Australia's electricity, natural gas, and LPG retailers. It is leveraging its experience and expertise to develop and deliver innovative energy solutions to a marketplace that is undergoing significant change. Energex's customer base consists of more than a million commercial and domestic consumers. The company is committed to offering a broad range of energy options and is positioning itself as an innovative multi-fuel retailer. This strategy has put significant focus on its product development capabilities. Energex products today include domestic and commercial electricity, natural gas, and LPG supply.

Energex responded to the challenge of deregulation by creating Energex Retail, a fast-moving market-focused corporation that concentrated on developing and marketing energy-based products to commercial and residential customers. It recruited some of the best people in the industry so that it could act swiftly to meet the changing needs of the evolving energy market.

Typical of the innovative, high value-added new products is the company's energy monitoring programme (EMP). EMP packages hardware and software into one product, which monitors all energy inputs and costs, providing instant access to information on energy usage, power quality, billing verification, on-charging and greenhouse gas emissions. Managers usually have access to volumes of data but still lack quality information about one of their most critical operating costs—their energy consumption levels. EMP changes this situation.

The R&D team at Energex needed a product development process that would help them manage critical risk without slowing them down. Product managers and the product development manager were dissatisfied with the quality of "pre-development homework" and wanted improvements in the quality of product definition and specification before committing to the development of new products. Energex chose business consultants to help them develop its new process and tackle the shortcomings identified.

With the guidance of the CEO, the Energex team decided that a stage–gate based product development process was right for their business. With the help of a business consultant, they have tailored the stage–gate product development system to suit their managerial needs.

Energex has seen that process development by an empowered cross-functional team is crucial to long-term project success. Such teams must have the authority to make real decisions as well as the personal backing of the senior management team. Good senior management support speeds process acceptance and early success. Therefore the first step was to establish a process improvement team (PIT crew) comprising product managers, the product development manager, and representatives from finance, customer service and technical services. This team represented all the functional groups in the product development environment.

The initial plan was to involve the PIT crew in all aspects of process development, but after the initial training, it was obvious that this would be hard to achieve. Energex chose instead to use a more manageable development team consisting of a quality manager, two of the product managers and the CEO, with the original PIT crew's role being that of process reviewers, the review happening at least once every two weeks. It does however place more emphasis on training, and the core process development team should not just represent one functional group otherwise process buyin will be adversely affected.

Design of this pre-development activity and the associated gates should always take most of the time in a stage–gate implementation project—70 per cent or more of project budget is not uncommon. Conversely, most companies are very competent at actual technical product development, so effort can be minimized in those areas. In the case of Energex, during the development of the process, as much as 60 per cent of the PIT team's time was spent in refining the tools for product definition and the first two critical gates.

The modified approach was much more productive than the initial plan, and the draft of the new process was developed in about ten weeks from project commencement. The new process follows the classic stage–gate model closely and has been christened RAPID by the Energex PIT crew.

Many companies struggle with the design of their early gates: simple questions like "Is the product aligned to our strategy?" can engender hours of debate if a company doesn't have a clear, documented and communicated strategy. When it came to gate design, Energex was better prepared than most. Energex Retail had just completed a major strategic planning exercise, the outcome of which had been clearly documented and communicated to all staff. It was a relatively easy process to express this strategy as a series of "must meet" filtering questions and "should meet" project prioritization questions that would be well understood by all users of the RAPID process.

Implementing a good stage–gate process is about changing attitudes and behaviour in an organization. It needs to be sold and sold well, to internal and external stakeholders. It is all about getting a "buy-in." Depending on the organization's size and complexity, the launch should consist of education and practical hands-on training for users and gatekeepers (senior management), accurate and concise process documentation, a process brochure for those who needed to be aware of but not use the new process, and some appropriate form of launch event to let everyone in the organization know that the process was now real and alive. New employees should also be trained in the process.

Energex handled the launch of the new process effectively. All process documents were published on the corporate network, a colour promotional brochure on RAPID was produced for internal circulation, and a launch function for the new idea process was held along with training for all users of the process.

During the implementation of RAPID, existing projects were mapped to the process and a number of pilot projects were conducted. The senior management gate-keeping team has already welcomed the consistency of business cases produced by the new process, and some tough and appropriate project "kill" decisions have been made—freeing up valuable resources for the best projects. Energex is experiencing a smooth lead-up to product launch with less re-work during the hectic pre-launch stages. This is a direct result of better pre-development homework, better cross-functional teamwork and tighter project specifications.

Within Energex Retail, the CEO's team has embarked on a formal product portfolio management programme, ably supported by the RAPID process. Portfolio management is a strategic management tool designed to balance and focus resources to support the long-term aims of the company.

QUESTIONS FOR DISCUSSION

1. What was the need for Energex to go for a stage–gate model? Was it worth the effort for them?
2. What are the major benefits an organization can derive from implementation of a stage–gate model for new-product development?
3. Comment on the statement, "The stage–gate process is difficult to manage."

Source: http://www.innovation.lv/ino2/publications/leonardo_manual/en/www.innosupport.net/webhelp/wso/index.cfm@fuseactionlearnl_id3836pl_id3557.htm.

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CHAPTER 12

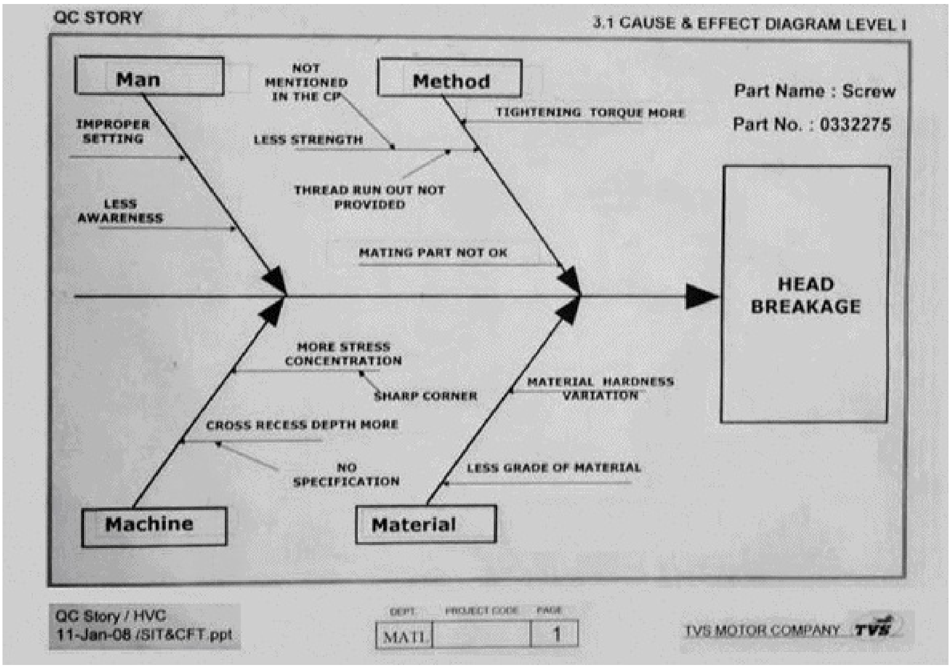
Total Quality Management

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- Who were the well-known quality gurus and what did they advocate for better quality management?
- How can we define quality? Are there implications for quality management when we change our definition of quality?
- What do we mean by total quality management (TQM)? What are the major components of a TQM system?
- What are the quality control tools used by organizations today?
- What are the well-known quality certification organizations and awards instituted today?
- What do you understand by the term “service quality”?
- What are the elements of a quality assurance system?

The fishbone diagram (also known as the cause–effect diagram) is one of Karou Ishikawa’s several contributions to the field of quality management. It is widely used in several manufacturing and service organizations worldwide for continuous quality improvement.



ideas at Work 12.1

Poka Yoke for Defect Prevention

Brakes India Limited (BIL) is a well-known manufacturer of automotive braking systems. BIL’s commitment to quality is evident from the fact that they won the Deming Award in 2003, as well as the other quality certifications that they have obtained. One of the methods they use for defect prevention and attaining parts per million (ppm) quality levels is poka yoke.

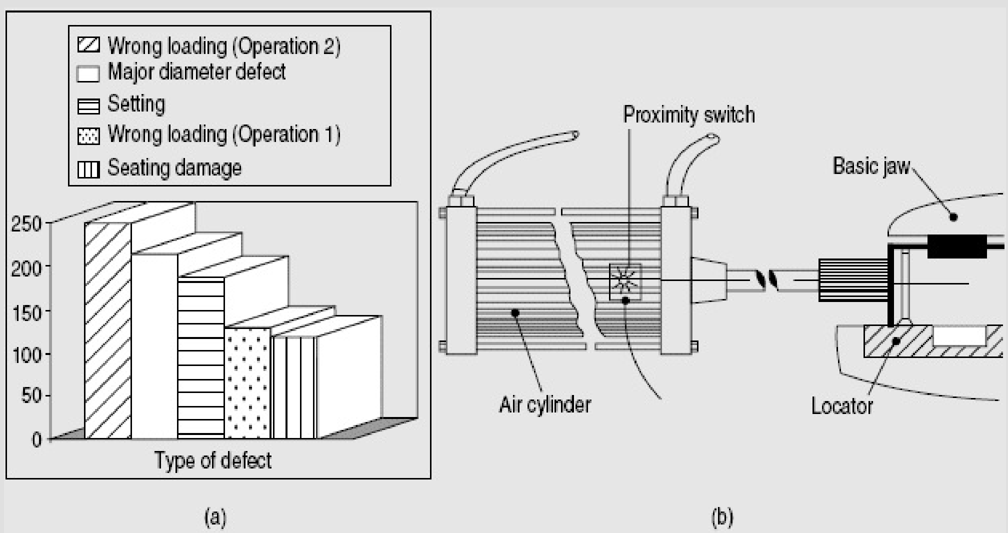
In their Sholingur plant, it was observed that the defect percentage in a particular process was higher than what was normally expected. The operators collected weekly data and used a simple system to classify the defects into various categories. Every week, an analysis of the data was done to identify high-defect areas. Wrong loading of the component for the second operation was the source of the problem (see Figure 12.1). After careful observation of the process, it was found that the existing operating procedure involved loading the component onto a chuck and using a hammer to gently hit the component to ensure that the chuck had firmly gripped the component. In the process, the worker was occasionally damaging one edge of the component due to fatigue.

Once this problem was identified, the process planning department developed a hydraulic mechanism that would perform the hammering. In the revised process, workers had to merely press a button which would activate the hydraulic mechanism to securely locate the component by hammering. By implementing this revised procedure, they eliminated defects arising out of the wrong loading of components.

Implementing this improvement brought down the defect levels significantly. Later, the group went on to identify more areas for defect prevention to bring the quality to the desired ppm levels.

Source: K. Sundar, "Poka Yoke and Continuous Improvement at Brakes India, Sholingur" (MPT Project Report. IIM Bangalore, 1995).

FIGURE 12.1 Wrong loading of the component for the second operation



Modern-day quality management is characterized by the use of several simple yet powerful tools such as those used by Brakes India Limited. It also requires that the employees participate in the improvement process and take initiatives that help the organization achieve superior quality in the long run. In this chapter, we shall look at various aspects of quality management. Globally, several organizations have adopted new quality management practices to compete effectively in the market.

The resounding success of several manufacturing and service firms in recent times has invariably been linked to excellent practices pertaining to quality management. If you consider the auto-component manufacturers in India, many of them have won the Deming Award for quality, the largest number outside Japan. Similarly, India has the largest number of CMM Level 5-certified software companies in the world. With such international recognition in quality, these two sectors of our industry were able to compete globally. In the past, firms such as Harley Davidson faced critical trade-offs while they made an effort to improve quality. For instance, providing a high-quality product would have meant higher cost, or compromising on flexibility or delivery commitments to the customer. However, successful firms like Kawasaki demonstrated that they need not make any trade-offs with cost or other performance attributes such as delivery and flexibility to offer better quality. On the other hand, they showed that it was possible to make significant improvements in quality and at the same time make the products or services available at a lower cost than that offered by the competition. Much of the success enjoyed by Japanese manufacturers during the 1970s and the 1980s is attributed to this phenomenon.

> The resounding success of several manufacturing and service firms in recent times was invariably linked to excellent quality management practices.

In this chapter, we shall see how traditional thinking on quality management has given way for an alternative known as total quality management (TQM). We will also see various components of a good TQM programme and the enabling mechanisms required for implementing a TQM programme.

12.1 THE QUALITY REVOLUTION

The success of Japanese manufacturing firms in the 1970s and the 1980s is largely attributed to a quality revolution sweeping across these firms. Japanese manufacturing firms penetrated established markets in the West by the sheer performance gaps that they created through the quality of the products that they brought to the market. Based on a study of air-conditioner manufacturers in both Japan and the United States during the early 1980s, David Garvin concluded that the best air-conditioner manufacturer in Japan brought the product to the market at a quality level 1000 times better than the worst manufacturer in the United States.[1] He further showed that the extra cost of making good-quality Japanese goods was much lower than the cost of fixing defective products made by the American manufacturers.

The quality revolution was possible because of new thinking on what constituted good quality and methods. Several new tools were utilized to assess the performance of an organization with respect to quality. Over time, several other tools helped organizations make sustained improvements in quality. At the same time, the top management realized the need for addressing certain mindset issues and providing a leadership role. The roles of middle managers and supervisors underwent a change from control to facilitation of the process of building quality into products and services. Workers were responsible for not only output but also quality.

Such improvements and wide-ranging changes did not happen all of a sudden. A rich repository of knowledge developed by several influential thinkers facilitated this process. Alternative definitions were coined for quality and people in organizations were trained in the new scheme of things. All these eventually led to the quality revolution.

12.2 QUALITY GURUS

The progress made in quality and productivity by organizations is mainly due to the teachings of quality gurus. Between 1950 and 1980, several people suggested alternative approaches to raise quality standards. Therefore, without knowing the salient aspects of these teachings, we may not be able to understand the current best practices in quality management. We shall focus on the teachings of some of the well-known quality gurus.

William Edwards Deming

William Edwards Deming is considered to be the father of the Japanese quality management systems. The Japanese owe much of their success in manufacturing to the teachings of Deming when he was in Japan from 1949–1958. In recognition of his contributions, the highest honour for excellence in quality management, the Deming Prize, is named after him. The Emperor of Japan hands over the Deming Prize to the winners of this award.[2] Several TVS Group companies from India are Deming award winners.

Deming's basic premise regarding quality management was that it is possible to provide good-quality products and services to customers at a much lower price and firms can operate profitably in the long run. He believed, however, that only good firms know this and the others were ignorant of this simple fact. In order to have a systematic approach to quality management, Deming proposed a four-step process, **plan–do–check–act**, popularly known as the **PDCA cycle**. He believed that every successful quality improvement and management programme would invariably follow the plan–do–check–act cycle of events. He proposed a 14-point agenda for quality improvement.[3]

> Deming proposed a four-step process, **plan–do–check–act**, popularly known as the **PDCA cycle**.

Joseph M. Juran

Juran visited Japan immediately after Deming and imparted to Japanese business executives the key principles behind quality management. Juran's approach to quality management complements that of Deming's. He believed that the quality problems faced by most companies are due the constraints imposed by the top management rather than by those at the operational level. Juran proposed a simple definition of quality—"fitness for use". This definition suggests that quality be viewed from both external and internal perspectives. The interdependency of these functions emphasizes the need for company-wide quality management. Juran also insisted that the senior management play an active role in the quality management process.

Juran emphasized the need for investing in superior quality systems, including a sound quality planning infrastructure. His approach to quality management focuses on three important aspects, known as **Juran's trilogy**:

- *Quality planning:* The process of preparing to meet quality goals
- *Quality control:* The process of making quality goals during operations
- *Quality improvement:* The process of breaking through to unprecedented levels of performance

> Juran's approach to quality management focuses on three important aspects known as **Juran's trilogy**: quality planning, quality control, and quality improvement.

Philip B. Crosby

Philip B. Crosby was the corporate vice-president for quality at International Telephone and Telegraph (ITT) in Japan for 14 years, after working his way up from the position of a line inspector. The essence of Crosby's quality philosophy is embodied in what he calls the "absolutes of quality management". The absolutes are:

- Absolute I: Definition of quality is conformance to standards
- Absolute II: The system of quality is prevention
- Absolute III: The performance standard is zero defects
- Absolute IV: Measurement of quality is the price of non-conformance
- Absolute V: There is no such thing as a quality problem

The five absolutes of quality provide a refreshingly different view on the issue of quality management. Crosby believed that the performance standard should be zero defects and hence popularized the phrase "do it right the first time". "Zero defects" implies that errors should not be expected or accepted as inevitable. Through a system of quality costing, Crosby provided a practical application of his absolute that measurement of quality is the price of non-conformance. Quality cost data are useful to draw the top management's attention to the problem, to select opportunities for corrective action, and to track quality improvement over time. We shall see in a later section of this chapter how the concept of quality costing can help organizations improve quality management practices.

> Crosby introduced the notion of zero-defect performance and hence popularized the phrase "do it right the first time".

Karou Ishikawa

Karou Ishikawa was the most prominent figure in Japanese quality management until his death in 1989. Dr Ishikawa influenced the development of a participative, bottom-up approach to quality management. He promoted greater involvement of all employees, from the top management to the front-line staff, reducing reliance on quality professionals and quality departments. He advocated collecting and analysing factual data using simple visual tools, statistical techniques and teamwork as the foundation for implementing quality. Amongst his several contributions, the fishbone diagram (also known as the cause– effect diagram) is widely used in several manufacturing and service organizations worldwide for continuous quality improvement. In a later section of this chapter, we shall discuss several quality control tools.

In a nutshell, Dr Ishikawa promoted the concept of company-wide quality. To help implement the philosophy of participation and to put the quality control tools to gainful exploitation in the hands of everyone in the organization, he developed quality control (QC) circles.

Ishikawa promoted the concept of company-wide quality through use of quality control (QC) circles. He also proposed the fishbone diagram to analyse quality problems at the workplace.

Shigeo Shingo

Shigeo Shingo's primary contribution to quality management is to suggest an approach for complete elimination of errors. He developed a systematic approach to understand why errors creep into any operation. Further, he devised a method to completely eliminate such errors over a period of time. In this manner, Shingo provided an operational angle to achieving zero defects, as proposed by Crosby. This method is called **poka yoke** or mistake-proofing. The idea is to handle errors as they occur. Since identifying the errors is vital to the success of poka yoke, it must be carried out rigorously and thoroughly. Once an error (or a defect) is found, a detailed analysis is done to understand what caused the error. Based on the analysis, alternative methods are identified to eliminate the cause once and for all.

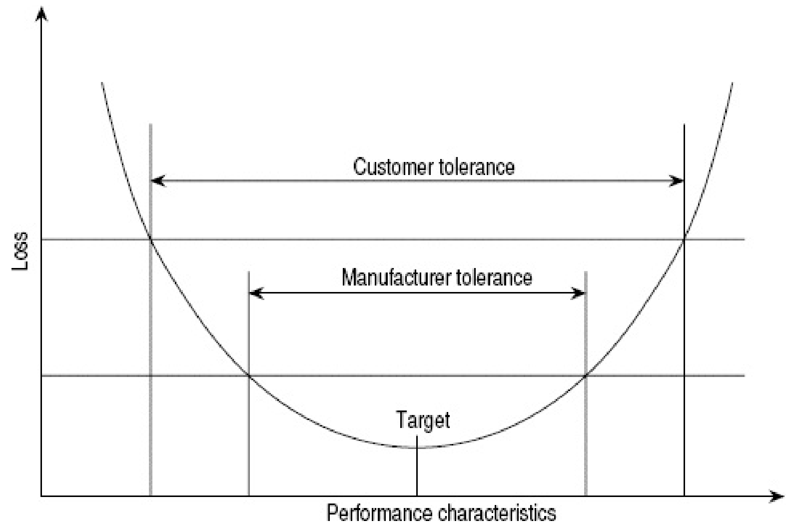
Shigeo Shingo proposed a method called **poka yoke** or mistake-proofing for eliminating defects once and for all.

Genichi Taguchi

Taguchi's focus was on achieving quality by reducing variations in processes. His approach is based on the basic premise that variations in processes eventually manifest as variations in the quality performance of the product or service. Therefore he advocated the need to keep the variations in the processes under control. A different method of measuring quality, the *loss function*, is central to Taguchi's approach. The loss function measures quality. A schematic representation of the loss function is given in Figure 12.2.

Taguchi proposed a three-stage approach to the design process: **systems design, parameter design**, and **tolerance design**.

FIGURE 12.2 A schematic representation of Taguchi's loss function



As shown in the figure, the loss function establishes a financial measure of user dissatisfaction with a product's performance as it deviates from a target value. The loss function captures the extent to which a process goes off target. Minimizing the loss calls for controlled experimentation in the process and setting up of various process parameters. Taguchi proposed detailed procedures for the design of experiments that must precede setting various process parameters.

12.3 DEFINITIONS OF QUALITY

The quality gurus provided alternative approaches to build quality into the products and services that a company offers. The critical differences in their approaches stem from their definition of quality. For instance, Deming's emphasis on process improvements and use of statistical process control charts (SPC) clearly point to a definition of quality that is linked to specifications.[4] On the other hand, Taguchi's loss function or Juran's notion of "fitness for use" extends the definition of quality to a larger domain. Therefore, it is important to understand the various definitions of quality and the implications of these alternative definitions.

Conformance to Specifications

The easiest definition of quality is conformance to specifications. This definition focuses on the manufacturing process and motivates the quality manager to develop mechanisms for ensuring that specifications are met with. Every component of a manufactured product has specifications. As long as the specifications are met, it is assumed that quality objectives are met with. Such a definition is very crucial for a manufacturing firm as it enables the management to develop unambiguous instructions for the worker on the shop floor to maintain quality. Just as we have specifications for products, specifications for services can also be developed. For instance, in a hotel, one could set a specification that check-in of arriving guests should be done in 3 minutes ±

30 seconds. Or, in a bank, the time for servicing a customer at the teller's counter could be specified and the process monitored and controlled to meet this specification.

Fulfilling Customer Needs

In the previous definition of quality, we made an important assumption that the specifications are right. Consider a two-wheeler such as the Kinetic Nova. Let us assume that the specifications include an overall weight of 115 kg, a height of 42 inches, and so on. If the manufacturing process is able to ensure that the scooters manufactured meet these specifications, have they met the quality objectives? The answer depends on whether they met the customer needs: If the customers have felt a strong need for a lighter scooter (less than 95 kg), with moderate height (less than 40 inches) then perhaps the scooter is not of good quality. Therefore, this definition of quality focuses not merely on the manufacturing process but also on the process of arriving at the specifications themselves. It emphasizes the need to have a system of collecting information regarding customers' perceptions about the product and preferences before the specifications are arrived at.

Fitness for Use

Quality can also be defined as "fitness for use". Such a definition of quality demands that an organization understands the preferred methods of use by prospective customers over an extended period of time. In order to develop this understanding, an organization needs to focus on customer relationships, the design, and the manufacturing processes. A variation of this definition is minimizing the loss to society. This definition of quality emphasizes a life-cycle approach to building quality. Ensuring quality in this manner also demands that considerable efforts are made at the concept and design stages of a product.

> An alternative method to define quality is to understand the various dimensions of quality. Garvin proposed that quality has eight dimensions.

An alternative method to define quality is to understand its various dimensions. Garvin proposed eight dimensions for quality:[5]

- *Performance*: The customer expects a certain level of performance from a product. It relates to the operational characteristics of the product. An industrial cooling application, for instance, requires that the fan be operational for a certain duration, without stopping at a particular temperature.
- *Features*: In addition to meeting the basic performance requirements of the product, features provide additional attributes that enhance the quality.
- *Reliability*: The expectation that the product will perform satisfactorily for a period of time is known as reliability. For instance, if a two-wheeler performs without any major repair or maintenance for five years, it may indicate a certain level of reliability.
- *Conformance*: Meeting the specifications and standards of design.
- *Durability*: How long the product lasts before it requires a replacement. Clearly, durability and reliability are related.
- *Serviceability*: The ease with which the product can be serviced.
- *Aesthetics*: Customers also value the aesthetics of the product. One can relate this idea to the various feel-good factors

that a customer evaluates before making a choice of, say, competing brands of passenger cars.

- *Safety*: Safety aspects denote the assurance to the customer that there are no hazards in using the product.
- *Other perceptions*: Customers may also have a host of subjective perceptions such as brand name, image, impact of advertising, etc. in his/her assessment of quality.

Irrespective of the nature of definitions, there are some important implications for quality managers:

- *Quality is both qualitative and quantitative*: Attributes of good quality are 100 per cent quantitative on the shop floor. A process engineer cannot ensure quality if the specifications of the product and the processes are ambiguous. On the contrary, on the ultimate customer side, attributes of good quality are 100 per cent qualitative. Customers usually recognize good quality, not by a set of attributes, but by experience and intangible issues. Thus, a customer using similar products from two competitors will find it much easier to rate one to be of better quality than the other. However, if you ask the customer to articulate clearly the attributes that made him/her conclude why one product was better than the other, he/she may have difficulty. Therefore, a good quality management system should enable the manager to understand the qualitative attributes that influence a customer, and have a method of translating these into unambiguous quantifiable parameters for design and manufacturing. The critical success factor lies in handling this challenge.
- *Changing definitions*: The definition of quality appears to be constantly changing over time. While it reflects the need to keep up with changing ground realities, the implication for organizations is to constantly invest in new capabilities and skills.
- *Quality is a moving target*: The operational aspects of the zero-defects measure of quality clearly demonstrate that quality is a moving target. For instance in their journey towards zero-defect status, organizations may change their measure of quality initially from percentage of defects to parts per million, and later to parts per billion. In such a scenario, how are organizations going to keep up their employees' enthusiasm in meeting the targeted quality standards? The implications for organizations are that there are mindset issues to be addressed in achieving a good quality management programme.

12.4 TOTAL QUALITY MANAGEMENT

The culmination of the discussions in the previous sections is the notion of total quality management (TQM). Modern quality management systems are built on the concept of TQM. **Total quality management** can be defined as an organization-wide effort to develop the systems, tools, techniques, skills, and mindset required to establish a quality assurance system that is responsive to emerging market needs. Such an effort will provide distinctive advantages to a firm and will enable it to compete effectively in the market. A good TQM programme consists of the following important elements:

a. Role of the top management
b. Employee involvement for continuous improvement
c. Addressing the training requirements of employees
d. Tools and techniques for quality assurance and continuous improvement

> **Total quality management (TQM)** can be defined as an organization-wide effort to develop the systems, tools, techniques, skills, and mindset required to establish a quality assurance system that is responsive to emerging market needs.

Commitment of Top Management

Total quality management calls for radical changes in the thinking among employees. First, the term "total" connotes "everyone", "everywhere" and "every time". Implementing this simple slogan is not an easy task. Involving everyone means that right from the CEO down to the lowest level employee in an organization, all must play their role in quality assurance. This would require that all employees have role clarity with respect to quality matters. In the traditional method, production workers were not expected to worry about quality. Their job was to engage in jobs allotted to them and take care of their productivity bonuses and earnings. The quality control department would assess quality and initiate the required actions, should there be a quality problem. In the TQM philosophy, the responsibility for quality shifts to the production workers.

> The term “total” in total quality management connotes “everyone”, “everywhere”, and “every time”.

Similarly, in the past, middle managers and top managers played the role of controllers. They directed improvement efforts and established tight controls and supervision to ensure that quality goals were met. On the contrary, in TQM, the focus shifts to one of facilitating the production workers in their efforts towards producing quality goods and services. This calls for a certain shifting of process ownership to the workers and their supervisors. The success of the TQM programme depends on how well this transition is made.

The notion of “every time” puts a different pressure on the traditional methods of operations. There is a greater degree of intangibility and uncertainty with respect to outcomes in the long term. On the other hand, short-term goals and benefits are like low-hanging fruits. They are not only easily reachable but also tangible. Managers are averse to working for long-term benefits and tend to compromise on them in order to post impressive performances in meeting short-term goals. If, for some reason, there is a quality problem in the production line, the manufacturing managers will choose to ignore it and continue to produce. When quality control rejects the components, they could be reworked later. Therefore, the top management has to play an important role in ensuring that “every time” is followed in letter and spirit. This may call for leadership and guidance in minimizing conflicts between short-term and the long-term goals.

Nothing is taken seriously when employees in organizations come to know that the changes do not have the top management’s involvement and commitment. This is a significant aspect of the management of change. The top management also needs to play a vital role in communication. They should not miss even a single opportunity that comes their way to demonstrate their support and involvement in the TQM implementation process. Moreover, issues pertaining to “everyone” and “every time” require clear directions and a leadership role from the CEO of an organization. Only then can the TQM process get a fair chance at success.

ideas at Work 12.2

Quality Policy in Some Organizations

GE Healthcare
Quality and continuous improvement are part of our culture, it is embedded in our processes, our recruitment, and our training. We take responsibility for the projects we execute, for maintaining the operation of the products we deliver, and for the traceability required by the authorities.

Hero Honda
Excellence in quality is the core value of Hero Honda's philosophy. We are committed at all levels to achieve high quality in whatever we do, particularly in our products and services that will meet and exceed customer's growing aspirations through:

- Innovation in products, processes, and services.
- Continuous improvement in our total quality management systems.
- Teamwork and responsibility.

Sasken
Achieve excellence through commitment and innovation surpassing the expectations of our customers. In this endeavor, we shall

- Set up and implement world-class systems and processes
- Sensitize and raise our quality consciousness
- Continuously strive for improvements to make quality a way of life
- Meet all applicable environmental, health, and safety standards and demonstrate corporate citizenship on an ongoing basis

Sources: http://www.gehealthcare.com/euen/hospital_solutions/quality_certification.html; http://www.herohonda.com/co_policy, htm#qp; and http://www.sasken.com/aboutus/quality.html, accessed on 25 December 2008.

A well-defined quality policy serves to signal the seriousness of an organization and the nature of its commitment to various stakeholders in the system. Therefore, the first step in launching a TQM programme pertains to stating a quality policy. Many Indian organizations have recently set forth their quality policies and have communicated it to all their stake-holders. It is not surprising that the top management takes a major responsibility in this process and thereby steers the TQM programme. They help establish an unambiguous quality policy and communicate it to all employees in the organization.

Employee Involvement

Shifting the responsibility of quality management to the workers must be accompanied by the necessary organizational changes enabling the employee to take on the responsibility. The important change is process ownership by the employee. **Process ownership** is the transformation of the role of employees from the function of merely accomplishing the assigned tasks related to a process to one of thinking through the various aspects of the process and taking on a conscious role in the overall management of the process.

> **Process ownership** is the transformation of the role of the employees from a mere function of accomplishing the assigned tasks to one of taking a conscious role in the overall management of the process.

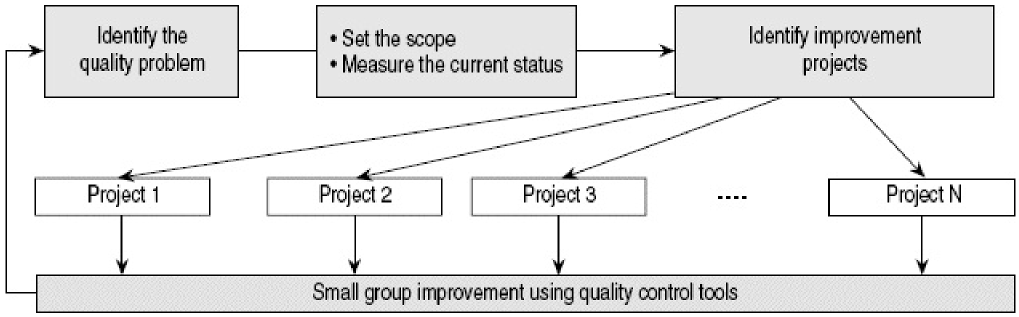
Consider two alternative roles for employees. In the first case, the employee will be merely focusing on producing a component using a machine. Maximizing production (and thereby the productivity bonus) may be of interest to the employee. The employee may not be motivated to maintain cleanliness in the working area or ensure good maintenance of the machine and other resources. Further piling up of inventory and problems related to the quality of the component are not his concern. There may be separate specialists to attend these problems.

In the second case, in addition to the production, the employee will have the ultimate responsibility of maintaining all the aspects of the processss. He will be responsible and accountable for all local issues pertaining to the process. This manner of relating to the entire process builds a sense of ownership in the employee and makes him/her get involved more intimately in the process. Employees eventually tend to take a greater interest in the overall improvement of the process, leading to better quality of the product. Therefore, employee involvement is an important aspect of TQM.

Employee involvement invariably requires employee empowerment. Employees must be allowed to take decisions pertaining to stopping the line when quality problems surface and they need mechanisms to work in small groups to make continuous improvements in the process. Each employee must also be able to improve the housekeeping of the resources in his/her work area and improve the upkeep and maintenance of machines and other resources. These require several organizational and procedural changes in the organization.

The other aspect of empowerment pertains to equipping employees with the required skills and tools for managing quality. Figure 12.3 shows the normal steps involved in quality improvement through a series of projects done in small groups. In order to be problem solvers, employees need problem-solving tools. They need to be trained in the required quality control tools. Small group improvement projects are the basic building blocks of a TQM programme for improving the quality over a period of time. This calls for a set of skills oriented towards working in a team; in other words, interpersonal skills to work with fellow employees. Moreover, employees need better communication skills to deal with one another in a group and with their subordinates and supervisors. Therefore, addressing these training needs is an important component of the TQM implementation process.

FIGURE 12.3 Quality improvement through small group improvement projects



Addressing Training Requirements

Successful TQM programmes demand substantial investment in communication. The top management is first educated regarding the need, the required changes and the potential benefits. The process then continues, until the lowest level in the organizational hierarchy is reached. The top management should be aware of the impending changes and the benefits. Only out of such an understanding can there be involvement and support in resolving conflicts that arise during the implementation stage. Middle-level managers often form part of the team of change agents. Moreover, changes may result in some of them giving up their traditional role of control over their subordinates. They need adequate exposure and clarity in the required changes, failing which they become insecure and try to stonewall the efforts. The workforce, the union, and the supervisors as well as the staff and managers belonging to the manufacturing-support and non-manufacturing areas should be appraised of the nature of changes and the potential benefits.

Communicating the need for alternative procedures, new methods of empowerment, and the benefits that are likely to accrue to the organization is just one aspect of training. The other aspect relates to educating all the employees in using the new quality control tools and techniques to be adopted for quality management. At the operational level, several new quality control tools are available. Employees need to be trained in using these tools. Supervisors require training in problem-solving approaches and working in small group improvement teams. Supervisors and the middle managers require several new skills for setting up a good quality management system at work. These include the following:

- Identifying problem areas
- Setting targets for improvement
- Participating in the improvement process
- Facilitating the process owners and monitoring and guiding them over time

12.5 QUALITY MANAGEMENT TOOLS

The greatest strength of a quality management system such as TQM is the emphasis laid on using simple yet powerful tools for tracking various aspects related to quality management. Over the years, several QC tools have been developed. These tools are widely applied in practice too. The QC tools fall under five broad categories. Table 12.1 has a description of these categories and the tools available in each category.

Let us take a look at the categories of tools discussed in the table:

- *Tools for highlighting quality problems*: These tools bring impending quality problems in a process to the attention of the operational personnel and alert him/her to the issue. The most commonly used tool is the process control chart. By carefully selecting a set of important process parameters, it is possible to set up a continuous monitoring system using statistical principles to identify when the process is likely to go out of control. An out-of-control situation points to deteriorating quality in the process. It triggers closer observation and further analysis to nip the problem in the bud. A detailed description of process control charts is available in Chapter 18.
- *Tools for identifying specific improvement opportunities*: Once an impending quality problem is brought to the attention of the concerned supervisor, manager and the employees involved in the work area, additional tools are required to zero in on the exact problem. This could be done by collecting some additional data, systematically plotting the data and analysing it. Several tools are available to perform this task. The most popular among them include check sheets, histograms, and pareto diagrams. Using these tools, it is possible to locate exactly where the problem lies.
- *Tools for analysing problems and their root causes*: The next step in quality assurance is to conduct a systematic analysis of the problems and their root causes. Only when the root causes are known can solutions be found for the elimination of the problem. The most popular tool used in this category is the cause and effect diagram (also known as fishbone diagram) and a variation of it known as the cause and effect diagram with action card (CEDAC).

Quality management tools available tools fall under five broad categories:

- Tools for highlighting quality problems
- Tools for identifying specific improvement opportunities
- Tools for analysing problems and their root causes
- Tools for operational planning
- Tools for strategic planning

TABLE 12.1 Tools and Techniques for TQM

Purpose of the Tool	Quality Control Tools6	Management Tools
Highlighting problems	• Control charts	
Identifying specific improvement opportunities	• Histograms • Check sheets • Pareto diagrams • Scatter diagrams • Graphs	
Analysing problems and their root causes	• Cause and effect (Fishbone) diagram • CEDAC	• Affinity diagram • Relationship diagram
Operational planning for building quality into products/services		• Tree diagram • Matrix diagram • Matrix data analysis • Process decision programme chart (PDPC) • Arrow diagram • Poka yoke

Strategic planning		• Quality function deployment (QFD) • Quality costing

These categories are tools for operational control. Once a quality problem manifests, these tools help in recognizing it and identifying the root causes. Once the causes and remedies are identified, it is possible to rectify the problem. However, a good quality management system also requires tools for planning purposes. Some of the improvement methods discovered while using the quality control tools can be permanently incorporated into operations in the future. Therefore, the use of quality tools that help prior planning minimizes the occurrence of quality problems during operations. Two categories of planning tools are advocated in TQM.

- *Tools for operational planning*: Operational planning tools pertain to prior planning done to minimize quality problems in operations. For instance, if some mistake-proof methods are incorporated in the system, it results in complete elimination of the problem.
- *Tools for strategic planning*: The strategic tools help an organization link the quality management initiatives to the requirements in the market place and provide overall direction for operational planning and improvement activities. Two popular tools in this category include the quality function deployment (QFD) and quality costing.

We shall now at some of these tools in greater detail.

Histograms[7]

The **histogram** is a simple method of graphically representing the frequency distribution of multiple attributes of interest. Based on a simple count of the number of occurrences of each attribute, a histogram can be constructed. In a manufacturer of earth moving equipment a study revealed that poor quality resulted in various snags in the assembly plant.[8] Due to a large number of adjustment snags, the throughput time was much higher. The data and the accompanying graph in Figure 12.4 shows the various causes for adjustment snags.

> A **histogram** is a simple method of graphically representing the frequency distribution of multiple attributes of interest.

The value of a histogram lies in its ability to graphically portray the various causes pertaining to the problem as well as the magnitude of these causes. Clearly, employees would like to focus on major problem areas and initiate further data collection to understand why problems occur in those areas. For instance, in this example, problems due to reworking are very significant. Therefore, employees would like to know more about the causes of such problems.

Pareto Diagrams

The process of data collection helps to understand where the problem lies and what the nature of the problem is. Using this information, it is easy to identify which aspects need improvement. The difficulty, however, is deciding where to start the improvement process. A **pareto diagram** is a method by which clear-cut priorities are established for directing the improvement efforts. Moreover, it helps organize the basic data in a systematic manner such that the improvement team detects the significant aspects of improvement and initiates necessary corrective actions.

> A **pareto diagram** is a method by which clear-cut priorities are established for directing the improvement efforts.

Let us look at the histogram shown in Figure 12.4 in an alternative fashion by plotting the data in decreasing order of occurrence. The revised histogram is presented in Figure 12.5. The revised representation of the histograms clearly establishes priorities for improvement. In the case of adjustment, snags, reworks, leakages and missing components are important elements that require immediate attention.

Cause and Effect (Fishbone) Diagrams

The earlier tools help to decide where to focus the improvement efforts for reducing defects. However, they do not point to the root causes of the problem. The **cause and effect diagram**, or the **fishbone diagram**, is a generic methodology developed to trace problems to their root causes. Since a total elimination of the problem requires understanding the root causes of the problem, this technique is vital for quality improvement.

> The **cause and effect diagram**, or the **fishbone diagram**, is a generic methodology developed to trace the problems to their root causes.

FIGURE 12.4 Histogram for the causes of adjustment snags

Causes for adjustment snags	Number of occurences
Leakage	250
Missing components	240
Fouling	50
Reworks	260
Poor routing	50
Loose filling	150

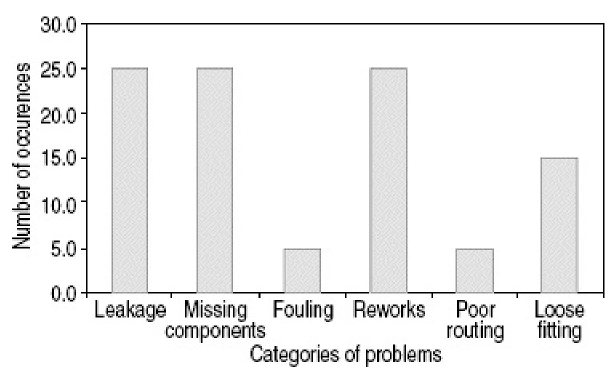
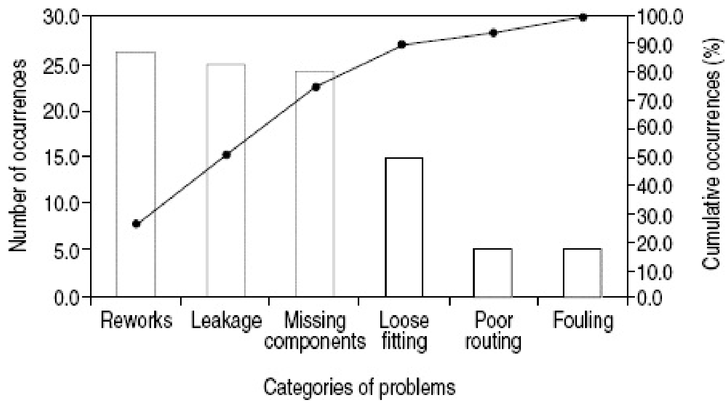


FIGURE 12.5 A pareto diagram for the causes of adjustment snags



At a more general level, a cause and effect diagram has a structure similar to that shown in Figure 12.6. The technique is based on the assumption that good or bad quality is on account of various causes pertaining to the process. Typically, the causes are due to the choice of material, work method, and equipment used as well as the impact of labour practices. A fish-bone diagram helps the quality improvement team to analyse problems in a structured manner and identify the root causes.

The cause and effect diagram is a very useful tool for problem solving in the small group improvement efforts that an organization wants to pursue. The tool enables members of the group to engage in a group discussion. Based on the discussion on each component of the fishbone diagram, it is possible to identify a set of potential causes for the problem. Organizations typically use the right side of the fishbone diagram to set the target for improvement. For example, in the case of Figure 12.6, we may like to set a target of 100 parts per million defects as the objective for the exercise and direct improvement efforts towards this.

CEDAC

A variation of the cause and effect diagram is CEDAC.[9] In this, the "AC" stands for "action cards". In the cause and effect diagram, there is a fishbone structure and the members of the small group improvement activity need to discuss on the problem, causes and solutions. On the other hand, in the case of CEDAC, this entire process is left open to all employees of the organization by adding two sets of cards to the fishbone. One set of cards is known as the *problem cards* and another set is known as the *solution cards*. By placing a visual board with the fishbone structure and problem and solution cards in two separate bins alongside the board, CEDAC enables any employee to contribute to problem solving. Normally, the problem and solution cards are colour-coded for easy identification. Figure 12.7 shows one such CEDAC system that was implemented as part of a study in an automobile braking system manufacturing plant in India.

> A variation of the cause and effect diagram is CEDAC. In this, "AC" stands for "action cards".

FIGURE 12.6 A generic representation of a cause-and-effect diagram

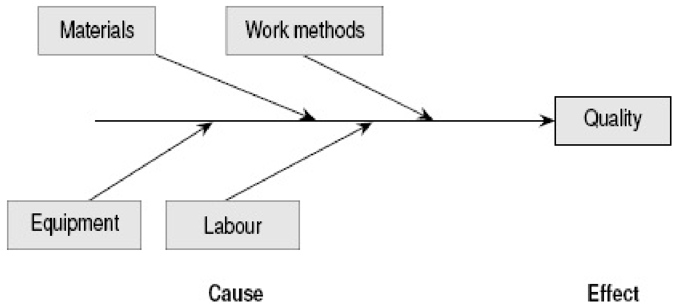
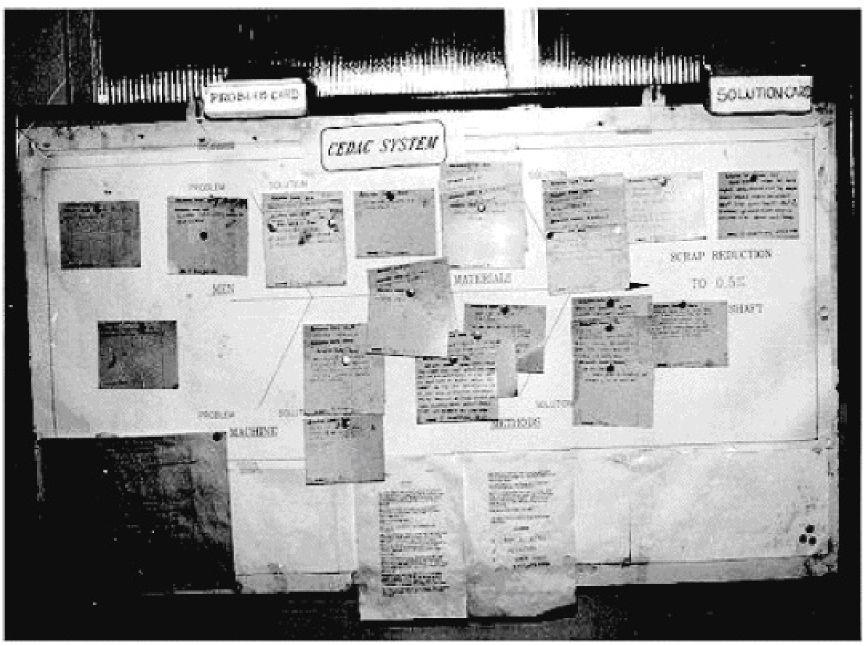


FIGURE 12.7 An example of CEDAC implementation



The implementation works as follows. Any employee who thinks that he/she knows what the problem or solution to the problem could be will pick up an appropriate card. He/she will then write his/her suggestions and affix it at the appropriate leg of the fishbone. Figure 12.7 is a snapshot of the status of the board after a week of its installation. Even in such a short period of time, nearly a dozen problem cards and another dozen solution cards have already been affixed to the board. It is clear from this example that the CEDAC system establishes an atmosphere of continuous improvement. It enables all the employees in an organization to make full use of their accumulated knowledge and experience. Furthermore, it helps change the organizational culture by empowering people to fully participate in the continuous improvement process.

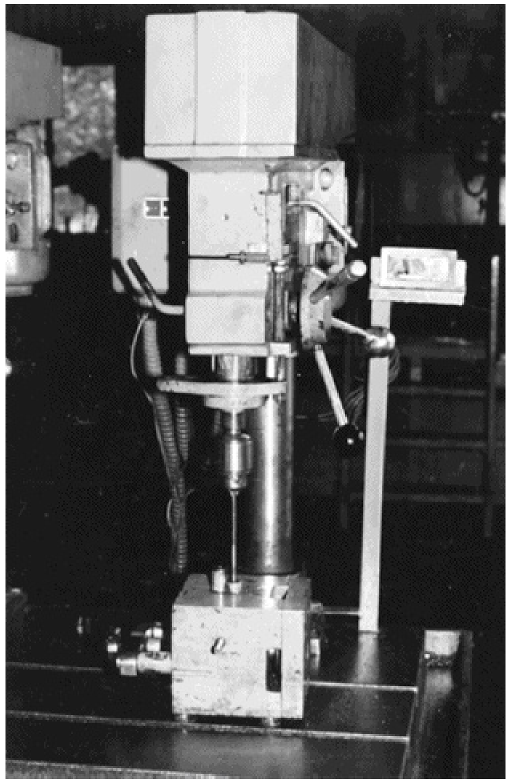
Poka Yoke

Poka yoke is a Japanese term for “mistake-proofing of operations”. Shingo proposed this method while he improved the Toyota Production System. The basic principle behind this method is that several defects that creep into an operation are usually avoidable. Errors and defects have a cause and effect relationship. If inadvertent errors in any process are not recognized and methods are not established to eliminate them, they will eventually manifest as defects. Only by a careful scrutiny of the process is it possible to identify the root causes of the defects. The root causes could then be completely eliminated by redesigning the operations and incorporating methods by which the process will not allow the errors to happen in the future.

Poka yoke is best explained with an actual example. Consider a component manufactured by an automobile component manufacturer that requires a through hole to be drilled using a hand-operated drilling machine.[10] If the worker operated the hand drill imperfectly, it is likely that he/she would not have traversed the drilling tool till the very end. Consequently, a through hole is not drilled. It may appear as though such errors are unlikely to creep into a manufacturing system. However, in reality, when a large number of pieces are produced, workers tend to commit such mistakes out of sheer mental and physical fatigue. In the auto-component manufacturing firm, the defect was found at a much later stage, during assembly.

When the worker at the assembly section wanted to insert another component he found that there was no hole (since the component is not drilled right through). Discovering this at this stage meant tearing down the assembly to remove the component and replacing it with a good-quality component. This resulted in considerable loss in productivity and added to the cost. One way to avoid this simple quality problem is to undertake mistake-proofing in the drilling process so that imperfect drilling of a component is completely avoided. Figure 12.8 shows the new arrangement.

FIGURE 12.8 Defect prevention through operations planning



ideas at Work 12.3

Matrix Diagram for Enhancing the Competitiveness of a Product

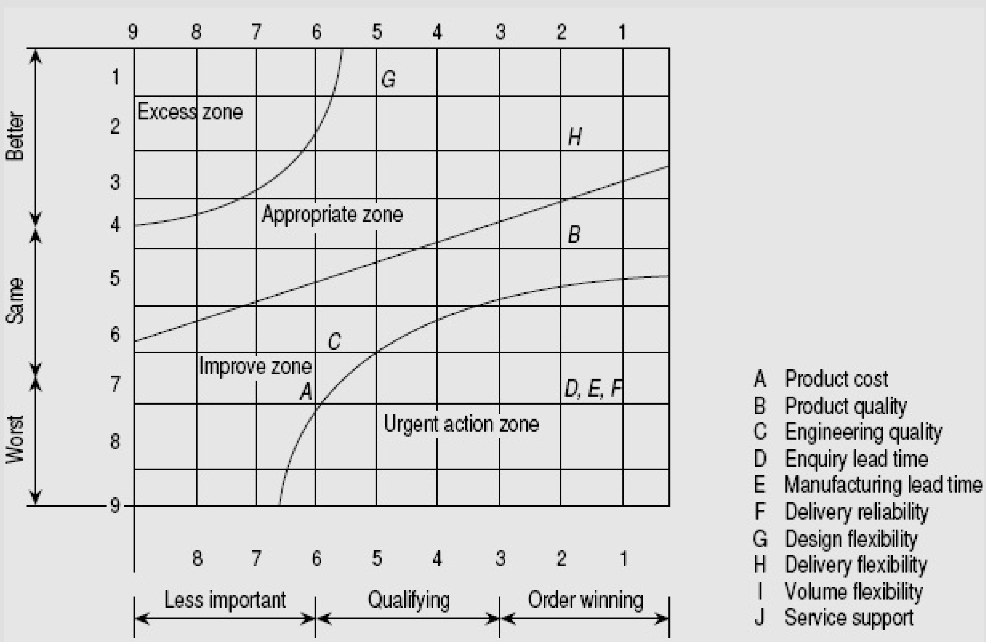
The matrix diagram is one of the quality management tools used in operational planning and for building quality into products and services. In a typical matrix diagram method, a two-dimensional matrix is constructed to analyse the quality problem and identify areas that require further improvement. Once the two dimensions of the matrix are identified, the relevant data is collected and represented in the matrix diagram. The visual method helps the management to easily identify areas that require improvement and to focus their efforts.

Several years ago, Hindustan Motors, a manufacturer of earth-moving equipment, undertook an improvement project to enhance the competitiveness of one of its products, the Hindustan 1035N dumper. The first step in this process was to identify key areas that it needed to improve vis-à-vis its competitors. Once Hindustan Motors was clear about the areas that required improvement, it was easier to focus improvement efforts through a small group “project-by-project” approach. The use of the matrix method came in handy for this purpose. To construct the matrix diagram, the two dimensions were first identified. On one dimension, the product attributes valued by the market were categorized as less important, order-qualifying, and order-winning. On the other dimension, the performance of 1035N Dumper vis-à-vis the competing products was classified as worst, same and better. Ten attributes were identified and for each attribute a 9-point scale was developed to rate the 1035N dumper along both these dimensions. Using this scheme, a matrix diagram was constructed (see Figure 12.9 for details).

Based on this analysis, it was found that four attributes required immediate action. These included enquiry lead time, manufacturing lead time, delivery reliability and volume flexibility. Further analysis clearly showed that in order to enhance the competitiveness of the product, throughput time reduction was very important. Based on this analysis, some throughput-time reduction exercises were taken up.

Source: N. Ravichandran, "A Framework for Creating Competitive Advantage Through Throughput Time Reduction" (MPT Report, Indian Institute of Management, Bangalore, 1996).

FIGURE 12.9 A matrix diagram to identify improvement opportunities



In the new arrangement, there is a pair of sensors controlling the hand drilling process. While the sensor at the top activates the forward movement of the handle, the sensor at the bottom activates the return path for the handle. Once the worker begins the forward movement of the spindle, there is no way he can retract the spindle, except by the activation of the lower sensor. In this process, it is ensured that a through hole is drilled. By incorporating these features in the process through prior planning, quality is built into the product.

Quality Function Deployment

Quality function deployment (QFD) is a tool developed to address these requirements.[11] It is a technique introduced in Japan by Yoji Akao in 1966 and used extensively by Toyota. According to Akao, QFD "is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase."[12] The technique aims to capture what the customer needs, and link it to operations to ensure that it is achieved.

Based on a set of structured information-gathering processes, QFD helps an organization to capture the qualitative attributes of the quality as perceived by customers, and translate them into meaningful quantitative measures. Once this transition is made, their functional aspects are deployed at various levels and control systems are established to monitor the extent to which these are effectively deployed.

> Based on a set of structured information gathering, QFD helps an organization to capture the qualitative attributes of the quality as perceived by the customers and translate them into meaningful quantitative measures.

QFD utilizes a set of four "houses of quality". Each house of quality captures certain information and uses a structured methodology to translate customer needs to actionable ideas and quantifiable attributes pertaining to the product/service. Figure 12.10 is a broad representation of the four houses. As is clear from the figure, during each stage of the process, specific details are culled out of the basic understanding of customer needs. In the first stage, design attributes are arrived at. During the second stage, the design attributes are linked to actionable items. The actions identified in the second stage are the basis for the third stage in aiming at specific decisions to be implemented. Finally, in the last stage, specific details pertaining to each process parameter are arrived at. The four houses are sequentially linked to one another. Therefore, the outcome of each preceding stage becomes the input for the next stage. Each stage is known as a "house of quality" simply because it is constructed in the shape of a house.[13]

Quality Costing

A useful tool for quality management is quality costing. **Quality costing** is a technique by which all the costs related to the delivering of a certain level of quality are captured and appropriately classified for the purpose of evaluating the quality management efforts in an organization. By translating the quality performance into monetary terms, quality costing captures the attention of the top management. Furthermore, it enables firms to prioritize various spending opportunities in the area of quality improvement. Juran advocated the notion of quality costing and Crosby encouraged firms to put a good quality costing system in place. According to Crosby, firms that begin measuring quality costs will first realize that nearly 25 per cent of their sales turnover is spent on quality management.

> **Quality costing** is a technique by which all the costs related to the delivering of quality are captured and classified for evaluation of the quality management efforts in an organization.

Quality costs in any organization fall under four categories (Figure 12.11). *Prevention costs* include all costs incurred to prevent, reduce, or eliminate the occurrence of defects. Expenses incurred towards training of employees in better methods, vendor development and small group improvement projects are some of the examples in the category. On the other hand, *appraisal costs* pertain to all expenses incurred in ascertaining the quality of a product, component or a service. The third category of costs relates to *costs of internal failures*. An appraisal activity may reveal defects and may call for scrapping components altogether or necessitate rework in several situations. This results in lost productivity and added costs for rectification. All these costs are classified as internal failure costs. The final category is the *external failure costs*. All costs related to rectifying the defects after the product is shipped out of a manufacturer's premises will be classified as external failure costs. The costs include warranty, cost of product returns and replacement, on-field maintenance, and any compensation for the damages incurred. It also includes the cost of lost customer goodwill.

FIGURE 12.10 The four houses of quality

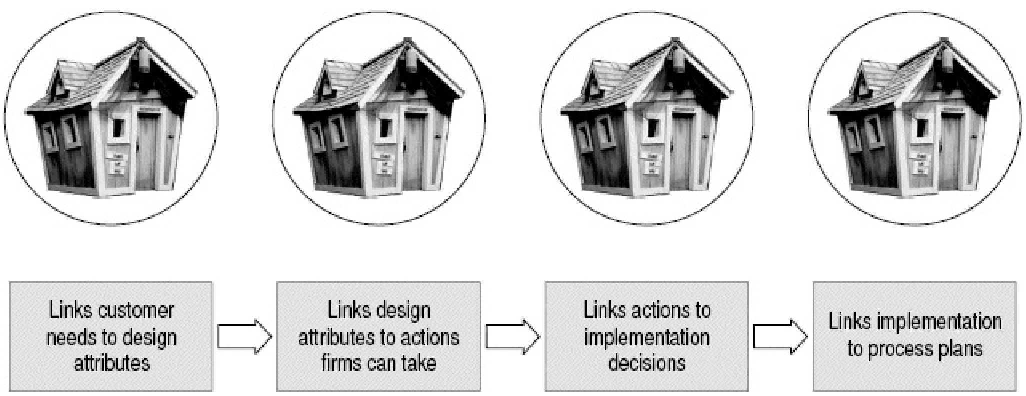
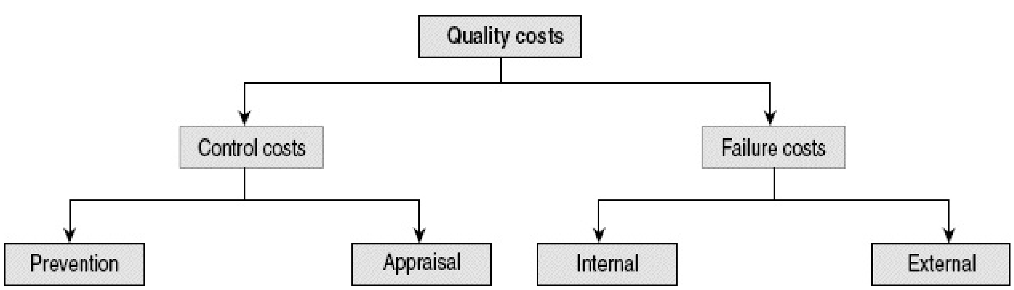


FIGURE 12.11 Classification of quality costs



Quality costing has several useful purposes. First, by translating quality parameters into monetary terms, it promotes quality as an important business parameter and helps capture the attention of the top management of an organization. Quality costs can be used for motivational purposes with regard to improvement at all levels in the organization. It is often found that many organizations are unclear about how to improve. In such cases, the use of quality costs could very well provide some direction. This is so as it enables an organization to set targets and budgets pertaining to quality improvement.

12.6 QUALITY CERTIFICATIONS AND AWARDS

Benchmarking exercises are an important component of good quality management. In the absence of these, an organization may not know how well it performs in quality management vis-à-vis its competitors. Amongst the several alternatives for benchmarking, one useful method is to make use of third-party quality rating services to assess the status of an organization's quality management practices. Use of third-party rating systems offers several advantages to an organization. It provides a neutral, unbiased, and fair method of evaluating its quality management practices. With such a rating, an organization may find it much easier to convince its prospective customers about its performance in quality management. This is especially true if the organization needs to tap overseas markets. Moreover, quality certifications and awards provide additional reputation effects to an organization and help the organization increase its market share and profitability in the long run.

The second advantage is that a third party rating provides a uniform nomenclature and helps understand the status of quality management cutting across geographical and sectoral domains. Finally, a third party will be better equipped to constantly invest in newer and better methods of measurement and it would be wasteful for every organization to individually invest in skill and expertise building in these areas. Therefore, quality certification and awards have become not only popular but also important for every organization to compete in a globalized market.

Quality Awards

Different countries have instituted quality awards to motivate business organizations towards achieving excellent performance. Table 12.2 has a list of awards and awarding agencies. The Deming Prize was one of the earliest awards instituted for excellence in quality management. Although only a few companies outside Japan have bagged the award, a majority of them are from India (Table 12.3). Although these awards differ from one another in the manner in which winners are selected, all of them have a system of identifying key components and a scoring system to rate the performance of each applicant against each parameter. Visits to applicant organizations and scrutinizing an extensive number of documents submitted in support of each component of the award form part of the process of selecting winners.

> Sixteen companies belonging to the automobile and other sectors such as steel have so far won the Deming application prize. A few Indian companies have won the Japan quality medal as well.

There two quality awards in India: the Rajiv Gandhi National Quality Award given by the Bureau of Indian Standards, and an award for business excellence instituted by the Confederation of Indian Industries along with the Export-Import (EXIM) Bank of India. Figure 12.12 shows the model utilized for the CII–EXIM Business Excellence Award. The model closely follows the one proposed by the European Foundation for Quality Management (EFQM). Out of a total 1000 points, 500 points each are awarded for enablers and results.

> In India, two quality awards are given; the Rajiv Gandhi National Quality award and the CII-EXIM Business Excellence Award.

Quality Certifications

Every country has a national standards body that is mandated by the government to establish standards and certify quality. The Bureau of Indian Standards is the Indian body for quality certification. However, over the years there has been a considerable convergence of alternative standards towards the International Organization for Standardization (ISO). ISO 9000 is a generic set of standards that enables organizations to build quality management and assurance systems. Individual sectors of industry have added more components to the basic ISO 9000 system to obtain their own standards for quality management. For example, automobile majors developed QS 9000. Similarly, the players in the telecommunications industry developed TL 9000. Growing concerns about environmental issues and occupational safety have necessitated the development of newer standards such as ISO 14000 and OHSAS 18000.

> **ISO 9000** is a generic set of standards that enable organizations to build a quality management and assurance systems.

TABLE 12.2 A List of Important Quality Certifications and Awards

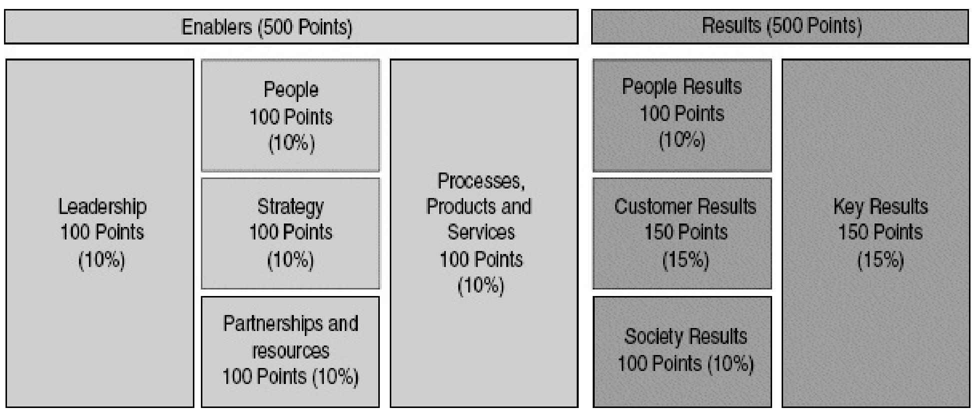
Name of the Award/ Certification	Awarding Agency	Applicable to Whom	Remarks
Some well-known quality awards			
The Deming Prize	Union of Japanese Scientists and Engineers (JUSE)	No geographical restrictions for applicants	More than one may be selected for the prize
The Malcom Baldrige National Quality Award	National Institute of Standards and Technology (NIST), U.S.	Open only to corporations based in the United States	Only one winner is selected for each category
European Quality Award	European Foundation for Quality Management (EFQM)	Open only to European companies	Only one winner selected for each category
The CII-EXIM Business Excellence Award	Confederation of Indian Industries (CII)	Any company in India can apply	Only one winner is selected for each category
The Rajiv Gandhi National Quality Award	Bureau of Indian Standards (BIS)	Indian companies can apply	Four categories (large-scale manufacturing, small-scale manufacturing, service sector, best of all)
Some well-known quality certifications			
ISO 9000 series, ISO 14000 series (Environmental issues), QS 9000 series (Automotive sector), TL 9000 series (Telecommunication Sector)	International Organization for Standardization	Any company can apply for the certification	Rating agencies assess and recommend certification. Certificates valid for three years
OHSAS 18001	An association of national standards bodies	Companies can apply to the respective national standards bodies	Deals with occupational health and safety management

TABLE 12.3 List of Deming Prize Winners (Indian Companies)

Year	Name of the Company
1998	Sundaram-Clayton Limited, Brakes Division
2001	Sundaram Brake Linings Limited (India)
2002	TVS Motor Company Limited (India)
2003	Brakes India Limited, Foundry Division (India)
	Mahindra and Mahindra Limited, Farm Equipment Sector (India)
	Rane Brake Linings Limited (India)
	Sona Koyo Steering Systems Limited (India)
2004	SRF Limited - Industrial Synthetics Business Lucas-TVS
	Indo-Gulf Fertilizers Limited
2005	Krishna Maruti Limited, Seat Division (India)
	Rane Engine Valves Limited (India)
	Rane TRW Steering Systems Limited,
	Steering Gear Division (India)

2007	Asahi India Glass Limited, Auto Glass Division (India)
	Rane (Madras) Limited (India)
	Reliance Industries Limited, Hazira Manufacturing Division
2008	Tata Steels Limited
2010	National Engineering Industries Limited
2011	Sandan Vikas Limited (India)
2012	SRF Limited, Chemicals Business
	Mahindra and Mahindra Limited, Farm Equipment Sector, Swaraj Division
2013	RSB Transmissions (India) Limited, Auto Division (Jamshedpur Unit 1, Pune, Pant Nagar Plants)

FIGURE 12.12 The CII-EXIM business excellence award model



Source: Adapted from http://www.cII.in/uploads/SMB899.pdf

ideas at Work 12.4

SRF's TQM Journey Towards the Deming Prize

SRF's journey towards the Deming Prize started many years ago. SRF had a joint venture with a Japanese company called Denso— a motor component manufacturer—in the early 1980s. In several interactions with them, the top management realized that the real catalyst behind the Japanese revolution in quality was total quality management. SRF started experimenting at that point of time with QC circles. However, it was a dismal failure because there was no preparation, no groundwork done for actually introducing QC circles—it was just something the management tried to push down and impose on its employees. SRF gave up on this effort after trying it for a few years.

The motivation to return to the quality movement seriously happened in the early 1990s. SRF sent eight or ten of their top executives to Japan to attend a programme organized by JUSE, the Union of Japanese Scientists and Engineers, which gives away the Deming Awards in Japan. When they returned, they resolved that the only way to make a change in their organization was to anchor it to TQM. In 1995, SRF engaged Professor Kume—one of the doyens of the TQM movement in Japan, an individual Deming Prize winner and a former chairman of the Deming examination committee—to help with the TQM initiative.

SRF faced credibility issues. Restarting something that has failed once is like going in on a losing wicket. There were many doubters, even at the higher levels of management, who believed it was not going to work, and that, being a Japanese technique, TQM was culturally unsuited to India. In 1994, SRF went through major industrial strife, and for almost four and a half months, the factory was not working optimally. The workers were not ready to listen to the management. However, there was a possibility that this would prove a catalyst to enthuse the workers, because the TQM movement was ultimately all about involvement, from the top right down to the lowest levels. Therefore, while SRF was determined to go ahead with TQM movement, the management did not push anything with the workers.

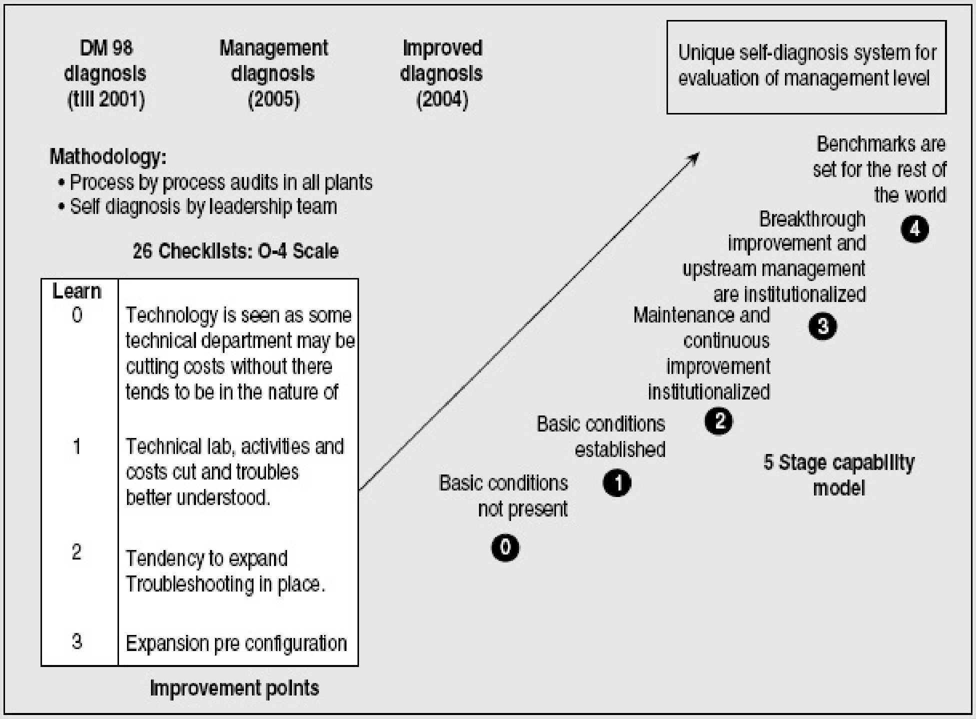
SRF first started with a massive communication drive explaining how it would be in the interest of the workers to return to normal working conditions, and how imbibing the TQM methodology and the concepts of TQM would provide them opportunities for growth. Simultaneously, an intensive education and training programme was started for top-level and then for middle-level executives on the philosophy of TQM, the training required, and the kind of changes that they would have to make in their mindsets.

When SRF started the plant in Chennai in 1974–75, 60 per cent to 70 per cent of the workers were illiterate. The TQM programme helped them to become literate so that they could start participating in the new culture and gave them immense satisfaction. They can understand what a histogram is, what a pareto diagram is, what the seven tools of QC are, and they actively participate in QC circles and put forward ideas through the kaizen movement.

The TQM journey facilitated SRF to put in place better workplace management systems. SRF implemented Daily Management, a rigorous system of ten elements, cutting across both manufacturing and non-manufacturing. This was deployed in all the units with a diagnosis score on a 100-point scale (see Figure 12.13 for an illustration). These are increasing levels of difficulty. At each level of capability of the organization, it helped the SRF executives learn more and understand the entire aspect of management better, as relevant to TQM. In later years they devised a system of “management diagnosis”, which included many elements that did not exist in the earlier framework, like leadership, strategy and technology development. This is a much more robust system of measuring the capability of the organization, and the management sets targets around these.

The SRF journey offers several interesting lessons for launching a successful TQM movement. One cannot expect to transform a company in two or three years. Organizations are likely to face a situation where people will start losing interest. Perseverance is very important, not just at the top, but at all levels; and communication is very important too. Organizations must not be looking merely for an end result; they must be looking for the journey. The moot question to keep asking all the time in a TQM journey is: are we continuously improving?

FIGURE 12.13 An illustration of SRF's daily management system



Source: B. Mahadevan, "Journey to the Deming: Implications for Corporate Transformation and Competitiveness—In Conversation with Arun Bharat Ram," *IIMB Management Review*, Vol. 17, no. 2 (2005): 59–70.

The software sector has adopted a unique quality certification programme developed by the Software Engineering Institute (SEI) at the Carnegie Mellon University, known as the **Capability Maturity Model (CMM)**. CMM is a model used by many organizations to identify the best practices useful in helping them increase the maturity of their processes. In 2000, CMM was upgraded to Capability Maturity Model Integration (CMMI). According to SEI, the goals in developing CMMs include addressing software engineering and other disciplines that have an effect on software development and maintenance and providing integrated process improvement reference models. Moreover, the models will also enable efficient improvement across disciplines relevant to software development and maintenance. Currently, six variations of CMM are available. These include the following:

- Capability Maturity Model Integration (CMMI)
- People Capability Maturity Model (P-CMM)
- Software Acquisition Capability Maturity Model (SA-CMM)
- Capability Maturity Model for Software (SW-CMM)

- Systems Engineering Capability Maturity Model (SE-CMM)
- Integrated Product Development Capability Maturity Model (IPD-CMM)

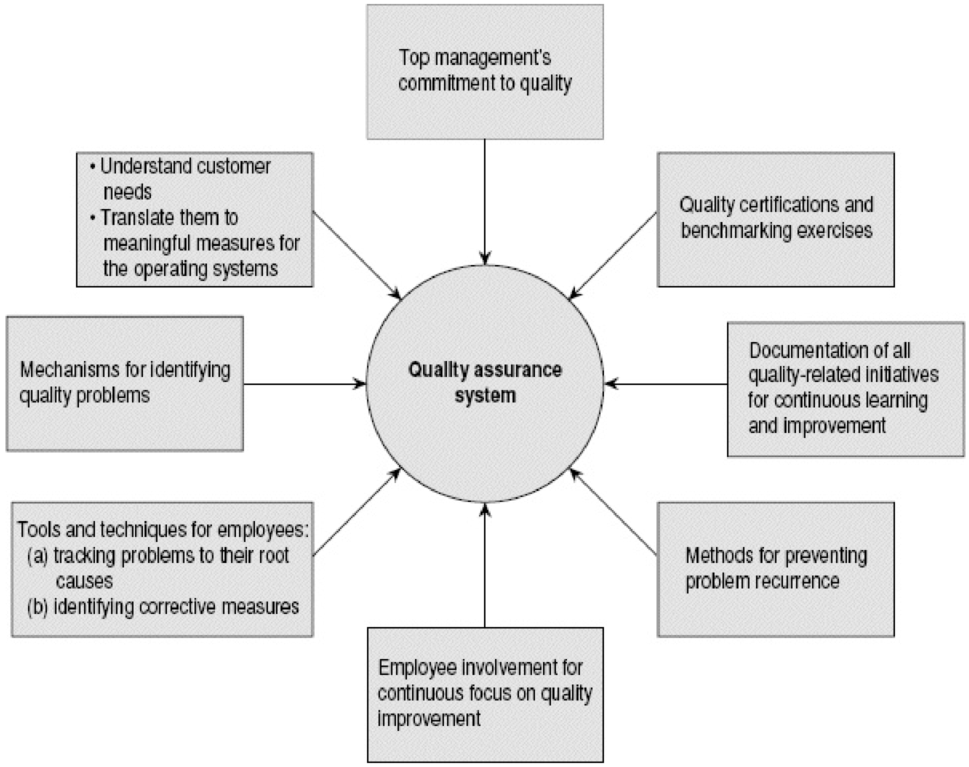
> The software sector has adopted a unique quality certification programme known as the **Capability Maturity Model (CMM),** used by organizations to identify the best practices useful in helping them increase the maturity of their processes.

12.7 DESIGN OF QUALITY ASSURANCE SYSTEMS

A quality assurance system is one that has all the components that promote total quality management in an organization. Based on the discussions in this chapter, we can clearly identify the key elements of a robust quality assurance system. Figure 12.14 is a graphical representation of such a system, the components of which are briefly here:

- *Top management commitment:* One of the important lessons of TQM is that the fundamental building block of a quality assurance system is the top management's commitment to quality.
- *Employee involvement:* The other pre-requisite for a robust quality assurance system is to develop a good atmosphere for employee involvement. Appropriate choice of quality management tools could further promote group working and inculcate a sense of ownership of the process.
- *Understanding customer wants and translating them into meaningful measures*: Without a good understanding of what the customer wants and what the market values, it is futile to establish a good quality management system. It is equally important that we have methods by which this is translated into meaningful measures at the workplace. Without this, all efforts directed towards quality will fetch products and services that customers are not interested in. Therefore, an important element of a good quality assurance system is to resolve this issue. Tools such as QFD are very useful for this purpose.
- *Identifying quality problems*: A good quality assurance system requires a methodology by which quality problems are brought to the attention of the employees and managers as quickly as possible. Control charts and other such visual control techniques enable an organization to achieve this requirement of a quality assurance system.
- *Providing tools and techniques for problem solving*: Lasting solutions to quality problems are found only when the problems are traced to their root causes and corrective measures are initiated. In the absence of this, organizations constantly face quality problems and incur high costs in rectifying them. Therefore, a quality assurance system will provide alternative tools and techniques, such as the fishbone diagram and CEDAC, to track the problems to their root causes. It will also promote small group improvement projects for continuous improvement.
- *Mistake-proofing of operations*: Higher levels of performance in quality management are attained when an organization rises to the level of avoiding quality problems by careful redesign of its operations and standard operating procedures. Tools such as poka yoke are valuable for such initiatives.
- *Documentation for continuous learning and improvement*: Organizations tend to benefit greatly from learning curve effects. Revisions and changes in operating procedures that lead to better practices need to be properly documented. Such practices build a strong knowledge base of quality management and help face a variety of situations in the future. Quality certification systems such as ISO 9000 equip an organization to perform this task very well.
- *Benchmarking*: The final aspect of a good quality assurance system lies in its ability to constantly point to new areas of improvement that an organization needs to make to remain competitive in the market. In addition to a firm-initiated internal benchmarking exercise, rating by an independent third party helps this process a great deal. Therefore, every organization should endeavour to work towards obtaining quality awards and certifications. Therein lies the ultimate test of the strength of its quality assurance system.

FIGURE 12.14 Elements of a quality assurance system



SUMMARY

- The resounding success of Japanese manufacturing firms has invariably been linked to excellent practices in quality management in the last 30 years.
- Much of the progress that organizations made in quality and productivity management is attributed to the teachings of quality gurus such as Deming, Juran, Crosby, Taguchi, Shingo and Ishikawa.
- A good quality management system must enable a manager to understand the qualitative attributes that influence a customer and have a method of translating these into unambiguous quantifiable parameters for design and manufacturing.
- A total quality management programme consists of four components: top management commitment, employee involvement in continuous improvement initiatives, training and skill development, and investment in robust systems.
- Several tools and techniques are available that help in highlighting problems, identifying specific improvement opportunities, analysing problems and their root causes, and operational and strategic planning for building quality into products and services.
- Alternative certification procedures and award mechanisms are available to recognize excellent quality management systems in organizations.

REVIEW QUESTIONS

1. What is the relevance of quality in today's competitive scenario? Was it any different during the 1970s and the 1980s?
2. Enumerate the key benefits that an organization derives by improving the quality of its products and services.
3. Compare the teachings of Deming and Juran and make a critical report of your key inferences from them. Were they advocating the same idea?
4. Identify three ways by which an organization can benefit from the teachings of the following gurus:

   a. Philip Crosby
   b. Karou Ishikawa
   c. Genechi Taguchi

5. For each of the products/services mentioned here, define quality from the customers' perspective:

   a. A laptop computer
   b. A weekend holiday in a beach resort in Goa
   c. A motorbike
   d. Legal services obtained from a lawyer
   e. A day-care centre (crèche)
   f. An electric bulb

6. For each of the products/services in Review Question 5, define quality from the perspective of the firm providing the products/services. Are these definitions the same or different? Explain your observations.
7. What are the challenges that an organization faces when it attempts to define quality? Is it possible to overcome these and if so how?
8. What is poka yoke? Can you identify one situation each in your classroom, hostel, and college administrative office that can potentially benefit from the application of this concept?
9. What do you mean by the term total quality management? Is there anything special about "total" in TQM?
10. If an organization practices employee involvement, how is it likely to be benefited?
11. How can the top management of an organization influence the quality management process?
12. What is the use of the QC tools in quality management?
13. What are the elements of a quality costing system? How does an organization benefit from a quality costing system?
14. In an organization if the prevention and appraisal costs are very low, what, according to you, will the magnitude of the other components of the quality costs be? Explain your answer with supporting arguments.
15. What is a quality house? What is the use of a quality house?
16. An organization does not know if it needs to go for ISO 9000 certification or ISO 14000 certification. They are also not aware why they should go for a certification. Prepare a one-page report to resolve their confusion.
17. How does an organization benefit by working towards obtaining a quality award? Explain with reference to the CII-EXIM Business Excellence Award.

PROBLEMS

1. A hospital buys medical consumables from several suppliers. The bad quality of consumables sometimes affects the hospital operations critically. Therefore, the hospital follows a quality control routine. Based on a weekly analysis of the quality of cotton and dressing material used in large quantities in the surgery section of the hospital, the following causes of defects were found out (see Table 12.4).

   a. Draw a histogram of the problem for further analysis.
   b. Draw a pareto diagram of the data in Table 12.4. Based on the pareto diagram, what course of action would you recommend?

2. A bank operating in a prominent residential area in the metropolitan city of New Delhi is facing tough competition from several of its competitors. Improving the quality of services has become a necessary condition for the branch to survive.

One of the major problems is the excessive delay that customers experience in the bank. After a brainstorming exercise, a group of bank employees came up with the possible causes for poor quality of the service. The following is the list:

TABLE 12.4 Causes of Defects

Sl. No.	Description	Number of Occurrences
1	Soiled and dirty	23
2	Cuts and discontinuities	12
3	Improper specifications	19
4	Weight loss	31
5	Defective packing	21

a. The number of employees are too few.
b. The use of technology was minimal.
c. Work distribution among employees is lopsided.
d. Employees have not been trained properly in using the system.
e. There is a space constraint in the bank with the result that the layout of the service counters is inconvenient.
f. There are procedural delays in the bank.
g. The existing performance measures do not motivate employees to provide faster service.
h. Employees have varied patterns of service delivery, leading to uneven service time.
i. Nobody in the bank is aware of how much time a customer waits.
j. Customers are not realistic in their expectations.
k. The number of accounts handled is far in excess of capacity.
l. There is too much variety in the services offered by the branch.
m. There is too much absenteeism among employees.

Represent the problem using a fishbone diagram. What future course of action should the group of employees take with respect to the problem?

3. The quality of the food services in a students' hostel mess is a cause of great concern among the students. Use the fishbone diagram and show how one should go about studying this problem.
4. A manufacturing company is keen to understand the notion of quality costing and its relevance to quality management. Based on one month's work by a task force, the following data have been collected from the accounts of the company, pertaining to the last three years. Table 12.5 has various items of cost (in thousand ₹):

a. Develop a quality costing system on the basis of the given data.

TABLE 12.5 The Items of Cost

Number	Description of Item of Cost	2002	2003	2004
1	Warranty costs	12,532	11,540	12,320
2	Cost of rework	9,348	18,540	17,439
3	Training costs	234	567	893
4	Supplier development costs	1,238	2,345	3,459
5	On-site repair of products	8,345	7,934	7,839
6	Cost of testing	4,567	5,672	5,789
7	Loss from product returns	4,562	4,234	2,389
8	Inspection costs	7,812	12,127	17,283
9	Calibration of testing devices	1,678	1,482	2,093
10	Scrap	2,568	4,298	6,238

b. What is the cost of quality as a percentage of turnover if the total turnover for the three years were ₹200 million, ₹240 million and ₹300 million during 2002, 2003 and 2004, respectively?
c. Plot the various components of the quality cost. Do you see any trend in the behaviour of the components of quality cost over time? Explain your key observations of this exercise.

NET-WISE EXERCISES

1. To get an overview of the Malcolm Baldrige Quality Award program, visit the URL: http://www.nist.gov/baldrige. Click on ‘About Us’ and read about the history of Malcom Baldrige National Quality Awards for background information about the award. Click on the ‘FAQs’**.** There are several side bars in ‘FAQs’ menu. Go through them to know more about the award.

   Next, visit the URL

   http://cii-iq.in/cii/sectors/BE/CII-Exim%20Bank%20Award%20for%20Excellence.html. There are details on various aspects of the award in several links in this page. Go through these links.

   a. What do you think is the basic purpose of the Malcolm Baldrige Award and the CII– EXIM Bank Award? How do they achieve this objective?
   b. Compare and contrast the two awards. Define three criteria for comparison and use them for answering this question.

MINI PROJECTS

1. Form a small group improvement team of six students. Visit the local branch of the bank or a hospital and get their approval to study the quality problems that they face for possible improvements and prepare a final report based on the entire exercise. The project should involve the following important steps:

   i. Develop an appropriate definition for quality pertaining to the problem taken up for the study in consultation with the employees in the organization.
   ii. Identify the metrics that needs improvement and set realistic targets for the metrics.
   iii. Collect data and use the available QC tools to analyse the problems, their root causes, and potential improvements.
      a. Estimate the projected improvements and the changes required in the system to improve the quality
      b. Discuss your results with the organization and understand the feasibility of your recommendations. Make further refinements of the proposed recommendations
      c. Write a detailed report based on your experiences in the project

2. Consider the following three quality awards; the CIIEXIM Business Excellence Award, the Deming Award, and Malcom Baldrige Award. Make a detailed study of these awards by visiting their respective websites and collecting information from secondary data such as published literature and reports. Based on this study, prepare a report to answer the following questions:

   a. What are the salient elements of each of these awards? Is there an underlying philosophy that governs selection of successful companies in each of these awards?
   b. Select one award-winning firm for each of these categories of awards and study them. Briefly document the experience of one firm each that has bagged these awards.
   c. What is the nature of the efforts required from a firm to get these awards? Is there a time frame involved? How do firms that qualify for these awards benefit from the exercise?
   d. What is the status of firms that obtain these awards? How do they perform after they obtain these awards? Are there any significant disadvantages or problems these firms go through in the process of obtaining the award?

3. Quality certification is an important aspect in quality management. Prepare a detailed report on the basis of your own study to answer the following questions:

   a. What are the emerging standards in the area of quality management? Why are they important?
   b. What are the industry specific initiatives in the area of quality certification? How are they different from generic standards?
   c. What benefits accrue to a firm that obtains a quality certification? Are there any prior experiences that confirm these findings?

CASE STUDY

Bangalore Garment Exports Limited

Bangalore Garment Exports Limited (BGEL) is a garments manufacturer in Bangalore primarily engaged in the manufacture of gents shirts against specific client orders. The garment sector is a competitive one and competing merely on price is an unsustainable strategy in the long run. The company has been in operation for the last 12 years and has earned a reputation for their delivery reliability and cost. However, they have not been able to establish a robust quality system. While they take care of the customer requirements through stringent inspection standards, they end up with a much higher proportion of rejects (seconds) than the industry average in the process. BGEL has made some initiatives in the recent past to address the issue of quality.

Operating Unit

BGEL has both manual and mechanized operations for shirt-making. The current capacity is for a daily production of 6500 shirts. While cutting and basic stitching are done using high-speed machines, there are portions of shirt-making that involves skilled labour in addition to the machines. In all, there are 65 machines and of there are 12 cutting machines, the rest being stitching machines. BGEL employs over 400 people; of these, 290 are engaged in production. The production workers are functionally organized into four sections; laying and cutting of cloth, body stitching, making slacks and attaching it to the body of the shirt, and finally, attaching the collar to the shirt. After this, it goes to the QC department for final checking and QC clearance. After the QC clearance, it is sent for packaging and dispatch. The production flows in this sequence, and each section employs a number of production workers in order to meet the daily demand.

There are separate sections for routine, preventive, and breakdown maintenance of the machines; quality control; and production planning. All these sections, as well as the production sections, have supervisors who are responsible for output and performance of the units. At the beginning of each shift, the production supervisor in the section assigns jobs to each worker based on the daily requirements. The production workers receive incentive pay on a “piece rate” basis, once they exceed the normal production in a shift.

Quality Management Issues

One of the major problems at BGEL has been the high proportion of rejection of the final product. Last year, the QC section initiated a system of recording daily rejects using a display board. The display board also recorded some significant events pertaining to the day along with the rejects data to help the management take corrective actions. The snapshot of the data on daily rejects for a period of ten days is given in Table 12.6.

Management Actions on Quality Management

The display board was primarily meant to highlight to the management the quality issues at BGEL. Every day, the management reviews the status of the board and “instructs” the supervisors on the nature of the actions to be taken to bring down the number of rejects. The supervisors in turn modify the work practices and/or the instructions to the workers working under them and monitor compliance of the requirements. The management also engaged an expert in textile technology to educate the supervisors on modern methods in textile manufacturing and the trends in usage of new machinery. On the other hand, the maintenance workers were sent to one-week training programmes on better maintenance practices. The management also appointed an expert on quality assurance so that better methods would be put in place to improve the quality. The display board was one of the suggestions of the expert to improve quality.

According to the QC section, the skill levels of the employees and absence of a quality monitoring system are the two major reasons for poor quality. The other issues are high levels of absenteeism and a high turnover of the production workers. Despite several efforts by the management in the past year, there has not been much improvement in the quality standards at BGEL. This is a major cause of concern for the MD of BGEL.

QUESTIONS FOR DISCUSSION

1. Comment on the current status of the quality management system at BGEL. Why have they not been able to make improvements in quality?
2. What are your observations based on the display board? Can you identify three areas that BGEL need to address in order to improve their quality standards?

   Suggest a suitable quality management system and a plan of action for BGEL for the next one year.

TABLE 12.6 A Snapshot of the Display Board at BGEL

	Daily Production	**Daily Rejects**	**Remarks on Significant Events**
Day 1	5957	298	Stoppage of machines, shortage of material to work on, high absenteeism
Day 2	6043	423	Schedule and specification changes not properly communicated, skill inadequacies
Day 3	5450	600	Machine failure, work reassignment to handle high absenteeism
Day 4	5878	353	Machine failure, specifications not met
Day 5	6012	541	Coordination problems among production sections, worker skill issues
Day 6	6123	490	Coordination problems among production sections, specifications not met
Day 7	5875	764	Skills mismatch, defective and improper instructions given to workers, specifications not met
Day 8	5367	590	Coordination delays, rework due to wrong assembly of pieces
Day 9	5590	839	Wrong specs used, malfunctioning of machines, missing instructions
Day 10	5670	510	Defects due to work reassignments, Too many rush orders squeezing capacity

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CHAPTER 13

Lean Management

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What is the philosophy of lean management?
- What are the structural and planning elements required for a lean manufacturing system?
- What is the difference between push-scheduling and pull-scheduling methodologies?
- How is kanban used as a production planning and control tool in just-in-time systems?
- What are the elements of a continuous improvement process?
- How can one create a context for continuous improvement of operations in an organization?
- What are the tools available for continuous improvement?
- How are tools such as BPR and process mapping used for continuous improvement?
- What is an appropriate organizational structure for implementing lean management? What are the implementation challenges? What is the role of top management?

A lean management system often involves major changes in the manufacturing architecture. It also involves other activities such as standardizing operations, quick changeovers, levelling production and use of better scheduling and planning methods.

Source: Milltec Machinery Pvt. Ltd.

ideas at Work 13.1

Notion of Waste in Offices

Central to creating a lean organization is continuous identification and elimination of waste. It is much easier to accomplish this in a manufacturing set-up because of tangibility. On the other hand, in service organizations and offices poor intangibility makes it a difficult exercise. Waste in offices can be broadly classified into four categories.

People Waste

People waste is the result of not utilizing workers' skills to their full potential due to little or no training, office politics, low-pay, or high turnover. People waste also happens on account of absence of goal setting, employees working at cross-purposes and people spending a lot of time correcting problems (re-work). Moreover, not assigning work properly or assigning unnecessary work is a waste of people resources.

Process Waste

Process waste usually occurs on account of neglect and bad design of the process. Moreover, the attitude of the people leading to mind-set inertia (we have always done it that way) also significantly contributes to process waste. There are several instances of process waste in service organizations. Some of them include:

a. Overproduction: Doing work before it is required
b. Over processing: Working on one item more than what is necessary

c. Control: Doing more monitoring than what is required
d. Too many rules leading to very complicated work and several errors that require re-work later
e. Non-adherence to standardization: Workers ignoring best practices
f. Sub-optimization: Duplicate or competing processes
g. Scheduling: Poor organization or planning
h. Uneven flow: Backlog of information and materials
i. Checking: Over-inspection and re-work
j. Error: Re-work to correct mistakes

Information Waste

Information waste leads to loss of value because of poor, outdated, duplicated, or incomplete data. This causes costly mistakes because the corrections (re-work) take a lot of time and effort. Some examples of information waste are:

a. Translation: exchanging bad data and formats between procedure steps and owners
b. Hand-off: transferring data/materials within a group that is not part of the procedure chain
c. Missing information leading to committing additional resources to correct key data or information
d. Irrelevant information: unnecessary data that creates confusion, slows processing, or causes errors
e. Inaccurate information: wrong data or information generating additional non-value added work to rectify the mistakes

Asset Waste

Asset waste is not using material and/or property efficiently. This includes buildings, office equipment, supplies, products, and services. Examples of asset waste include:

a. Excess inventory, time, supplies, and piles of unused or outdated materials
b. Work in progress (WIP) that cannot be completed because of inefficient workflow
c. Resources committed to rectify defects or mistakes created by other categories of wastes
d. Moving product/material around inefficiently; transportation of information and materials; late deliveries to customers; concentration of consumables

Creating lean systems in any organization calls for identifying various waste generating incidences under each category of waste. Furthermore, the waste must be eliminated progressively using some tools and techniques. For example, some of the waste could be eliminated by re-designing the structural arrangement of resources and some others by implementing simpler methods for planning and operational control. We shall see these aspects in some detail in this chapter.

Source: Based on http://www.leanexpertise.com/MTL/LeanOffice/LeanOfficeBasics.htm last accessed on 27 June 2014.

13.1 THE ORIGINS OF LEAN MANAGEMENT

The process of manufacturing has been significantly influenced by the turn of events in history. In the beginning of the twentieth century, Henry Ford pioneered the mass production system as a way for manufacturing organizations to organize, plan, control, and evaluate their operations. Several operations management tools developed during that time sought to promote the mass production philosophy. During World War II, flexibility was a key requirement and this altered the manner in which operations management theory and practice developed.

During the oil crisis, recession put new pressures on the manufacturing system and demanded better methods of managing operations in manufacturing organizations. Customers demanded better products at lower prices. They increasingly demanded more options, along with a commitment to deliver products and services faster. In response to these changing requirements, new principles of managing operations were required. Managing the operations efficiently, developing alternative methods for quality management, and creating responsive organizational structures were some of the newer requirements. Notably, Japanese manufacturers developed a set of tools and techniques over a period of two decades that addressed many of these requirements. These are collectively known as lean management practices.

Using the new capabilities, Japanese manufacturers threatened to alter the forces of competition and sought to provide new value to customers. In the automobile sector, passenger-car manufacturers such as Toyota and motorcycle manufacturers such as Kawasaki competed effectively with established giants in the United States, such as General Motors (GM) and Harley Davidson, respectively. While Japanese manufacturers could offer products that came at a low cost along with high quality, American manufacturers were offering exactly the reverse, that is, low-quality products at a high cost. The initial success of the Japanese manufacturers in the automobile sector was soon to be replicated in other sectors of the industry. Notable among them include electronic components such as resistors, memory chips, and transistors, and entertainment electronics products such as cameras and musical systems.

13.2 WHY LEAN MANAGEMENT?

The world was in the midst of a severe global economic slowdown after 2007, and all major economies underwent a slowdown, shrinkage, or even severe depression during this period. If we carefully analyse the trends during the five years preceding this recession, we will find that there were enough signals. Organizations in some sectors of the industry made concerted efforts to respond to the emerging scenario. Some of the trends during this period and their impact are worth mentioning:

a. The “Big Three”, the three large automobile manufacturers in the United States, along with other global auto majors, faced severe problems due to the economic slowdown. The inventory of vehicles was mounting and the companies had to cover high structural costs. General Motors had lost USD 82 billion since 2004, its last profitable year. In order to stay alive, GM announced a USD 10 billion cut in costs in July 2008 and a further USD 5 billion in November 2008. These included a dramatic cut in its 2009 capital expenditures and additional cuts for its white-collar workforce.
b. Due to the mounting cost of crude and the competition in the civilian aerospace market, Boeing and Airbus began working with the central theme of enhancing efficiency and cost-cutting. Their new models (the Dreamliner of Boeing and the A380 of Airbus) emphasized these aspects in product development and production. There was increased competition from low-cost economies.
c. In the textile sector, Indian companies suffered from longer lead times, lower productivity, and smaller plants compared to Chinese ones. Therefore, the Indian textile industry was not able to benefit much from the multi-fibre agreement that promotes free global trade in the garment sector.

In the light of the recent economic slowdown, it has become very important for organizations to improve productivity and response time and cut costs so that they can stay competitive. Manufacturing and service organizations are required to first understand how to develop better operational systems and deliver better quality products and services using fewer resources. The underlying requirement to be more competitive in the market is to ensure that less is more productive. Lean management principles address these issues directly and efficiently.

13.3 THE PHILOSOPHY OF LEAN MANAGEMENT

Lean management is a new philosophy of operations management that provides a set of tools and techniques to compete in an increasingly fierce marketplace. It is an organizational mechanism for defining value and thereby creating a value stream for customers. Lean management is based on the premise that by identifying waste in any system and removing it, it is possible to create a value stream for the products and services that an organization offers to its customers. It enables organizations to provide better value in their offerings by constantly improving their operations.A good understanding of waste and value and a set of tools and techniques to eliminate waste from the system are crucial to creating a lean enterprise. To understand lean management better, we need to familiarize ourselves with the concepts and definitions of *value-added (VA), non-value-added (NVA), and necessary but non-value-added (NNVA) activities*. These concepts have been discussed in detail in Chapter 8. We should also understand the concepts of waste, value stream, and lean management. These terms are defined here.

- *Waste*: Any process or set of activities that does not add value as perceived by the customer is classified as **waste**.[1] It consists of both NVA and NNVA. From a short-term perspective, NVA is avoidable waste whereas NNVA is an unavoidable waste.
- *Value stream*: All activities that need to be performed (VA and NNVA) from the time the customer order is received to the time the order is fulfilled make up the value stream for an organization. Depending on the nature of the business, it may span activities from concept to launch, order to delivery, or raw material to finished product.
- *Lean management*: Lean management is a process by which the continuous efforts of all concerned parties enable an organization to create a channel for the value stream by eliminating waste from the system.

> Any process or set of activities that does not add value as perceived by the customer is classified as **waste**.

Viewed from this perspective, the entire notion of lean management revolves around the issue of waste and waste elimination. The starting point for lean management is to develop a good understanding of waste. Once the notion of waste is understood, it is easy to create a lean enterprise. Let us hypothetically compare two competitors. Competitor A may have 40 days of inventory, may employ 150 people in its factory, and may have a layout in which jobs travel 6 km from the raw material stage to finished goods. They may also have an inward goods inspection department employing three inspectors to inspect quality of the incoming lot of materials. On the other hand, Competitor B may have 20 days of inventory, employ 120 people for the same level of production, with jobs travelling less than 3 km on the shop floor, and may have no inward goods department. It may be receiving direct in-line supply of materials by the suppliers.

After a quick comparison, we infer that Competitor B is more efficient. It appears that Competitor B is deploying fewer resources than A, has a better layout, and is carrying less inventory. Clearly, a customer may not want to pay for many of the activities that Competitor A does and for the inefficiencies in the system. As per our definition of waste, Competitor A seems to be generating more waste in the system. Table 13.1 lists some common sources of waste in manufacturing and service organizations as per the lean management definition.

TABLE 13.1 Some Common Sources of Waste

Category	**Manufacturing Organizations**	**Service Organizations**
Inventory-related waste	Accumulating inventory	Overflowing “in baskets”
	Waiting for material to work on	Duplication of work
		Excessive paper work
	Stock verification	Incomplete information
	Counting the number of parts	leading to pending decisions
	Temporary storage	
	Parts shortage	
Waste due to processes	Defects and rework	Payments not made on time
	Machine breakdowns	
	Watching the machine run	Wrong service delivery (service failure)
		Proposals not completed on time for the bid
		Customer orders taking too long to be filled
Waste due to planning	Looking for tools	Complicated office layouts
	Carrying heavy pieces	
	Transferring parts over long distances	Poorly planned meetings
		Documents handled many times before a decision is taken
	Overproduction and double handling	
		Extra signature needed that holds up completion
		Teams with incomplete or no direction

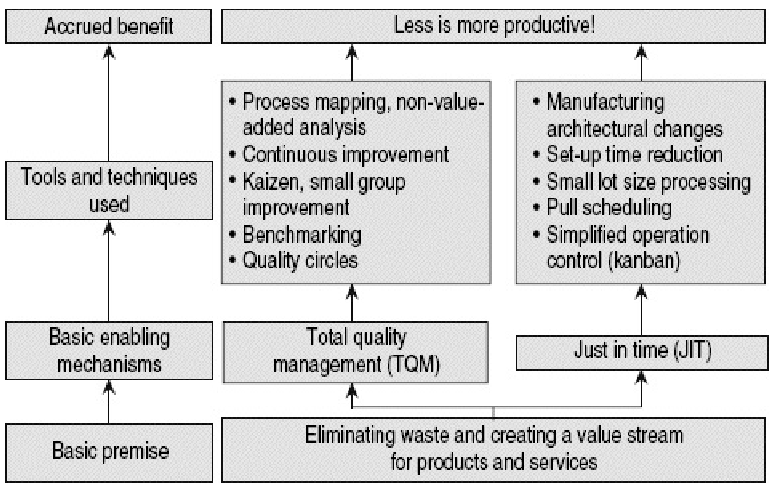
13.4 CREATING A LEAN ENTERPRISE

When organizations begin their journey towards creating a lean enterprise through a process of continuous waste elimination, they make several changes in the organization. This includes changing the structural elements in the system, simplifying operations planning and control by introducing alternative scheduling methodologies, and improving the responsiveness of the system to the market. Figure 13.1 illustrates various aspects of the lean management process. As we have already seen, the basic premise of lean management is to eliminate waste. Therefore, every activity undertaken under the banner of lean management must result in elimination of waste.

The changes made are principally governed by two philosophies: just-in-time manufacturing (JIT) and total quality management (TQM). JIT and TQM fundamentally aim at elimination of waste. While JIT is an organization-wide mechanism for exposing problems (related to wasteful activities in an organization), TQM is an organization-wide mechanism for solving problems. Therefore, these two are the basic enabling mechanisms of any conceivable lean management system.

The introduction of changes by adopting the JIT philosophy may require certain changes in the manner in which resources are organized and scheduled. Furthermore, it may call for reducing the lot size by embarking on set-up time reduction activities. Use of simplified operations planning control systems also helps in dramatically reducing waste arising out of poor planning. On the other hand, the introduction of TQM enables an organization to eliminate waste on an ongoing basis. By setting on a trajectory of benchmarking and continuous improvement, organizations can utilize several QC tools and small-group improvement activities to make continuous waste elimination a workable reality.

FIGURE 13.1 The lean management process



Lean enterprises have realized several benefits. In their book *Re-engineering the Corporation*, Hammer and Champy showed how, for a similar procurement requirement, Ford employed 500 engineers whereas Mazda employed only five.[2] Similarly, a comparative study of automobile manufacturers such as Toyota and GM showed that for similar production activity, GM had nearly 27 times more employees in production and 17 times more employees in purchasing compared with Toyota.[3] Deming-winner SRF Limited claims that, after lean manufacturing is implemented, parameters such as the size of international business, productivity of employees, and employee involvement increased over time. Others, such as breakdown hours, customer complaints, scrap and downgrade, and the number of employees in the organization, came down.[4] All these examples clearly demonstrate that the accrued benefit of practising lean management is that less resources become more productive.

It is evident that improvement in operations fundamentally means better use of available resources and greater productivity of resources. Such improvements include an increase in production with no addition of capacity; elimination of manpower even when production levels go up; the lack of appreciable increase in the cost of production even when the volume drops; increase in the velocity of various business processes without anyaddition of new capacity or technology; significant reduction in defects, rework and inventory investments when the production rates go up; and an overall increase in the productivity. Clearly, all these point to the elimination of wasteful activities in an organization. Moreover, on account of waste elimination, the organization becomes more responsive, agile, and flexible to handle changing needs at the marketplace.

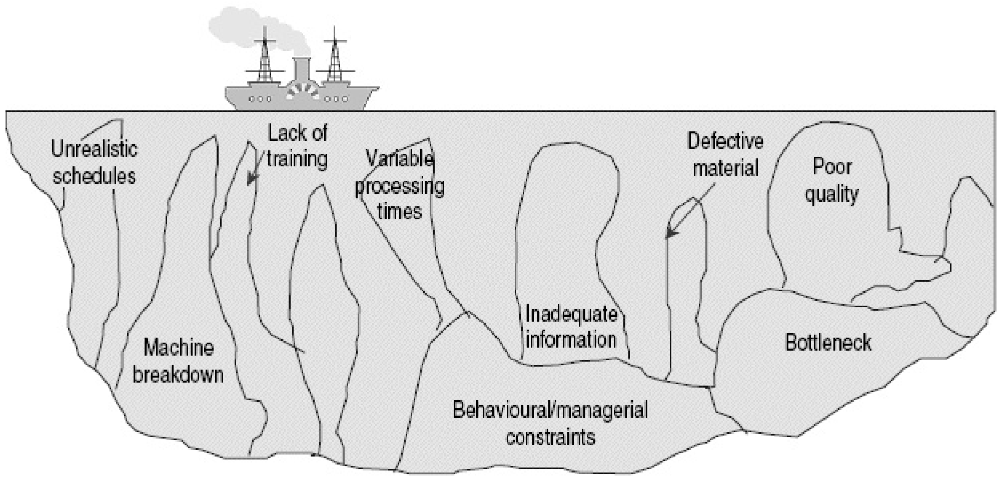
13.5 WASTE ELIMINATION AS THE CORE LOGIC OF JIT

The core logic of JIT is that of elimination of waste in a manufacturing system using a *deliberate* method. In order to understand this logic, the water-flow analogy given in Figure 13.2 will be useful. Consider a water-flow system such as a river. The river has rocky terrain and outgrowths from its bed. If we want to sail on the river using a boat, the amount of water required is a function of the technical specifications of the boat. The boat requires a certain clearance of water above the rocks and outgrowth in order to sail unhindered.

> The core logic of JIT is that of elimination of waste in a manufacturing system using a *deliberate* method.

One can use this analogy to represent a manufacturing system. In a manufacturing system, the smooth flow of material is often hindered by several constraints in the system. Quality problems at the manufacturing plant of the vendor may result in shortage and production disruptions. Poor maintenance of resources may take away valuable capacity through unscheduled breakdowns. Inadequate information and poor managerial decision making may stall production. In order to protect the manufacturing plant from such disruptions, it is customary to have excess inventory of material, manpower, machining, and other resources. We use terms such as *buffer* and *safety stock* to denote these excess investments in resources.

FIGURE 13.2 Water-flow analogy of a manufacturing system



In the water-flow analogy, only a certain volume of water will ensure that the required clearance for the smooth sailing of the boat is available. In the same manner, in a manufacturing organization, a certain level of investment is made as a buffer to protect the production system from disruptions. Therefore, the volume of water directly corresponds to the buffer built into a manufacturing system. Similar examples can be found in service organisations also. Excess capacity of resources (mainly human), tossing of information access various stages of operations happen in service systems.

Let us now try to understand how organizations react to certain events. Let us assume that there is frequent production disruption due to the poor quality of material supplied by a vendor. Traditionally, how have organizations solved this problem? The materials and production planning managers review the situation and re-estimate an appropriate level of safety stock to be built into the system. It may require additions to the safety stock to restore production levels back to normal rates. One can advance similar arguments for solving problems arising out of excess absenteeism of workers and frequent breakdown of machines. These issues will call for similar methods of increasing the buffer in the system Let us now try to understand how organizations react to certain events. Let us assume that there is frequent production disruption due to the poor quality of material supplied by a vendor. Traditionally, how have organizations solved this problem? The materials and production planning managers review the situation and re-estimate an appropriate level of safety stock to be built into the system. It may require additions to the safety stock to restore production levels back to normal rates. One can advance similar arguments for solving problems arising out of excess absenteeism of workers and frequent breakdown of machines. These issues will call for similar methods of increasing the buffer in the system to restore smooth production rates. In our water-flow analogy, the situation corresponds to adding more water into the system because one of the rocks is surfacing above the water level.

The philosophy of JIT is in contradiction with traditional thinking on solving such problems encountered in manufacturing and service systems. It works in two ways. In the case of water flow, instead of pouring more water into the system to cover the newly grown structure, efforts will be made to “trim” the new growth and bring it back to a limit so that the boat can continue to sail smoothly. In our manufacturing example, if there is a problem with the supplier, instead of increasing the safety stock, collaborative efforts will be launched with the suppliers to solve the problem.

> The philosophy of JIT is in contradiction with traditional thinking on solving problems encountered in manufacturing systems.

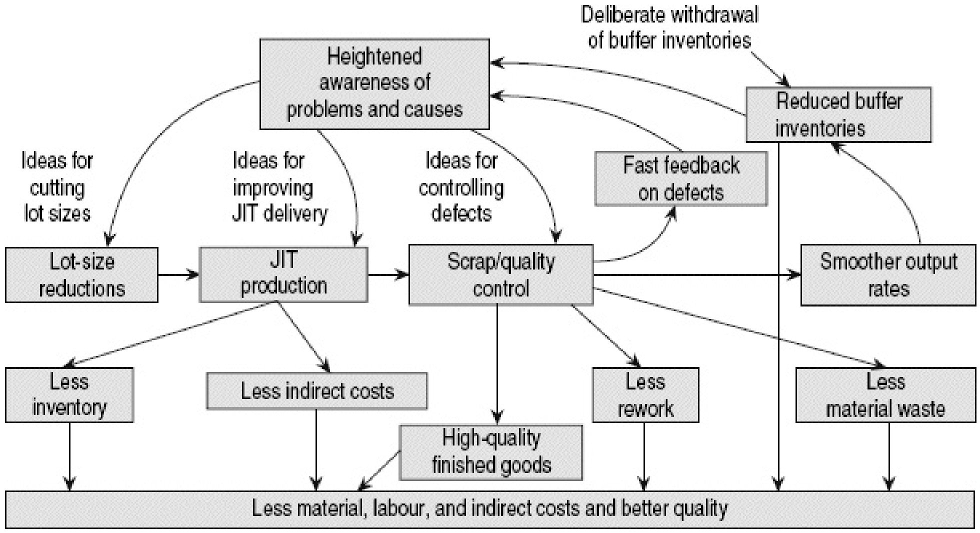
However, the crux of JIT philosophy is to go one step further and deliberately create some disturbances in the system in order to uncover problem areas. Once the problems are exposed, the organization will work towards solving the problem and restoring smooth production rates. Returning to our water-flow example, what it means is that when the boat sails smoothly, we pump out some water from the system and expose the tallest rock, then chisel the rock to a level that the boat can resume sailing smoothly. After a few rounds of smooth sailing, pump out some more water and continue the process.

In the manufacturing example, what it means is to have a method by which the buffer is withdrawn from the system. By withdrawing the buffer, new problems are exposed. By studying the problem, new methods will be devised to restore smooth production rates. After one cycle of this exercise is satisfactorily completed, begin the next cycle by withdrawing the buffer once again. Proceeding in this manner, the buffer in the system could be progressively reduced even while smooth production rates are restored.

What makes JIT philosophy different from conventional thinking is the “deliberate” choice on the part of management to expose hidden problems even while the production system is operating at a certain level of equilibrium. Therefore, one can define JIT as an organization-wide mandate to systematically expose hidden problems.

Figure 13.3 presents a schematic representation of JIT logic and the overall impact it has on the manufacturing system. When the system has smoother production rates, deliberate withdrawal of buffer inventories results in reduced buffer in the system. Moreover, as we discussed, it exposes problems and the causes of these problems. To solve the problem, ideas are required for controlling defects, improving delivery performances, and cutting lot sizes. These ideas are implemented in the core manufacturing and quality assurance systems in the organization. Once these ideas are satisfactorily implemented, the systemresumes its smooth production rate. The upper half of Figure 13.4 portrays these components of JIT logic. The key difference between the earlier state and the current state is that there will be a reduced level of buffer inventories in the system.

FIGURE 13.3 JIT logic and its beneficial effects on a manufacturing system



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The benefits accruing to the system are not just reduction in inventory. They are manifold. The lower part of Figure 13.4 captures the beneficial effects of implementing JIT in a manufacturing organization. One significant benefit arising out of smaller lot sizes is the faster feedback on quality. Assume that a firm was earlier working with a batch size of 1,000. After some investment of efforts and technology let us assume that they brought down the batch size to 100. This has significant advantages to the firm. First, if a batch has to be scrapped or reworked on account of a defective process or tool discovered much later, then a smaller batch size of 100 would mean fewer hours of rework or fewer hours of valuable productive capacity lost on account of scrap. Moreover, a smaller batch size means that the problem is discovered much earlier. All these result in improved productivity and reduced product cost as depicted in the lower part of Figure 13.4.

FIGURE 13.4 A schematic representation of the architectural change required for JIT

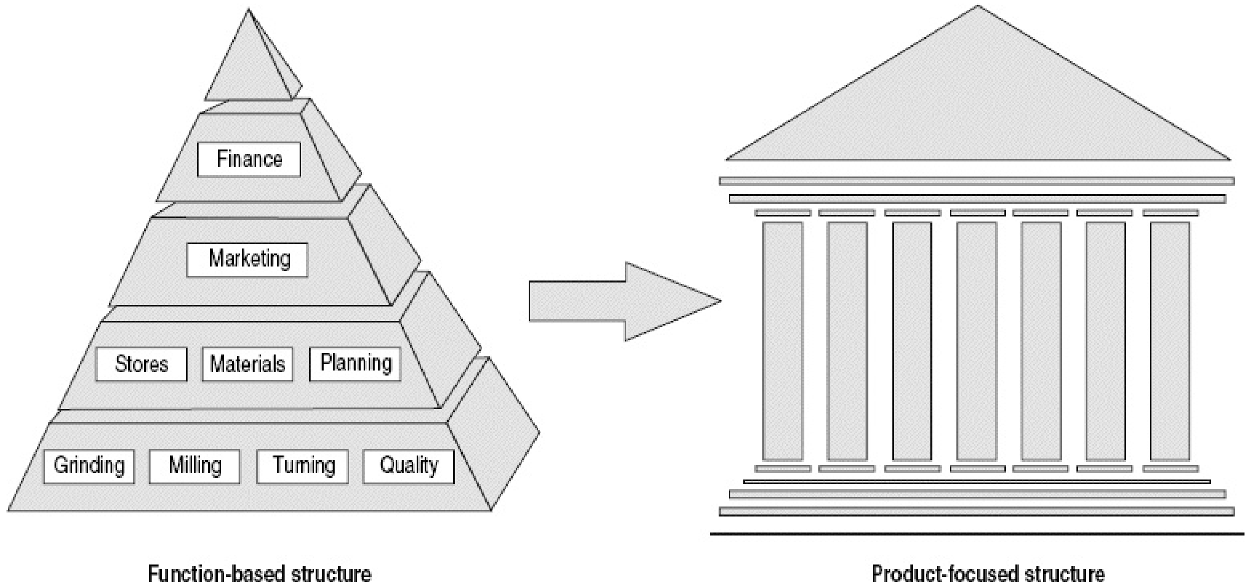


TABLE 13.2 JIT Logic and Overall Impact

JIT Logic	The Overall Impact of JIT
Withdraw buffer “deliberately”	Faster feedback on quality
Expose hidden problems in the system	Quality improvement
Identify solutions to the problems, implement and attain smooth production rates	Tight linking of preceding and subsequent processes
Repeat the above steps	Increased responsibility effects

Moreover, as the lot size is reduced, the succeeding process no longer views inventory as the critical link in the operations. Rather, the preceding process and the succeeding process get tightly linked as we typically see in the case of single-piece flow systems with no intermediate inventory. In such systems, making system-wide improvements is not only feasible but also a common reality. Table 13.2 summarizes the key features of JIT logic and the benefits of JIT.

> The benefits accruing to the system are not just a reduction in inventory. They result in improved productivity and reduced product cost.

VIDEO INSIGHTS 13.1

Lean manufacturing principles were initially introduced by Toyota in their production systems. Over the years, all manufacturing companies irrespective of the nature of manufacturing have embraced the lean philosophy. Of late, Aerospace manufacturers have also found the need to implement the principles of lean. To know more about how Boeing uses principle of lean in their manufacturing system, find the video links (Video Insights) in the Instructor

Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

13.6 ELEMENTS OF JIT MANUFACTURING

Although the logic of JIT is intuitively appealing, in reality, to practice it and reap the promised benefits, an organization needs to have several key elements in the manufacturing system. We have already seen that lot size reduction is one such element of JIT manufacturing. We discuss some of the other key features in this section.[5]

Changes in the Manufacturing Architecture

Manufacturing architecture provides an overall framework in which the various activities, people, and issues that are related to the production and distribution of goods and services either directly or otherwise are organized.[6] Essentially, manufacturing architecture defines the nature of the relationships between the various functional units in an organization and addresses issues relating to structure, systems, procedures and people. Through a careful choice of system and structure issues, it tries to create a seamless structure that encompasses the entire value stream and brings about a physical and logistical linkage among the functional units.

Manufacturing architecture defines the nature of relationships between various functional units in an organization and addresses issues arising out of structure, systems, procedures, and people.

The most significant change required to practice JIT is to create a new manufacturing architecture. JIT emphasizes waste elimination, and in order to perform this, the manufacturing architecture should be conducive. Figure 13.4 illustrates the transformation schematically. The principles of making changes in the manufacturing architecture address two types of issues. The first is the *structural issue*. Structural issues confine themselves to the physical aspects of carving out the new architecture. This includes the layout of machines and other resources on the shop floor and in the offices, and the organization structure and reporting relationships between employees in an organization.

The second is a set of logistical issues. Issues related to systems, procedures, and people are referred to as *logistical issues*. Organizations need to understand that changes in structural issues need to be complemented by corresponding changes in logistical issues. Merely changing the physical aspects at the shop floor and the offices does not provide the desired improvements. The actual improvements and benefits accrued are commensurate to the corresponding changes made in certain systems, procedures, and people-related issues. For example, the new structure will demand that the skills of people be re-distributed in a different fashion. The predominant customer focus of the whole design will force radical changes in the systems used for measuring performance and rewarding people in the organization. New systems and procedures will be required to seamlessly integrate the supplier layer with other layers internal to an organization.

Changing the layout, re-deploying the workforce, and redefining the organization structure are not likely to be easy. They result in altered power structures, and call for a different working style and behaviour. Effort is required to design a better workplace organization. Visual boards can play a major motivational role in directing improvements and increasing the ownership of product and process. They can play a leading role in linking all the functional areas of an organization through an information network. Without such exercises, the agenda of waste elimination using JIT may not be feasible.

The final outcome of the architectural changes made to a manufacturing organization is that a system having a chain of customers–suppliers emerges[7]. Beginning with marketing, which is the internal arm of the ultimate customer, a chain of preceding and succeeding processes is established. Finished goods (FG) stores will have a supplier relationship with marketing. Similarly, final assembly will become a supplier to FG stores. Manufacturing will resemble a linked chain with several links. Each link will have a supplier–customer relationship and will feed the material from the raw material stores right up to the final assembly. This chain structure will greatly aid material flow, production planning, and control functions.

Lot-size Reduction

Capacity issues in JIT need to be addressed using an approach that is different from traditional thinking. As JIT is about waste elimination, there is a greater emphasis on uncovering capacity wasted in manufacturing systems due to large set-up times and poor maintenance. In Japanese manufacturing management, capacity is nothing but a sum of actual production and waste. Thus, if there is a mass manufacturer with an installed capacity for producing 25,000 items per month using a set of resources, but averages a monthly production of only 22,000, then the balance 3,000 units lost is accounted as waste.

One major source for waste elimination in most organization is set-up time reduction. When set-up time is reduced, it is obvious that the lot size will also be smaller. Imagine that there are two identical manufacturing set-ups. In the first, the set-up time is 12 hours and in the second the set-up time is 30 minutes. Clearly, in the first case, it makes very little sense to set up a machine for 12 hours and engage in production for say 1 or 2 hours. Therefore, the lot size will tend to be at least equal to the production for 12 hours. In contrast, in the second case, it is possible to set up the machine frequently and produce in smaller quantities. This increases the ability of the organization to respond to changes better. We have already seen the benefits that accrue to an organization on account of smaller lot sizes.

Set-up Time Reduction Through SMED

Set-up time is the time required to set up a process (or a machine) before it can be used for production. Typically, before a machine can be used for production, the required tools are to be loaded to the machine. Furthermore, the required jigs, fixtures, and work holding devices are to be set up on the machine table and some referencing of these with respect to the table are to be made in order to ensure that parts of correct geometry and specifications are finally produced.

Usually, it takes a long time to complete this initial operation. Set-up time is directly related to the ability of an organization to change over from one variety to another.[8] It also influences the batch size (as explained earlier). Automobile manufacturing firms make use of large presses to bend sheet metal to required shapes, and these presses require large set-up times. Therefore, one method of continuous improvement was to reduce the set-up time on these presses.

Set-up time is the time required to set up a process (or a machine) before it could be used for production.

The earliest success stories in JIT have a strong component of set-up time reduction initiatives. Shigeo Shingo developed the **single-minute exchange of die (SMED) system** to drive down set-up time. The philosophy behind SMED is that there are internal and external operations involved in any set-up of machines. *Internal operations* are those that require interruption of the machine for performing the set-up operation. Therefore, it results in loss of capacity. For example, changing a die in a press or a cutting tool requires stopping of the machine. On the other hand, there are several operations pertaining to set-up that could be done off-line. These operations are known as *external operations* and they do not result in any loss of capacity. Obvious examples include planning the set-up operation, obtaining the set of tools and other resources required, as well as obtaining the required authorizations. It is clear from this classification that internal activities are to be kept to the barest minimum so that capacity losses and inventory build-up can be eliminated.

Single-minute exchange of die (SMED) is a methodology proposed by Shingo to reduce set-up time.

SMED is a systematic method by which internal operations are progressively converted into external operations[9]. Initially, there will be minimum use of technology to achieve this. However, as the SMED process proceeds, it may call for a very close study of the set-up process and use of technology to make modifications on the equipment.

Set-up time reduction happens in stages. In the first stage, obvious imperfections in planning and procedural aspects are addressed. This may bring down the set-up time from several hours to about an hour. In the second stage, some technology is introduced to alter the design of fixtures, dies etc. This may bring down the set-up time to less than 30 minutes. In the final stage, extensive use of advanced technologies to make significant design changes on the equipment will be required to bring down the set-up to a “one-touch set-up” (of having a set-up time of about 100 seconds). This results in uncovering large amounts of wasted capacity and making the system flexible and responsive to changes. Batch sizes eventually drop close to one, permitting manufacturers to develop single-piece flow systems.

Set-up time reduction is a powerful tool for continuous improvement in a manufacturing organization. In a manufacturer of automotive components, the installed capacity of a certain part of the manufacturing system was 32,000 components per month. However, the organization never achieved a monthly production of more than 24,000 components. This was mainly attributed to the loss of capacity due to the large set-up time required for the machines. Instead of augmenting the capacity by adding new machines, the organization chose to launch a set-up time reduction campaign. Table 13.3 shows the results after four rounds of iteration. Due to a dramatic reduction in set-up times, the company was able to produce over 29,000 components. Such examples are not isolated in manufacturing organizations. In fact, several progressive organizations utilize SMED for such continuous improvement efforts and instantly reap the benefits.

> SMED is a systematic method by which internal operations are converted into external operations progressively.

Though the concept of SMED was initially applied only to presses, soon it was extended to all manufacturing processes and later even to administrative processes. The value of set-up time reduction lies in an organization's ability to produce in smaller batch sizes and thereby respond faster to market requirements. It enables an organization with the necessary conditions for lead time reduction and JIT manufacturing.

Kanban as a Control Tool

Production control is primarily achieved by passing information pertaining to production to the respective work centres. The information typically consists of an authorization to produce a certain quantity of items beginning at a particular time. Although this appears to be a simple task, traditional manufacturing systems have experienced difficulties in performing this task. This is partly due to bad structures emphasizing functional orientation. However, JIT systems make architectural changes and simplify the planning and control process to a large extent. Therefore, it is possible to devise alternative methods for production control. Typically, JIT manufacturers utilize a concept known as **kanban**. *Kanban* is a Japanese word, which approximately denotes a card or a visible signal.

> JIT manufacturers utilize a concept known as **kanban**, which denotes a card or a visible signal.

TABLE 13.3 Results of a Set-up Time Reduction in a Manufacturing System

Operation/machine	Changeover Time (in minutes)			
	Round 1	Round 2	Round 3	Round 4
Wyvomatic A	540	450	205	
Acme gridley	1020	315		
Wyvomatic B		165		
Stama feed machine		510	180	60
Stama bleed machine			110	65

TABLE 13.4 Production Planning and Control using Kanban

Governing Principles of Kanban Usage	Production Planning and Control Implications
Subsequent process picksup as indicated by kanban	Provides pickup or transport information
Preceding process produces as indicated by kanban	Provides production information
No production at a work centre or movement of material between processes without kanban	Prevents overproduction and excess transport
Always attach kanbans to goods	Serves as a work order
Defects not sent at all	Prevents defective products by identifying the process
Reducing the number of kanbans is the long-term focus	Exposes problems, reduces inventory and eliminates waste from the system

Taichii Ohno, the father of the Toyota production system, conceived the logic of kanban as a production control tool based on the stock replenishment process in a supermarket. In a super market, various goods are displayed on the shelf in limited numbers. As customers “pull out” their requirement, the inventory of items in display depletes. Therefore, at the end of the day (or as soon as the shelf empties), the shelves are refilled to the extent of consumption. The use of kanban for production control is very similar.

A pre-determined quantity of items is to be stacked between every pair of succeeding and preceding processes. As the customer pulls out her requirement, the signal travels along the chain and each link in the chain schedules production only to the extent of refilling the stocking points. The signalling from the customer down to the raw material stores is done through kanban. Kanban could be a card, an electrical signal, or a message flashed through the Web.

Table 13.4 outlines the guiding principles of kanban usage and its implications for the production planning and control function. Kanban provides the production, pickup, and transport quantity required in any production planning control function. This is achieved by ensuring that the preceding and succeeding processes pick up or produce only the amount indicated in the kanban. Since neither pickup nor production is possible without a kanban, it not only serves as a production and move authorization note but also eliminates overproduction and excess transport. By replacing the work order with a kanban, it is ensured that kanban is attached to goods at various stocking points. Finally, waste reduction by the deliberate withdrawal of buffers from the system could be achieved by progressively removing kanban cards circulating between a pair of preceding and succeeding processes. As we discussed in the core logic of JIT, this is a long-term focus for using kanbans as a production control tool.

ideas at Work 13.2

Set-Up Time Reduction in Brakes India

Automotive component manufacturers are at the cutting edge of technology and process innovation in the manufacturing sector in India. Brakes India, a leading auto-braking system manufacturer, is among the early adopters of JIT techniques in the country. Amongst their several initiatives, set-up time reduction deserves attention as it is one of the key enablers in JIT. Figure 13.5 shows a cell in one of their manufacturing units where the set-up time reduction exercise was taken up several years ago.

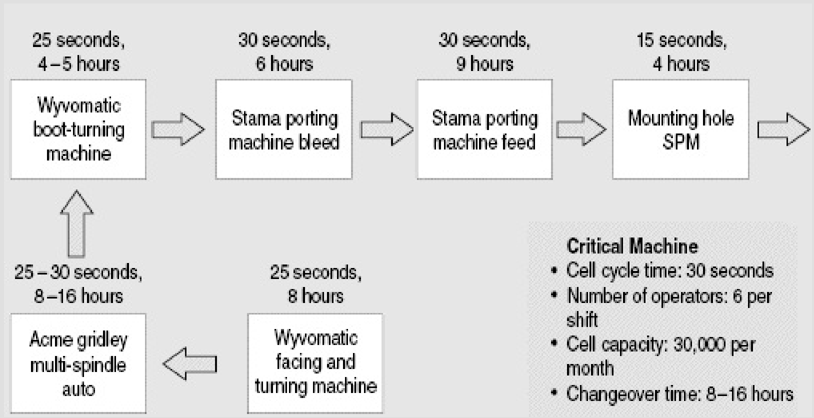
The cell has six machines and the set-up time varied between 4 hours and 16 hours. Such large set-up times did not allow Brakes India to implement JIT and handle the several varieties of their products. Therefore, a set-up time reduction exercise became inevitable. Before the start of the process, the installed capacity of the cell was 32,000 pieces in a month, and the maximum production that they could achieve was in the order of 24,000. There was a growing demand and uncovering hidden capacity made business sense as well.

Detailed process mapping was done based on several set-ups done during the study. Process mapping revealed the nature of activities undertaken for set-up and the time taken for each activity. Based on more than a dozen such observations, it was found that the large set-up time could be attributed to three major reasons: technological issues, procedural issues, and planning issues. Poor planning and improper procedures consumed close to 75 per cent of the time taken for set-up. It was possible to address these immediately.

The identification of alternative planning and procedures for machine set-up was done on the basis of brainstorming and an analysis of the data collected. It took about a month to implement the revised operating procedure in the cell. The benefits accrued were direct and significant. The set-up time dropped to significant levels. The production in the cell rose from 24,000 to over 29,000 pieces per month. The other benefits included reduced lot size, less inventory in the system, faster feedback on operating performance, and an increase in the quality level.

Source: Based on K. Sunder, “Introduction of SMED and Poka-Yoke Concepts,” Unpublished Report Submitted in the MPT Programme, IIM Bangalore.

FIGURE 13.5 A cell in one of the manufacturing units



There are different types of kanbans. The exact purpose of each of these alternative types, and the number of kanbans required for a given manufacturing situation are important design issues in using kanban-based production control systems. However, implementing a kanban-based production control system requires standard containers (corresponding to the quantity that we would like to keep at each stocking point).

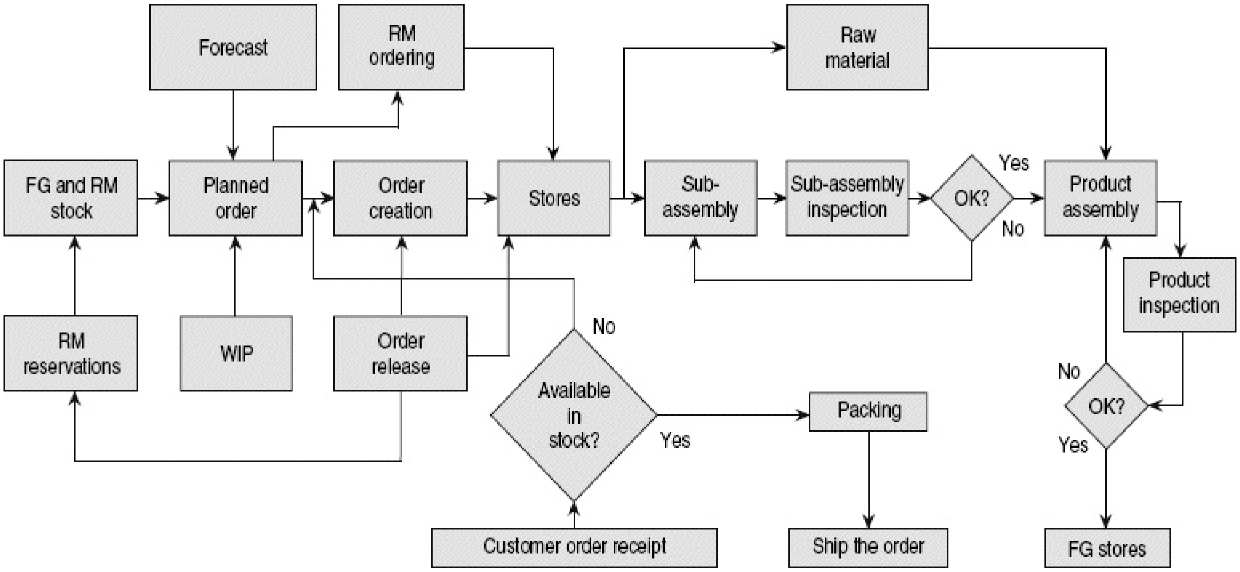
> Kanban provides the production, pickup, and transport quantity required in any production planning control function.

13.7 PRODUCTION PLANNING AND CONTROL IN JIT

The supermarket example clearly shows that the activities in the entire system are triggered the moment a customer "pulls" out a certain quantity of finished goods. Since kanbans use a similar system, the scheduling logic used is known as *pull scheduling*. In contrast, traditional approaches to scheduling utilize "push" logic and are hence known as *push scheduling*. Before we look into the detailed working of a kanban-based system, it is important to know the key differences between pull-scheduling and push-scheduling logic.

> The scheduling logic used in JIT is known as pull scheduling. A pull-type scheduling works with the supermarket logic.

FIGURE 13.6 Schematic illustration of push scheduling



Push and Pull Scheduling

Figure 13.6 illustrates the key elements of a push-scheduling system. In this system, forecasts drive the entire production. To begin with, detailed forecasts of demand are made and then refined further on the basis of recent information to provide the input for an MPS/MRP system to derive the detailed week-by-week schedule for each work centre in the manufacturing system.[10] The actual offtake by the customer (or the market) is not taken directly into consideration. Instead, it needs to be factored into the forecasting/demand management module well in advance. Once the planning is finalized and released to the production shop, raw material is issued from the stores to respective work centres and the components are progressively “pushed” towards the final assembly and eventually to the finished goods stores. As a result of this method, planning drives production and determines the availability of finished goods. It is generally assumed that the planning premise is good. Therefore, when the customer order arrives, the item is picked up from the finished goods stores and shipped. Otherwise, it may call for a detailed product chase and expedition before actually shipping the customer order.

> In a push-scheduling system, forecasts drive the entire production.

In contrast, a pull-type scheduling works with the supermarket logic. A customer order triggers production in a pull-scheduling system. Assume that customer demand for 50 units of an item is met with available finished goods in the stores. Since 50 units are dispatched, an order will be placed with the final assembly shop to assemble 50 units of the product so that stocks are replenished. In the process of assembling 50 units, the final assembly would have consumed the required number of sub-assemblies as specified by the product structure. Therefore, respective orders will be placed to the feeder shops to manufacture the sub-assemblies to the extent of replenishing the stock of sub-assemblies consumed. The information passes in this manner up to the raw material stores. At each stage of manufacturing, the shop pulls a certain quantity of input material and the preceding shop responds to the pull.

The choice between a pull-type system and a push-type system is dictated by several factors governing the operation of a manufacturing system. Pull-type scheduling cannot be implemented in all manufacturing systems. It requires that the manufacturing system have sufficient flexibility to respond swiftly to changes. Moreover, it implies that the organization is customer-focused and has low demand variations. On the other hand, if the manufacturing system works with long lead time and a greater emphasis on utilization-based measures of performance, the push method of scheduling may be appropriate. However, since the actual customer demand is not directly incorporated into the scheduling exercise, build-up of inventory may take place in a push system. Moreover, an organization practising push-scheduling tends to be internally focused.

However, the choice of pull or push type of scheduling has greater implications for the manufacturing system. These relate to the ability to react to changes, responsibility issues, and the method and ease of control. In a pull-type schedule, the responsibility of monitoring always rests with the centralized scheduler. If plans go awry, the scheduler will perform a major re-planning exercise and try to bring the system back to order with a fresh set of directives regarding what to manufacture and when. The people in the system merely wait for the next planning document and react to it. On the other hand, in a pull system, the responsibility rests with the operating personnel, as it is their responsibility to ensure that stocks are quickly replenished as soon as the upstream process consumes a certain quantity. Therefore, in a push-type system, the problems are hidden, whereas in a pull-type system, the problems are exposed directly and create a sense of urgency among the operating personnel.

> In a push-type scheduling system, problems are hidden, whereas in a pull-type system, the problems are exposed directly.

Moreover, in a pull-type system, a visible indication of the problem is that production stops on account of nonreplenishment of stocks by the downstream process. In the case of push-type scheduling, the only way to know that there are problems in the existing system is by recognizing the piling up of inventory (mostly unwanted and mismatched). Therefore, push-type scheduling requires a considerable amount of paperwork to plan and control operations. On the other hand, in a pull-type system, simple visible controls are established automatically by the logic behind the system. Table 13.5 outlines the salient features of pull- and push-type scheduling from the perspective of production planning and control.

The Kanban System

Different variations of kanban exist today. Although the basic logic does not change, there are some minor differences in operating policies between these variations. However, it is useful to understand the working of the dual-card kanban system. In a dual-card kanban, two cards are used for planning and control purposes. These are **production kanban (P-kanban)** and **conveyance kanban (C-kanban)**. Irrespective of the type of kanban, each of them have basic information about the item, its specifications, details about the preceding and succeeding processes, and the quantity of items associated with each such kanban. A P-kanban basically serves as the authorization for production of the number of items indicated in the kanban. For example, if a P-kanban has the indicated quantity to be 40 units, then each such P-kanban serves as an authorization for the work centre to manufacture 40 units. In a similar fashion, a C-kanban serves as the authorization to move that many units from the preceding process to the succeeding process, where it is used for processing.

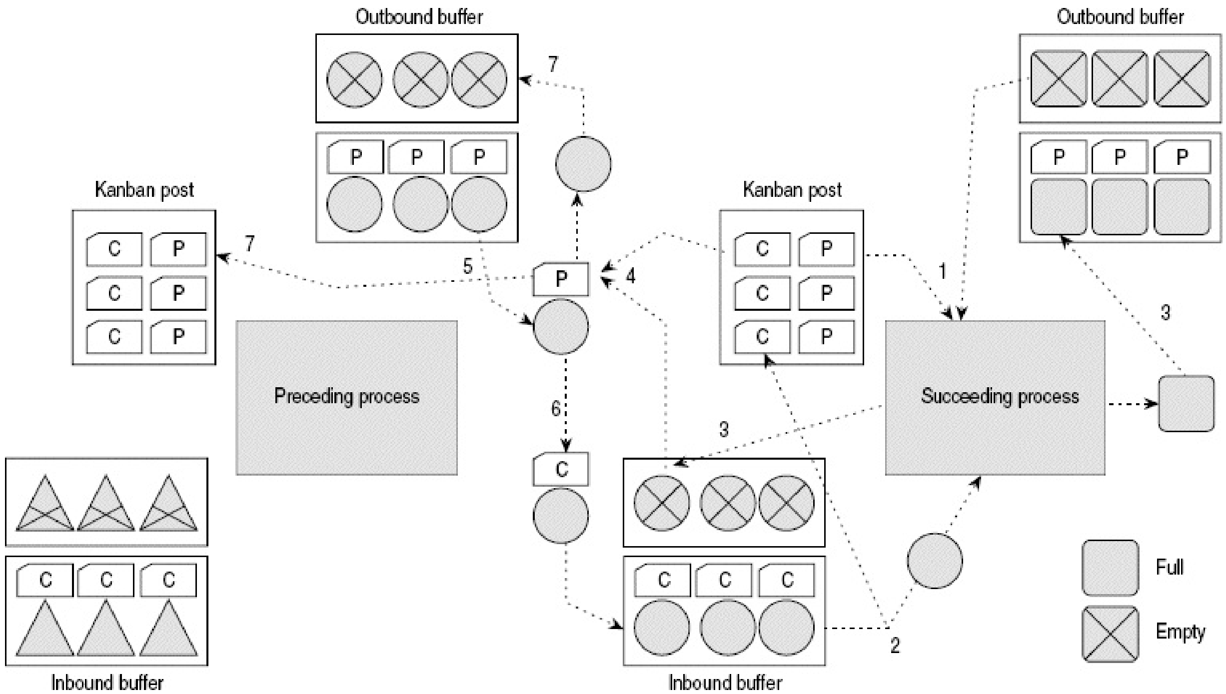
> In a dual-card kanban, two cards are made use of for planning and control purposes. These are **production kanban** and **conveyance kanban**.

Figure 13.7 presents a schematic representation of the working of a dual-card kanban system. Before we understand the working of the kanban system, it helps to acquaint ourselves with the structural features of the manufacturing system as depicted in the figure.

TABLE 13.5 Push and Pull Scheduling: A Comparison

Issues to Consider	Push Scheduling	Pull Scheduling
Responsibility to monitor	Scheduler/system	People in manufacturing
Flow control	If all standards are met	Always
Signal to build	Schedule/system	Visible—from customer
Inventory	No limit—higher	Limits— lower
Problems	Can be hidden	Exposed—creates urgency
Communication between operations	By chance—individual operators work on their orders	By necessity
React time:changes/problems	Through the system— rescheduling required	Immediate—online and visible
Visible indication of problem	Inventory	Production stops
Shop-floor control	System, transactions, paper work	Automatic, visible, and simple

FIGURE 13.7 Working of a dual-card kanban system



- *Preceding and succeeding processes*: The basic element of material flow in a JIT system is between a pair of processes. The preceding process feeds the required components to the succeeding process. A pair-wise relationship of such preceding and succeeding processes is primarily responsible for cascading the pull effect from the final customer down to the raw material stores, as we have already seen.
- *Inbound buffer*: Every process has a designated space for an inbound buffer. The inbound buffer has provisions for storing the components moved from a preceding process using a C-kanban. Therefore, each full container of inbound buffer will have a C-kanban attached to it. However, after utilizing the components for processing, the empty container is usually returned to the inbound buffer and the associated C-kanban to a kanban post (or holder).
- *Outbound buffer*: Just as in an inbound buffer, each process in an outbound buffer has a designated place to store the components after processing is completed. Since processing is always authorized only by a P-kanban, we would expect every full container to have a P-kanban attached to it. The succeeding process would have left empty containers in the outbound area, which need to be subsequently replenished by the process. The associated P-kanban will be deposited in a kanban post (or holder).
- *Kanban post*: The number of C-kanbans and P-kanbans and the quantity for each kanban associated with each item of inventory in a manufacturing system is a design issue. However, since more than one P-kanban and C-kanban may be there for each item of inventory, and since several items may be produced in a particular work centre, it is typical to have a kanban post to hold these kanban systematically. Moreover, the kanban post also serves as a visual control aid to production control.

The working of the kanban is best explained using a serial set of actions taken at the succeeding and preceding processes using the numbered sequence in Figure 13.7. The step-by-step explanation corresponding to the numbers in Figure 13.7 is as follows:

- **Step 1:** The succeeding process begins one cycle of production as soon as P-kanbans (which authorize the production) and empty containers are available. One P-kanban is drawn from the kanban post and an empty container is picked up from the outbound buffer area.
- **Step 2:** In order to begin production, one full container with an attached C-kanban is moved from the inbound buffer area to the processing area. The C-kanban is detached from the container and displayed at the kanban post. Production of components begins.
- **Step 3:** As production is completed, the P-kanban is attached to the full container of finished item and the container is

moved to the outbound area. Similarly, the empty container (since all components are used up for manufacturing) is moved back to the inbound buffer area.

Since the succeeding process pulled out one full container of components from the inbound buffer area, used it for manufacture and returned back the empty container, it will trigger action in the preceding process to replenish what the succeeding process consumed. The remaining steps describe this process.

- **Step 4:** One empty container from the input buffer area of a succeeding process and a C-kanban from the kanban post of the succeeding process will be taken to the outbound buffer area of the preceding process for replenishment.
- **Step 5:** Swapping of kanban cards between containers takes place at the outbound buffer area of the preceding process. What this means is that the P-kanban attached to the full container will be replaced by a C-kanban.
- **Step 6:** As a result of this swapping operation, the full container and C-kanban will return to the inbound buffer area of the succeeding process.
- **Step 7:** The empty container will be placed in the outbound buffer area of the preceding process. The P-kanban will be displayed at the kanban post of the preceding process.

It may be noted that using this 7-step process, we have ensured that empty containers and P-kanbans are available at the preceding process. Therefore, we can return to Step 1 and perform one more iteration of moving empty containers and P-kanbans to an earlier process. This is how the pull effect cascades through the system.

Design of Kanban Quantities

One crucial question that we need to answer in the working of a kanban system is the choice of container size and the number of such containers that we need to have. Since each container should be attached with a kanban, the number of containers required is nothing but the number of kanbans in the system.

> The number of containers required is equal to the number of kanbans in the system.

The design of a kanban-based system very closely follows the fixed order quantity (FOQ) system in traditional inventory control.[11] In the FOQ system, an order is placed for an item when the stock level reaches the reorder point. The quantity ordered is a fixed number arrived on the basis of some considerations, which could include set-up costs carrying costs and other practical considerations. These inputs are used for computing the container size and the number of kanbans required in a JIT system.

Standard containers

In a JIT manufacturing system material, flow control is obtained through the use of predetermined quantities stored in standard containers. The size of the container is the first issue to be resolved. Generally, containers of smaller quantities are recommended. This has several advantages. Smaller containers are easy to move between stations, require lesser space to store, provide better methods of access and material handling and permit the build-up of lesser buffer quantities in the system. Typically, the thumb rule is to have about 10 per cent of the daily demand as the quantity per container. If the daily requirement of an item is 200 units, then the size of the container is usually kept at 20. The size of the standard containers is denoted as Q.

> Material flow control is obtained in a JIT manufacturing system through the use of predetermined quantities stored in standard containers.

Number of kanbans

The number of kanbans is clearly the function of the demand during lead time, the safety factor, and the size of each container. Assume that

Demand rate = D
Number of kanbans = K
Production lead time = P
Conveyance lead time = C
Safety factor = α
Container size = Q

Since the total lead time is the sum of production and conveyance lead times, the number of kanbans is given by:

$$K = \frac{D(P + C) \times (1 + \alpha)}{Q} \tag{13.1}$$

The production and conveyance lead times are critical parameters for computing K. Therefore, organizations need to have a better understanding of what constitutes these lead times. Let us go back to the working of the dual-card kanban system once again. The C-kanban initially waits at the kanban post. It then moves to the output buffer area of the preceding process (with an empty container) and moves back (with full container) to the input buffer area of the succeeding process. It waits in the input buffer area until a container is pulled out for processing. During this time, the C-kanban again reaches the kanban post. The elapsed time between these stages is the conveyance lead time. It is possible to estimate an average conveyance lead time based on several observations of this process.

We can map a similar process for estimating the production lead time. The P-kanban waits at the kanban post. It then moves to the processing station (along with an empty container). After processing is completed, the P-kanban comes back to the output buffer area (with a full container). It waits at the output buffer area until a C-kanban from the succeeding process arrives to swap the kanban cards of the containers. The P-kanban then reaches the kanban post again. The time elapsed between these stages is the production lead time. The processing time will be the major component of production lead time. It consists of set-up time, processing time and in-process waiting time.

Equation 13.1 is a general expression for computing the number of kanbans. It can be suitably adopted to compute the number of C-kanbans (K_c) and the number of P-kanbans (K_p) in the case of a dual-card kanban. The expressions for K_c and K_p are as follows:

Number of C-kanbans:

$$K_c = \frac{D(C) \times (1+\alpha)}{Q} \tag{13.2}$$

Number of P-kanbans:

$$K_p = \frac{D(P) \times (1+\alpha)}{Q} \tag{13.3}$$

EXAMPLE 13.1

Consider a JIT manufacturing with a dual-card kanban system for production control. The daily demand for a component is 19,200. The plant works on a single-shift basis. The conveyance time and the processing time for the components are estimated to be 30 minutes and 45 minutes. Assume a safety factor of 10 per cent. If the standard container for the item can hold 240 items,

a. Determine the number of kanbans required.
b. What is the effective level protection provided for the conveyance and the production process in the system?

Solution
(a) Number of kanbans required
The daily demand is 19,200. Since the plant works for eight hours, the demand rate is 2,400 per hour, the number of conveyance kanbans (K_c) required can be computed using Eq. 13.2.

Substituting the values, we get,

$$K_c = \frac{D(C) \times (1+\alpha)}{Q} = \frac{2400 \times 0.50 \times (1+0.10)}{240} \times 5.5 \cong 6$$

Similarly, the number of production kanbans (K_p) can be computed using Eq. 13.3 as follows:

Substituting the values, we get,

$$K_p = \frac{D(P) \times (1+\alpha)}{Q} = \frac{2400 \times 0.75 \times (1+0.10)}{240} = 8.25 \cong 9$$

(b) Effective level of protection
In these computations, we did not obtain integer values for K_c and K_p. Therefore, we had to round it off to either the lower or the higher integer. In this example, we have rounded them to the next higher integer. The implication of this is that we have more inventory in the

system than required for a safety factor of 10 per cent. Re-computing the safety factor will reveal the actual safety that we have built in the system. Solving Equations 13.2 and 13.3 for α, we get:

$$\alpha_c = \frac{K_C Q}{D(C)} - 1 = \frac{6 \times 240}{2400 \times 0.5} - 1 = \frac{1}{5} = 20\%$$
$$\alpha_p = \frac{K_P Q}{D(P)} - 1 = \frac{9 \times 240}{2400 \times 0.75} - 1 = \frac{1}{5} = 20\%$$

Therefore, by rounding off the number of kanbans to a higher integer, we have provided a safety factor of 20 per cent for both the conveyance and the production process.

13.8 THE CONTINUOUS IMPROVEMENT PROCESS

Industrial customers demand that their suppliers reduce the price of the components that they purchase on an annual basis. It is very common to negotiate and finalize annual supply contracts with a requirement to reduce cost by 3–5 per cent. At an inflation of 5 per cent, this translates into nearly a 10 per cent reduction in the cost over the previous year. They also demand lead time reduction and greater variety in their offerings. Moreover, firms also set their own internal targets to reduce the level of inventory and the cost of manufacturing in the future. All these will mean that operations need to improve continuously on a year-to-year basis to match with the market demands. Therefore, the continuous improvement of operations is an important element of modern operations management practices in every manufacturing and service firm in the country. Moreover, continuous improvement is a crucial element of lean management.

The success of Japanese firms in the early 1970s was largely attributed to their predominant use of continuous improvement methods to bring down the cost and lead time in their manufacturing operations. By **continuous improvement**, we mean a positive change in the working conditions in an operating system leading to better performance of the operating system, which would be evident from key performance measures on an ongoing basis. For example, in 1976, nearly 49 per cent of all set-up time activities in Jidhosha Kiki Ltd., Japan, took more than 30 minutes. However, by 1981, 62 per cent of all set-up time activities were completed within 100 seconds. In this example, we are able to conclude that a visible improvement in the operating system leads to better performance and elimination of wasteful activities. Such an improvement is typically done through the **continuous improvement** of operations.

Continuous improvement means a positive change in the working conditions in an operating system leading to better performance evident from key performance measures on an on going basis.

ideas at Work 13.3

Towards Zero Non-value-added Activities

A manufacturer of industrial transportation equipment had to devise ways and means of cutting down the cost and lead time of a particular product that they had been manufacturing for several years. These concerns were never there during the firm's long history of operation. However, increased competitive pressures forced the organization to make improvements in the process. After some preliminary data collection and brainstorming exercises, it was decided to study a few important sub-assemblies with respect to the average lead time taken to manufacture these sub-assemblies with a view to reduce the lead time.

For each of the sub-assemblies identified, various activities were first documented based on an observation of process over a two-month period. For a particular sub-assembly, there were 81 activities in all, which were required to complete processing and it took, on an average, nearly 1,680 hours of time. Analysis of the data (shown in Table 13.6) revealed the following:

Table 13.6 shows that value-added activities account for just 6 per cent of the total. A large percentage of time was being spent on waiting, an activity considered to be wasteful. This represented a huge opportunity for making improvements in the system. Very large waiting time points to poor planning and control of operations on the shop floor. Large moving time, on the other hand, points to a poor layout of the manufacturing resources.

TABLE 13.6 Analysis of the Data

Description of the Activity	Number of Activities	Time Taken (Hours)	Percentage of the Total
Value-added activities	5	104	6.1
Non-value-added activities	76	1,598	93.9
(a) Waiting	53	1,098	65.4
(b) Moving	18	373	22.2
(c) Adding cost	5	106	6.3

With the available data, the organization set out on in its journey towards eliminating non-value-added activities in the existing process. Detailed studies were conducted by groups of people in various work areas to understand what caused these excessive waiting times and movement in the shop floor. Based on these studies, recommendations were made which included far-ranging options, including re-layout of the machines and significant reduction in part varieties. An interesting fallout of the exercise was the classification of all the deburring operations as adding cost. Immediate actions were initiated to modify the process plan to eliminate the deburring operations altogether.

Source: S. Seshadri and B. S. Manjunath, "Creating Competitive Advantage Through Costing and Manufacturing," Unplished Report submitted in the MPT Programme, IIM Bangalore.

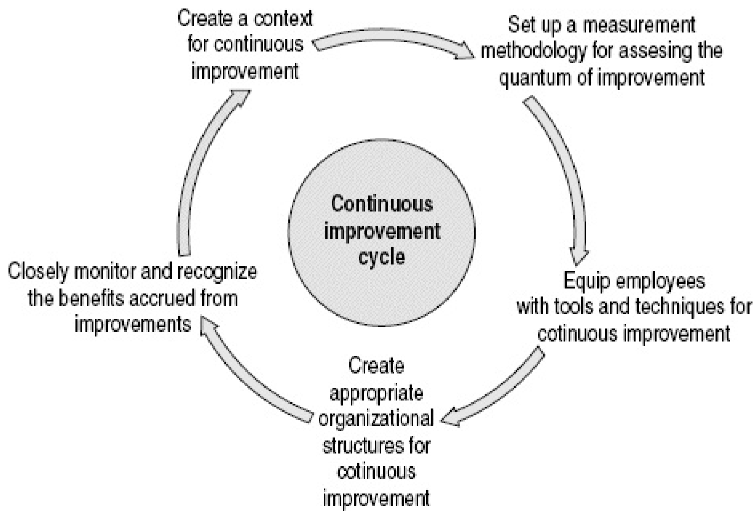
Continuous improvement method requires a lower capital outlay and can be practised on an ongoing basis. Therefore, it is relatively easy for organizations to launch a continuous improvement process. However, it requires greater stamina on the part of the workers and the middle managers, along with closer monitoring and tacit support from the top management. These are needed to sustain it over a long period of time and obtain fruitful results from it. The challenges of a successful continuous improvement programme hinges on these issues.

In the early 1980s several Indian organizations made a beginning towards the launch of quality circles. In several manufacturing firms, quality circles were formed, and improvement projects were launched with much fanfare. However, within a period of 9–12 months, most of them did not even survive and a majority of those still operational made practically no improvements in the system. Instead of motivating employees, these attempts left a bad impression among the employees and many felt that this was yet another trick to get productivity gains from the workforce without paying for it. This was against the very spirit of continuous improvement philosophy.

This experience clearly showed that continuous improvement does not take place in an organization on its own, nor is it an accidental benefit accruing to an organization. On the other hand, it calls for a structured process to establish and promote continuous improvement and motivate the employees towards an improvement trajectory. In the absence of such an approach, it is quite likely that organizations make a grand beginning and end up with nothing worthwhile. In order that any continuous improvement effort is fruitful, it calls for a set of enabling mechanisms to be put in place. Figure 13.8 illustrates this idea pictorially.

The first step in the continuous improvement process is to create a context for improvement. Context provides a perspective to the continuous improvement activities undertaken by an organization and enables a meaningful application of tools and techniques to improvement projects. The top management in an organization has to create a constancy of purpose and incentives for the middle management and the other workforce to make improvements by establishing an appropriate context for improvement. Several alternatives are available for creating the context. These include benchmarking exercises, TPM and TQM initiatives, preparing the organization for international awards (such as the TPM Prize, the Shingo Prize and other quality awards and certifications), and participating in industry-wide initiatives for overall improvement of the firms in the sector. In all these cases, there is both motivation and peer pressure for making improvements.

FIGURE 13.8 The continuous improvement cycle



The second step in the process is to set up a measurement methodology for assessing the improvement efforts. For example, an organization may have to considerably improve its quality and delivery to face up to competition in future. In order to quantify the nature of improvements in these two attributes, concrete measures may be needed. The measures should be easily measurable, objective enough, and relate directly to the attribute (quality and delivery in our case). For example, a set of lead time measures may be used for a number of processes, schedule adherence, and on-time delivery index as the possible measures relating to delivery. In the absence of a measurement system, employees do not know what the effect of their improvement initiatives has been. They also face considerable ambiguity in assessing if the quantum of improvement made is substantial or not.

> In the absence of a measurement system, employees may not know what the effect of their improvement initiatives has been.

Making continuous improvement calls for the application of several simple tools and techniques. In quality management literature, one finds several quality circle tools that aim at the improvement of processes. For example, poka yoke, the mistake-proofing method, enables organizations to improve the production process and eliminate defects. Similarly, there are other tools available for making a systematic study of the processes and identifying improvement opportunities. Employees need to be trained in the use of these tools and techniques for continuous improvement. Furthermore, continuous improvement requires unique organizational structures. It typically calls for a structure consisting of a large number of small groups of employees. Depending on the nature of improvements to be made, the employees could be from the same functional area or from a diverse set of functional skills. An appropriate organizational structure will provide the required mandate for the groups to champion the cause for improvement and attain the stated goals.

Finally, the top management needs to closely monitor the improvement programmes undertaken and utilize every opportunity to signal the importance it attaches to these efforts. It should also establish checks and balances in the system to ensure that there is role and goal congruence among the various teams with respect to the improvement trajectories they are pursuing.

VIDEO INSIGHTS 13.2

The first principles of lean are applicable in all sectors of business as waste elimination is the crying need of all organizations. Despite this basic understanding, it is not clear how the principle of lean will be applicable in offices. Moreover, there is resistance to implement lean in offices. How can one address these issues in a service set-up? To know more about this, find the video links (Video Insights) in the Instructor Resources or Student Resources under section **Downloadable Resources** (http://www.pearsoned.co.in/BMahadevan/) subsections **Bonus Material**.

13.9 TOOLS FOR CONTINUOUS IMPROVEMENT

Continuous improvement is a matter of the systematic study of an existing process and the identification promising opportunities for improvement. Improvements happen only when the extent of usage of resources is reduced while discharging the same set of activities. Alternatively, with the same set of resources, the level of activity must increase. To give a specific example, if there are five people in the purchase department of a firm, after an improvement, fewer than five should be able to complete the requirements of the department, or the existing five should be able to handle more procurement-related activities. It will be difficult to make such improvements without the use of some standard methods such as process mapping, non-value-added analysis, business process re-engineering (BPR), and QC tools, and kaizen. We discussed process mapping, non-value-added analysis and BPR in detail in Chapter 8. In Chapter 12, we introduced TQM and discussed several QC tools. The fundamental philosophy of TQM is to improve the quality of both the product and process and eliminate waste from the system. Therefore, it is obvious that the QC tools are ideally suited for continuous improvement in an organization. In this section, we shall look at how kaizen is employed for making improvements.

Kaizen is a Japanese term that literally means “change for the better”.[13] In the context of business organizations, it implies making continuous improvement involving everyone in the organization in a structured manner. A 5S campaign is frequently an operational aspect of most kaizen projects. 5S derives its name from five Japanese words, all starting with S.

- Step 1: *Seiri*, or “sort”, deals with the contents of a workplace and removes all items that are not needed there.
- Step 2: *Seiton*, or “set in order”, refers to “a place for everything, and everything in its place” to enable easy access to needed items.
- Step 3: *Seiso*, or “scrub”, refers to cleaning, so that employees can be proud about the way the workplace is organized and kept in good condition.
- Step 4: *Seiketsu*, or “standardize”, refers to having standards that everyone has to adhere to. Visual management is an important aspect to facilitate easy understanding of these standards.
- Step 5: *Shitsuki*, or “sustain”, refers to training all employees to ensure 5S application.

Typically, before the start of any 5S programme, the shop floor is not clean and also very cluttered. Machines do not have any maintenance schedules and they accumulate lots of dust and filth. Furthermore, improper operating procedures are adopted. This leads to a pile up of inventory on the shop floor, poor utilization of machines and avoidable wastages. A 5S programme helps keep the shop floor clean and orderly and provides a better working atmosphere for everyone. Due to the daily management discipline that develops through a 5S programme, better team play and improved employee morale and participation are promoted. Furthermore, it promotes process ownership by teams of workers and helps them with proper maintenance and cleaning schedules. Due to these changes, organizations experience considerable waste reduction and overall process improvement.

> A 5S campaign is the operational aspect of most Kaizen projects.

13.10 ORGANIZATION FOR CONTINUOUS IMPROVEMENT

Creating a context for continuous improvement is an important and the first step in a continuous improvement process. Providing the necessary tools is also important. However, what provides the final impetus is the setting up of appropriate organizational structures. In a normal sense, every employee is part of an organizational structure, reports to a superior, and performs the tasks assigned to him/her. However, when it comes to improvement, a similar structure is required. Making improvements in the business processes often calls for collaborating with people in different functional areas. Therefore, unless they have the required mandate, a clash of priorities is inevitable. Employees may find it hard to choose between spending time between an improvement initiative and the routine production tasks. Superiors will emphasize on production tasks and signal the need to complete them before they spend time on other activities. Due to these ground realities, employees may not be able to perform improvement activities in a sustained fashion, and improvement activities in the organization will cease to exist soon.

In recognition of the importance of appropriate organizational structures for continuous improvement processes, organizations have resorted to some methods for continuous improvement initiatives. We shall briefly look at some of them.

Task Force for Continuous Improvement

A good organizational approach to introduce a culture of continuous improvement is to have a task force that champions the cause of continuous improvement. This could be achieved by creating a team of managers who will initially own the process of implementing a continuous improvement culture in the organization and act as change agents. Such a task force would serve to catalyse the process by various means. These include, for example, getting constant support from the top management and talking to various groups of the workforce, the union, the maintenance and other support functions, and the middle management. The task force will also perform the important task of communicating the need for the changes and solicit employees' support.

However, there are other important roles the task force has to play. They will prepare a project proposal that outlines the various steps to be taken to implement the changes. Capital budgeting expenditure plans will have to be drawn out and approvals obtained. The various activities to be performed, the chronological order and time estimates will have to be prepared. The required organizational resources will have to be clearly identified. Using the information generated, major milestones have to be identified. Monitoring and control of the project also needs to be established.

Quality Circles

One of the popular methods to implement a continuous improvement process in an organization is to make small groups of employees, known as quality circles, and provide them with the required tools, techniques and the mandate to identify problems and solve them by making the required changes in the business processes. Typically, a quality circle is made up of 8–12 employees, either from the same work area or from different areas of the organization. The quality circle members meet at regular intervals, usually for about 90 minutes in a week and discuss various problems and possible solutions to eliminate the problems. Instead of focusing on several issues at the same time, they work with one problem at a time and after the problem is solved they take up another. In order to signal the importance of such methods of continuous improvement, the management of the organization normally permits the quality circle members to meet during work hours at a pre-designated time. Furthermore, to promote excellence and healthy competition, annual awards are presented to the best quality circle initiative.

> A quality circle is made up of 8–12 employees either from the same work area or from different areas of the organization.

Quality circles help organizations in several ways in their journey of continuous improvement.

- They provide a structured methodology for making improvements in a sustained fashion over a longer time.
- They provide the required organizational mandate for a small group of employees to make continuous improvement without fear of their superiors and conflicts of purpose and motives.
- They provide greater empowerment to the employees, raise their morale, and improve their job satisfaction.
- They equip every employee with the tools and techniques for continuous improvement.

Project-based Small Group Improvement Activities (SGIA)

Initially, the activities of quality circles were confined only to quality improvements. However, over a period of time, organizations found value in the methodology adopted in making these improvements and therefore, broad based the application of quality circles to any business process improvement. "Small group improvement activities" (SGIA) is therefore an alternative term to describe quality circles and is used for any business process improvement including quality improvements. Based on the experiences of quality circles certain improvements were made for directing the activities of SGIA. SGIA is done on a project-by-project basis. To understand how SGIA is implemented, readers are advised to refer to Figure 12.3 in Chapter 12. Initially, the product/service that requires improvement is identified and the scope set for the nature and extent of improvements to be made. Once these targets are established, detailed mapping of the processes is done and several improvement projects are identified. Each SGIA is focused on one project and an appropriate improvement methodology is applied to meet the objectives of the improvement initiative.

Visual Control Aids for Improvement

Visual control aids provide a powerful means for triggering improvement initiatives in an organization and motivating the employees to make improvements in the processes. They also provide a convincing basis for the management to support such improvement projects and provide them with verifiable and direct results of the improvement projects undertaken.

Furthermore, visual control aids serve as a formal mechanism for employees to perform SGIA. Developing a visual control aid typically involves the following steps:

1. Identifying core operational measures that are to be improved.
2. Creating a visual information system incorporating a measurement system for the measures identified.
3. Setting up a visual control display board.
4. Facilitating the employees for conducting SGIA.

It is easy to come up with a big list of items that could be measured at each work area. However, it is important to bear in mind that the number of items included on the display board should be kept to a minimum. A large number of measures will confuse and divert the attention of the employees when it comes to making a choice of improvement projects. There should be three sets of measures on the display board. One set will consist of core operational measures ranging from two to four. These measures will be permanently monitored and used for making improvements in the core business processes performed at the workplace. Often, these may include measures related to quality, lead time, schedule adherence, and customer complaints.

The second set will consist of measures that help the workers to improve on certain time-bound programmes. For example, when the 5S campaign is on, it may be useful to have a few measures that help in improving workplace organization. The third set of measures is intended to bring out exceptional performances from employees at the workplace, either individually or in groups. These measures often help to positively reinforce the employees and provide them with a sense of satisfaction and pride. They will also help in establishing a healthy and competitive spirit among the various small groups, thereby orchestrating a company-wide improvement plan.

Improvement projects in the core manufacturing areas usually begin when the members of SGIA analyse the operational measures plotted on a weekly basis. For example, if the schedule adherence or the quality is deteriorating, the group members brainstorm on the possible reasons. Based on the discussions, an action plan is chalked out. At this stage, the help of other manufacturing support functions, such as industrial engineering, design, quality and purchase, is taken. The group works on this project and completes it by documenting the experiences and the benefits obtained. Similarly, in the manufacturing support area, members representing costing, design, and production planning may have discovered a problem of long lead time from order enquiry to sending a quotation to the customer. They can make use of the data captured through the dis-play board and improve the process by proposing certain administrative procedural improvements.

13.11 ORGANIZATIONAL CHALLENGES IN LEAN MANAGEMENT

Lean management is not rocket science. As we have already seen in the chapter, it uses simple and already available tools in other domains of operations management such as TQM to set up a robust system for waste elimination. Despite this, experience shows that organizations find it difficult to successfully transform a traditional organization into a lean organization. The reasons often pertain to mindsets, people and culture issues, and the varying role of the top management in the transformation process. Lack of top management vision, practice–preach gap, reluctance to empower people at the lower levels, tunnel vision at the top, and not knowing where and how to make improvements are some of the often quoted reasons. We shall examine some of them.

JIT Implementation Issues

Earlier studies indicate that companies that have initiated major JIT programmes have very different concerns from those who merely “think” about JIT.[14] Moreover, when firms try to implement JIT half-heartedly, they demonstrate their reluctance to initiate system-level changes. This is evident from a significant difference in the perception of the importance of factors for successful JIT implementation. Firms with major JIT programmes have considered factors such as cellular manufacturing, kanban, set-up time reduction exercises, and total productive maintenance (TPM) more important. Clearly, all these imply initiating certain system-level changes.

There are crucial perceptual differences between the “thinkers” and “doers” of JIT implementation. Introduction of the cellular manufacturing system and kanban, for example, will result in drastic changes in workplace organization, power structure among employees, supervisors and middle managers, and the method of planning and controlling operations. Similarly, implementation of TPM and set-up time reduction exercises demands a different mindset and patience. Lack of conviction and clarity in thinking would result in firms either avoiding or postponing such changes in the system. Unfortunately, such half-hearted attempts or reluctance would result in not reaping the full benefits of JIT implementation.

ideas at Work 13.4

Application of Lean Management in Healthcare

The cost of healthcare is on the increase globally. This erodes margins for the healthcare providers and thereby threatens the viability of healthcare institutions. In the long run it makes healthcare expensive and minimizes social welfare opportunities for the citizens as a whole. Therefore, use of lean management principles in healthcare is very valuable. A good way to start is to create value stream mapping (process maps) and to estimate the resource costs involved in treating patients over their care cycle. This will provide new opportunities to restructure healthcare delivery and improve the healthcare delivery processes.

One of the basic premises in creating a lean organization is to eliminate unnecessary process variations and processes that don't add value. Typically in today's healthcare system there are significant variations in the processes, tools, equipment, and materials used by physicians performing the same service within the same unit in the same facility. For example, in total knee replacement, surgeons use different implants, surgical kits, surgeons' hoods, and supplies, thereby introducing substantial cost variation in treating patients with the same condition at the same site. A study of such processes from the perspective of lean management would reveal how best to standardize care and treatment processes to reduce the costs of variability and limit the use of expensive approaches and materials that do not demonstrably lead to improved outcomes. In addition to reducing process variations, eliminating steps or entire processes that do not improve outcomes will be an outcome of such an exercise.

By comparing process maps and resource costs for the same medical condition across multiple sites, it is possible to determine the cost impact of variations in processes, protocols, and productivity. Such an approach would provide a sustainable agenda for creating lean processes in healthcare institutions.

Detail studies could also reveal how much of each resource's capacity is actually used to perform processes and treat patients versus how much is unused and idle. Managers can clearly see the quantity and cost of unused resource capacity at the level of individual physicians, nurses, technicians, pieces of equipment, administrators, or organizational units. Where substantial and expensive unused capacity exists, they can identify the root causes and take steps to improve utilization. Changes in process design would result in better and a more balanced utilization of the resources in healthcare delivery network. For example, some under utilization of expensive space, equipment, and personnel is caused by poor coordination and delays when a patient is handed off from one specialty or service to the next. Another cause of low resource utilization is having specialized equipment available just in case the need arises.

Much excess resource capacity, however, is due to the prevailing tendency of many hospitals and clinics to provide care for almost every type of medical problem. Such fragmentation of service lines introduces costly redundancy throughout the healthcare system. Many services today are delivered in over resourced facilities or facilities designed for the most complex patient rather than the typical patient. A lean management initiative could challenge the assumptions behind such operating policies and help develop newer and better methods of addressing patient care.

The process maps developed could often reveal opportunities for appropriately skilled but lower-cost healthcare professionals to perform some of the processes currently performed by physicians without adversely affecting outcomes. Moreover, healthcare providers may discover multiple opportunities to reduce cycle times for treating patients, which in turn will reduce demand for resource capacity. For example, reducing the time that patients have to wait will reduce demand for patient supervision and space.

Source: Based on R. Kaplan and M. Porter, 'How to Solve the Cost Crisis in Health Care', *Harvard Business Review*, 89 (9), September 2011, 47-64.

Practitioners often think that JIT is applicable only to volume producers belonging to the discrete engineering industry. However, the underlying principle of JIT is one of continuous waste elimination and hence is universally applicable. Obviously, the manner in which JIT principles are applied across different industries will vary. For example, in process industries, potential applications of JIT philosophy would include implementation of TPM, vendor development, and JIT purchasing. On the other hand, in the automobile sector, in addition to the the ones just mentioned, factors such as cellular manufacturing, multi-skilled workforce, and small lot sizing may also find application. A high-volume manufacturer may find kanban to be a useful tool.

When different organizations begin to implement changes in their manufacturing and business systems, they end up with a wide spectrum of variations in the nature of efforts and the quantum of benefits realized. JIT implementation is no exception to this. The conceptual details of JIT, TQM, and other such new approaches to manufacturing management are well known to many Indian firms. However, there is a lack of internalization of these concepts, leading to varying degrees of conviction and clarity at the time of implementation. This has resulted in wide variations in the perception and implementation patterns among Indian firms.

Major JIT efforts succeed only when they are part of a strategic planning exercise. Such a process will ensure top management's active role and commitment. However, what hampers successful JIT implementation is the lack of clarity and priority, leading to confusion and wasteful expenditure of organizational energy.

Cultural and Human Issues

Introducing a continuous improvement culture in an organization is not a simple and straightforward task. The extent to which organizations actually realize the benefits is directly related to how well the system is introduced and this requires careful thought and consideration. Top management needs to understand the role they should play in this process. The middle level managers, the union, and the workforce need to be convinced about the need for the change. Only when there is such a conviction, will there be emotional attachment, support, and cooperation in sustaining the improvement effort. In particular, one can foresee the following challenges:

Resistance to change

The fundamental issue challenging lean management efforts in any organization is the inertia to change. Managers, line supervisors, and the workforce resist any change in their status quo. They are often gripped by the fear of the unknown. Changes that alter the existing layout on the shop floor will evoke significant resistance from the workforce because such changes alter the social structure existing on the shop floor. Groups are disbanded, new groups are carved out, and the power structure within each group is likely to be realigned. Moreover, workers tend to imagine that the new mechanism is yet another method to get more work out of them at no extra cost.

The middle managers worry about their power structure being disturbed. They foresee an impending reduction in their power and influence over each other and the workforce. If small groups consisting of workers and machines are formed and encouraged to work in an autonomous fashion with respect to several day-to-day production functions, managers and line supervisors feel threatened. They instinctively stonewall the changes out of the fear of losing control over the production workers. Functional managers may not understand why these changes are required and line supervisors foresee the absence of their role in the new set-up. Similarly, there could be resistance from several other quarters.

Incentives and reward systems

Reward systems based on individual performances (such as piece rate incentives) for shop floor workers create the maximum damage to any improvement initiative in the organization. Several organizations have abandoned them in favour of group incentive schemes. These, for example, include incentives based on throughput time, throughput rate at the final assembly of the product, and productivity measured at the department or product level. Often, in many organizations, incentive schemes are designed as a combination of these factors.

The middle and the junior management often experience difficulties in resolving the conflict between the long-term and short-term goals of an organization when a continuous improvement programme is put in place. Many of the long-term benefits suffer from a high degree of intangibility and uncertainty with respect to outcomes. On the other hand, short-term goals and benefits are like low-hanging fruits. They are not only easily reachable but are also tangible. Functional managers will be averse to working for long–term benefits because the organization hardly recognizes and rewards such efforts.

Tangibility of improvements

Organizations are likely to face tougher challenges while making improvements in non-manufacturing areas of business. Unlike office areas, improvements made on the shop floor have better visibility and are relatively easy to initiate. But that does not mean that they are the only places to look for improvements. There is a limit to which these improvements can take place. Moreover, it is important to realize that in order to make these improvements reach the marketplace, the business processes in non-manufacturing areas also need improvement. Hence, efforts are required for inculcating a continuous improvement culture among the white-collar staff in organizations.

Nothing is taken seriously when employees in organizations come to know that changes have neither the top management's blessing nor their involvement and commitment. This is a significant aspect in the introduction of a culture of continuous improvement. The top management can help in many ways to ensure the smooth and successful implementation of the changes. On the contrary, playing the role of a mute spectator can take away the spirit of the whole exercise and cause significant damage, not only to the initiative, but also to the morale of the workforce actively involved in the change process.

The top management also needs to play a vital role in communication. They should demonstrate their support and involvement in the implementation process. Discussions about the changes, the role played by the employees, and the benefits accrued so far should happen while addressing the employees in all in-company programmes and functions. The top management should be aware of the impending changes and the benefits. Only out of such understanding comes involvement and support in resolving conflicts that arise during the implementation stage. Middle-level managers often form part of the team of change agents. Moreover, the changes may result in some of them giving up their traditional role of control over their subordinates. They need adequate exposure and clarity regarding the required changes, failing which they become insecure and try to stonewall the efforts.

SUMMARY

- The philosophy of lean management is one of continuous waste elimination. Therefore, lean systems have an unambiguous definition of what constitutes waste in the system.
- Contrary to traditional thinking, the inventory in a JIT system is deliberately removed to expose hidden problems. These problems are solved resulting in lower inventory and waste in the system, along with greater productivity.
- The implementation of JIT requires that the manufacturing architecture is converted into a chain of internal customers. Each element in the chain will have a customer-supplier relationship with the adjacent element.
- Lot-size reduction and the use of standard containers are other elements of a JIT system.
- Production planning and control in JIT systems is achieved through the use of kanban. There are prescribed guidelines for the use of kanbans. Moreover, kanban enables waste elimination from the system by preventing overproduction and exposing problems in processes.
- Traditional operations systems are scheduled by the push approach. In contrast, JIT systems utilize pull-type scheduling. Pull-type scheduling is very effective in providing visible control of the processes and bringing problems to the surface rapidly.
- The number of kanbans required is a function of production and conveyance lead time, the size of the standard container, and the demand rate.
- Organizations make improvements either in step-wise mode or a gradual mode. The step-mode improvement happens on account of radical innovations. On the other hand, gradual-mode improvements happen on account of continuous improvements.
- A continuous improvement does not require any radically new technology or product. It concentrates on improving the effectiveness of existing processes in small steps.
- A process mapping exercise provides vital clues for improvement. It enables organizations to segregate value-added activities from non-value-added ones and concentrate their efforts on eliminating the latter.

REVIEW QUESTIONS

1. What is lean management? Why do organizations need it?
2. What is the relationship between lean management and JIT manufacturing?
3. How is the logic of JIT manufacturing different from the traditional principles of manufacturing management Use two specific illustrations to explain your answer.
4. The following are some statements on JIT. Comment on each of the statements.

    a. JIT is nothing but a good inventory management system.
    b. The success of JIT is primarily due to its ability to constantly expose problems in an organization.
    c. Without standard containers it is not possible to implement JIT.
    d. JIT utilizes a push approach to operations scheduling.
    e. Application of JIT varies from one type of industry to another.
    f. kanban-based scheduling serves as a good inventory control tool.
    g. The number of P-kanbans is equal to the number of C-kanbans.
    h. A P-kanban is always attached to an empty container.
    i. A C-kanban is always attached to a full container.

5. Why does JIT manufacturing require changes in manufacturing architecture? What are the key changes made to a manufacturing system for JIT manufacturing?
6. How does push scheduling differ from pull scheduling? What are the key implications of these two methods to an operating system?
7. What are the key benefits of lot-size reduction to a manufacturing system? How can a manufacturing firm achieve lot-size reduction?
8. Explain the working of a dual-card kanban system.
9. Under what conditions will the kanban-based scheduling systems fail to produce satisfactory results?
10. What are the perceptual differences between an organization implementing JIT and another not implementing JIT?
11. What do you mean by continuous improvement? Give two examples of continuous improvements that organizations undertake.
12. What are the differences between continuous improvement and radical improvement? What is your recommendation to manufacturing organizations for improving their performance?
13. Briefly describe the various steps involved in a continuous improvement process.
14. Compare and contrast quality circles and small-group improvement activities.
15. Explain the relevance of visual control aids for the continuous improvement process.
16. Identify some major stumbling blocks in the way of continuous improvement process in an organization. What are your recommendations for avoiding them?

PROBLEMS

1. The following information is available from a manufacturer who is using a single-card kanban. Standard container size = 50 units, the daily demand = 1,600 units, working hours per day = 8, conveyance time = 20 minutes, production time = 30 minutes, safety factor = 5 per cent. Estimate the number of kanbans required.
2. A manufacturing system uses a single-card kanban system for production control. The system is operating satisfactorily with a 10 per cent safety factor. The size of the standard container is 20 and the conveyance and production times are 20 and 10 minutes, respectively. The factory operates on a two-shift basis (of 16 hours). They currently use 12 kanban cards for production scheduling

    a. What is the daily demand that the manufacturing system is facing?

b. If the demand goes up by 20 per cent, will the system work satisfactorily or will it need some modifications?
c. Analyse the system for an increase by 20 per cent in the production time.

3. Consider a pair of processes scheduled using a single-card kanban system. The conveyance time and the processing time for the items are 20 minutes and 40 minutes, respectively. Currently the system uses standard containers that can hold 200 units and has a demand rate of 2,000 units per hour. They are using nine kanbans to schedule the system. They have been experiencing some problems in the system.

   a. Can you identify the reasons for the problems that they have been facing?
   b. Rectify the system so that it operates with a safety factor of at least 10 per cent.

4. A dual-card kanban system needs to be designed for a manufacturing process that has a demand rate of 200 per hour of a certain item. The standard containers designed for the components can hold 25 items. The conveyance time and the production time for the components are 30 minutes and one hour, respectively. Assume a safety factor of 10 per cent.

   a. Identify the number of C-kanbans and P-kanbans required in the system.
   b. If there is a rounding off involved in arriving at the number of kanbans in the above case, compare the performance of the system when the number is rounded off to the next lower and the next higher integer.

MINI PROJECTS

1. The TVS group of companies that produce automotive components has implemented several principles of JIT. Notable among them are Brakes India Limited, Lucas TVS, Sundaram Fasteners, and TVS Motor Company. Similarly other companies such as ABB, Maruti Udyog, Mahindra & Mahindra, Mico, Siemens, and Hindustan Motors have also implemented JIT practices. This list of companies is partial and only suggestive. Select two companies and study the JIT-related practices that the company has established by gathering data from the following sources:

   - The company Web site
   - Visits to the company and interviews with key operating personnel
   - Secondary data from company annual reports
   - Reports of awards and achievements secured by the company
   - Information from:
     - Industry associations and trade journals
     - Scholarly journals and business press reports

   a. Prepare a report detailing the following aspects:
      i. The extent to which the company has implemented JIT.
      ii. The key features and challenges they faced while implementing JIT.
      iii. The benefits that they have acquired in the process.
   b. How have these efforts impacted the competitive positioning of the company?
   c. What are the steps that the company needs to take in future to complete the JIT implementation process?
   d. Based on the data gathered here, make a comparative study of the two companies and prepare a critical report of two pages.

Making continuous improvements is an essential requirement of all organizations, no matter how successful they are. Choose one organization from the following list to conduct a improvement project:

a. Any retail branch of a bank
b. Any medium-sized post office in your neighbourhood
c. The hostel administration in your college hostel
d. The general office administration in your college or any nearby office
e. Any small or medium-sized manufacturing firm in your locality

For the organization that you have chosen, undertake an improvement project along the following lines:

- First talk to the head of the organization to understand the major problems and concerns.
- Based on your understanding of the problem and the consultation with the members in the organization, identify a set of measures that needs to be improved in order to solve the problem and set some meaningful targets for the same over the next six months.
- Collect data to assess the current status of these measures, the business processes affecting its performance, and the activities that currently constitute these business processes.
- Perform the necessary analyses of the various business processes.

Write a final report detailing these steps and your recommendations to the organization regarding the nature of efforts to be undertaken for improving the situation and solving some of the problems listed. Also, clearly identify the challenges in the process and the nature of precautions that the unit head should take while implementing your recommendations.

CASE STUDY

Bharat Auto Components Limited (BACL)

Bharat Auto Components Ltd. (BACL) is a leading supplier of auto components and has a good presence in India. BACL set up its manufacturing operations in the country in 1978, and has grown over the years. It manufactures and trades products pertaining to auto-electricals. The company has developed good R&D and manufacturing capabilities.

The Market Scenario

The Indian automotive sector has posted a very impressive growth pattern during the last few years. The turnover of auto-components during 2004–2005 was USD 8 billion and it rose to USD 18 billion by 2007–2008. The corresponding figures for investment made in the sector during the same period were USD 3.7 billion and USD 7.2 billion. However, 2008–2009 was a dramatic reversal of this trend due to the global economic meltdown. For the period April–September 2008, the growth in exports was 6 per cent, compared to a 25 per cent compounded annual rate of growth (CARG) in the last 5 years. According to the Society of Indian Automobile Manufacturers, the passenger vehicles segment registered a negative growth of 1.21 per cent during April 2008–January 2009, compared to April 2007–January 2008. More specifically, the demand for passenger cars fell by 0.62 per cent and that for utility vehicles by 7.38 per cent. Sales in the commercial vehicles segment again registered severe de-growth. The segment declined by 19.83 per cent during April–January 2009 as compared to the same period last year. As BACL is a supplier of auto components, these developments have their impact on it.

BACL believes in developing good products with good technology. However, on the issue of manufacturing and operational excellence, there was some scope for improvement. The management initiated several operational excellence initiatives under the banner of the lean production system (LPS). It mainly focused on operational excellence through lean initiatives in the plant and better supply chain practices to cascade the lean philosophy through the value chain. The emerging economic scenario has further emphasized the need for operational excellence at BACL.

Lean Management at BACL

True to any lean implementation, LPS implementation also had training as an initial, albeit, important element. Many senior managers had extensive training as part of the project. A typical lean implementation requires substantial changes in several areas in a manufacturing enterprise. At BACL, lean initiatives involved certain key words: milk runs, common pull collection (CPC), direct online, supermarket, standard containers, kanban, etc.

Milk Runs and CP

There is a dual arrangement for every supplier in and around the plant. One is a milk run which has a window of delivery in the morning session. In the afternoon, the CPC schedule is operated. The quantity for the milk run is fixed (standardized) by the planner. On the other hand, the CPC quantity can be variable.

During discussions with executives, the following issues pertaining to these two routines emerged:

At this point in time, more components are scheduled through the CPC compared to the milk run arrangement. There seems to be less appreciation of the need to procure more items through the milk run. Consequently, there is a tendency to use the CPC in the afternoon more than the milk run in the morning. The quantity for the milk run is fixed. Since this is not aligned to consumption, there is no pull happening in reality. CPC quantities can be variable: say 500 on a day, 0 on another day, 800 on another day, and so on. Again, this is not related to level production and consumptions. It is not even clear how suppliers can align to lean with such a practice.

Direct Online Sourcing

In the direct online sourcing methodology, the components are directly supplied at the workplace, where it is consumed. The idea is to minimize delays, link supply to consumption, and reduce non-value-added activities, thereby improving the value stream. It also helps build greater responsibility among the production workers and better coordination between two successive stages of the value chain (the supplier and the user in this case).

Of a total of about 1,500 active parts, nearly 300–400 parts are shipped to the line. While a majority of them are “C” class items such as packaging material, it also has about 50 parts that are “A” category. In everybody’s mind, the simple understanding of direct online is “no inspection”. The items are directly delivered on the shop floor and the foreman signs the receipt. This creates operational complexities, audit objections as to user signing and receiving, etc. These have been to an extent addressed with paperwork and procedural changes. One shop floor executive commented on the idea of direct on line as follows:

“We have not created proper space to keep these parts. Our ordering is also not tuned to the consumption pattern. Therefore we find a sudden pile-up of material. Sometimes, the items are under lock and key and it introduces delays and hold-ups. Can we not synchronize the direct on-line and internal milk runs in such a fashion that there is some synchronized order launch and work flow pattern on the shop floor? It can even make production planning and control a little simpler.”

Smaller Batch Sizes and Standard Containers

The milk run required that we reduce batch sizes and invest in different bins. Old, large containers were no longer required. Getting rid of them, however, has not been easy for two reasons. First, people do not appreciate the need for smaller batch sizes. There is still a dominant large-batch orientation to the running of operations. Second, newer bins required additional investments and getting approvals for this is an involved exercise. “How can one justify investments on plastic containers in the short run, and for that matter of any lean initiative?” “Simple cost–benefit exercises cannot bring good lean implementation into an organization.” retorted one executive championing the lean initiative.

Despite some challenges and operational changes required, LPS implementation has brought several changes in the manner operational issues are addressed in the shop floor. Figure 13.9 presents snapshots of some of the LPS implementations carried out.

a. Batch size reduction using standard containers
b. Supermarket

Implementation Challenges

A senior executive had the following to comment on the lean initiatives in BACL:

“We have made some progress in the last two years in the plant, some with suppliers and the logistics. However, my personal sense is that it is not picking up fast enough. I think it is primarily because: (a) there are varying levels of understanding of the concept of lean management and its usefulness; (b) mounting pressures in business sometimes pushes us back on the lean initiatives that we would have otherwise embarked on; (c) we have the culture of focusing on short-term returns on the investments and expenditures that we make on any new initiative. Lean management is not an exception to this norm.”

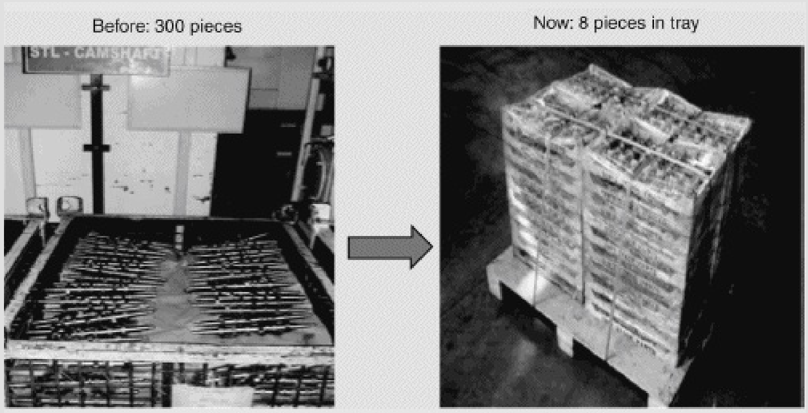
According to another senior manager, the implementation of the LPS did not fully meet the requirements, although there was every effort from the top management. He had the following to say:

“Changing the layout, re-deploying the workforce, and redefining organization structure are not going be to be easy. It results in an altered power structure of the various individuals in the organization. It calls for a different working style and behaviour. Efforts are also required to design a better workplace organization.”

It was not clear if the lean management practices at BACL indeed focused on several aspects of a lean system, with the result that the implementation of LPS could be at variance with the core logic of lean management and might not deliver some of the promised benefits of lean. One expert had the following to say:

“In lean management, God is in the details and the results are likely to accrue over a slightly longer time. It also demands a different mindset from the top management, one in which short-term orientation must give way to long-term orientation. Only with such perspective and support will the process deliver improvements and develop new capabilities in the organization.”

FIGURE 13.9 Implementations of LPS: some examples



(a) Batch size reduction using standard containers

(b) Supermarket

While discussing the challenges of lean implementation with a senior manager at BACL, he said:

“We have not done a very good job of reducing the batch size in our production. There is still a dominant mindset for running larger batch sizes. I see two underlying reasons for this. Many other lean management initiatives have also suffered from these underlying causes.

First and the foremost is that there is a genuine issue of lack of understanding of what “lean philosophy” is all about. Therefore many do not know about the benefits of lean, leave alone appreciating them. We have implemented the kanban system in some areas but it does not work the way it ought to. This is an indication of a lack of clarity about the intended system and its benefits. While we had good training programmes on lean management, I feel it may not be enough. It requires multiple exposures and visits to a few other lean implementations outside to appreciate and internalize these ideas. Only then will there be a conviction and perseverance in pursuing them relentlessly.

The second stumbling block is the classical short-term-versus–long-term conflict. Short-term benefits are easy to quantify. On the other hand, long-term benefits are quite difficult to value in monetary terms. Does that simply mean that we can ignore long-term benefits and save us the trouble and inconvenience of searching for ways and means of quantifying long-term benefits? My sense is that in the existing scheme of things, we seem to take the easy route and there is a tacit acceptance to this way of dealing with improvement projects.

I will give you one specific example. Let us look at the issue of standard containers. In order to implement this, we were required to invest in new tote boxes and plastic containers. In some cases it also required fabricating newer storage devices. In order to get this project approved we may need to provide a cost–benefit exercise. Quantifying the benefits is not impossible. But it is also not straightforward and requires straining one's imagination. I don't think many of the managers would take this trouble. It is much easier to abandon this project and continue with old storage devices. This is what you will see."

The Way Forward

Despite some of the issues that BACL went through, the basic philosophy of the company provides a lot of strength to weather the challenges. BACL has put in place good controls and processes. The market developments and the mounting pressure due to the economic meltdown clearly signal the need to improve operations. Manufacturing needs to become more efficient, more responsive, and cost-effective. An inclusive approach that embraces the supply chain partners and builds stronger capabilities among them as well will be an important element of the current strategy for BACL. The key question is how to take these initiatives forward.

QUESTIONS FOR DISCUSSION

1. What is the role of lean management practices at BACL? Why are they not adequately seeing the benefits of lean management?
2. Will the organizational systems, controls, culture, and mindset come in the way of improvements? What should be the strategy for addressing these?

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Part IV

Planning and Control of Operations

CHAPTER 14

Demand Forecasting

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What is the role of forecasting in an organization? How does it help the planning process?
- How does the forecasting methodology and context change with respect to the time horizon?
- What are the steps involved in designing a forecasting system?
- What are the sources of data for forecasting? How do organizations use these data?
- What are the well-known models used for forecasting? How can we estimate the model's parameters?
- How can we assess the accuracy of forecasts obtained from a forecasting model?
- What are the managerial considerations in using a forecasting system?

Every organization invariably engages in an annual planning exercise. The heads of various functional areas such as marketing, production, materials, and finance take part in this exercise with specific objectives. The marketing function provides data on the sales the organization should target in the coming year.

Source: Milltec Machinery Pvt. Ltd.

ideas at Work 14.1

The Role of Forecasting in a Petrochemical-manufacturing Company

Forecasting has always been an important activity in manufacturing and service organizations. For a manufacturer of petrochemicals, its role is crucial as long-term contracts for feedstock (the prime raw material in the petrochemical industry) could provide the competitive advantage of cost-effective inputs. With the wild fluctuations in the price of crude in recent times, the value of forecasting is even greater.

Consider the polyethylene plant of Reliance Industries Limited (India's largest petrochemical manufacturer) at Hazira, near Surat. Forecasting the requirement of polyethylene is no simple task. There are several complexities in the process. For example, exchange rate fluctuations and geopolitical movements (such as the Kuwait, Afghan, and Iraq wars) could significantly affect the demand–supply of feed-stock. On the domestic front, the installed capacity and capacity projections of all the players in the sector and excise and customs tariff schedules could affect the demand–supply scenario for its final product. Let us understand the various steps involved in the forecasting process and the nature of decisions taken.

The process starts with certain assumptions about the tariff structure for customs and excise, the prevailing local price, exchange rate fluctuations, import price, and the nature of competition. Based on these assumptions, the total market for polyethylene in the medium term of 18 to 36 months is arrived at. In the next step, an analysis of the supply–demand position is made on the basis of its own capacity and competitors' capacity and expansion plans during the year.

Based on these, the demand to be met during the next planning year is arrived at. This is based on a series of forecasting exercises done at various levels and actual collection and analysis of the end-use data of the previous year. At this stage, a certain level of aggregation of data is required. For example, there will be several grades of polyethylene in production and several new grades will be introduced during the planning year. This data needs to be aggregated in order to analyse capacity requirements and match them with capacity availability. Similarly, the end-use data is collected at the tertiary level and progressively aggregated at regional and national levels. This data is used in the forecasting exercises carried out to estimate future demand.

The output from forecasting is put to several important uses. The foremost use is balancing capacity availability to actual projected requirement for the planning year. This is done by some decisions on de-bottlenecking schedules, adjusting planned maintenance schedules and reworking some technology upgradation initiatives. Furthermore, the forecasting exercise directly leads to detailed production planning for the year. During this stage, the data is disaggregated into specific product variants and scheduling plans for each variant arrived at. At this stage, changeover considerations from one product variant to another are taken into consideration. The forecasting exercise also helps in establishing performance targets for the year for various departments such as production, materials, and marketing, as well as in the setting up of control systems.

Source: Based on the author's own research.

Every organization invariably engages in an annual planning exercise. The heads of various functional areas such as marketing, production, materials, and finance take part in this exercise with specific objectives. The marketing function provides data on the sales the organization should target in the coming year. This is primarily achieved through forecasting. Based on this input, the production function prepares an annual production plan and projects various requirements on the basis of this plan. The materials function prepares a procurement plan to match the requirements projected by the production function. Finally, on the basis of all these, the finance function undertakes cash planning and funds management. Therefore, forecasting plays a vital role in every organization. In this chapter, we deal with various aspects of forecasting. This includes the need for forecasts, methods of making reliable forecasts, and managerial issues in using a forecasting system.

14.1 FORECASTING AS A PLANNING TOOL

Managerial decision making is often complicated due to an element of uncertainty in the variables affecting the decision-making process. For example, when the decision to build a new production facility is made, the demand for its products is not known with certainty. Similarly, when a hospital chooses to add one more specialty healthcare wing, it needs to make some assumptions about the demand for the facility. Since these decisions often involve considerable cash flow and time in creating new facilities, accurate estimates of the future events for which the decisions have been made are crucial. Forecasting is the branch of operations management that addresses these issues and provides the manager with a set of tools and techniques for the estimation process.

At a more general level, **forecasts** are estimates of the timing and the magnitude of occurrence of future events. It is clear from this definition that forecasting involves two important aspects: the magnitude and the timing of occurrence of events. Consider a fast-food joint that operates in the vicinity of a commercial centre. As a large number of visitors throng the commercial centre, one could expect a good demand for food and beverages. Let us suppose that the owner of the fast-food joint estimates the daily demand for beverages to be 3,000 cups. However, this information is not sufficient for the owner to service the demand. The timing of the demand is very crucial. For example, if 40 per cent of the estimated demand happens in just two blocks of two hours each in the morning and the evening, then the nature of planning and even operational practices during these peak hours could be very different. Manufacturing and service systems experience peak demand during certain times and average or even low demand during other times. Hence, estimating the timing of the demand is as important as estimating its magnitude.

> **Forecasts** are estimates of the timing and magnitude of the occurrence of future events.

The timing of the occurrence of events is not only important in short-term planning, as described; it is equally important in several other situations. Let us consider another example. Suppose a manufacturer of household appliances decides to add one more product line—microwave ovens—to its existing product portfolio. The decision to add microwave ovens to the product line requires a good understanding of the nature of demand for the range of microwave ovens proposed to be manufactured. Depending on both the timing and the magnitude of demand, the manufacturer will schedule the building of new plants, planning of the product launch, and the creation of the necessary infrastructure for the marketing and distribution of microwave ovens.

Forecasting is an important tool in public policy decisions as well. For example, the Government of India needs to have a reasonable estimate of the population growth over the next 10–20 years in order to formulate long-term plans for creating infrastructure for transportation and the development of cities and towns. Based on the estimates of population growth, the government may formulate detailed plans to channel investment into certain sectors of industry. Another example is the meteorological department’s annual forecasting exercise to predict the monsoons.

In all these examples, we see that forecasting plays a vital role. Specifically, one can identify the following key functions of forecasting:

a. An estimation tool
b. A way of addressing the complex and uncertain environment surrounding business decision making
c. A tool for predicting events related to operations planning and control
d. A vital prerequisite for the planning process in organizations

14.2 WHY DO WE FORECAST?

Since forecasting activity typically precedes a planning process, one can identify specific reasons for the use of forecasting in organizations. Organizations face a different set of issues while they engage in planning, and in each of these, forecasting plays an important role as a tool for the planning process. Based on the examples discussed, we can summarize the key areas of application of forecasting:

- *Dynamic and complex environments*: Forecasting is not required if an organization has complete control over market forces and knows exactly what the sale of its products is going to be in the future. However, as we have already seen, such situations seldom exist.
- *Short-term fluctuations in production*: A good forecasting system will be able to predict the occurrence of short-term fluctuations in demand. Therefore, from this knowledge, organizations can avoid knee-jerk reactions to the unfolding reality. Production planning decisions could utilize this information and develop plans that minimize the costs of adjusting the production system for short-term fluctuations.
- *Better resources management*: Since the impending events in an organization are predicted through a forecasting

system, organizations can benefit from better materials management and ensure better resources availability. Returning to the fast-food joint example, if the owner could predict the occurrence of peak hours in his joint, he would have planned and ensured better material and greater availability of resources.

- *Rationalized manpower decisions*: Organizations can minimize hiring and lay-off decisions through forecasting. Moreover, better planning of overtime and idle time can also be done based on this information.
- *Strategic decisions*: Our earlier example of microwave ovens suggests that forecasting plays an important role in long-term strategic decision making. This includes planning for product line decisions, new products, augmenting capacity, building new factories, and expanding the current level of activities. In each of these, an understanding of the unfolding future is a key factor in decision making and forecasting plays a role in providing this information.

> A good forecasting system will be able to predict the occurrence of short-term fluctuations in demand.

14.3 FORECASTING TIME HORIZON

The use of forecasting is clearly pervasive. However, the type of data used, the nature of analysis done, and the tools and techniques employed could vary from one situation to another. Therefore, it is useful to understand what causes these variations and how one can sub-classify and group them. Amongst other parameters, the time horizon for forecasting provides a sound basis for classification. The three categories are short-term, medium-term and long-term horizons. Table 14.1 lists the salient features of this classification.

Short-term Forecasting

Typically, short-term forecasting is employed to fine-tune an existing plan on the basis of the new information obtained. Forecasting acts as an input for the tactical decisions that an organization makes. For example, based on the sales in the last quarter, an organization could develop better estimates of the demand in the next quarter and use that information for adjusting various quarterly plans. The errors in forecasting that are sought to be corrected by an alternative estimate are more related to random events than any long-term cyclical patterns or medium-term seasonal patterns. The forecasting data is used in a disaggregated fashion and analysed in detail. For example, the sales data will be analysed by region and product variety for possible short-term impact in a particular region or for a variant of a product. Specific corrective measures could be taken after analysis of the data. The techniques used in this case are simple extrapolation of the immediate past data and mechanisms for the incorporation of new data and period-by-period adjustments.

TABLE 14.1 Forecasting Time Horizon—Some Implications

Criterion	Short-term	Medium-term	Long-term
Typical duration	1–3 months	12–18 months	5–10 Years
Nature of decisions	Purely tactical	Tactical as well as strategic	Purely strategic
Key considerations	Random (short-term) effects	Seasonal and cyclical effects	Long-term trends and business cycles
Nature of data	Mostly quantitative	Subjective and quantitative	Largely subjective
Degree of uncertainty	Low	Significant	High
Some examples	› Revising quarterly production plans	› Annual production planning	› New product introduction
	› Rescheduling supply of raw material	› Capacity augmentation	› Facilities location decisions
			› New business development

Medium-term Forecasting

An organization uses forecasting as a starting point to the annual business planning exercise. This typically constitutes medium-term forecasting. In medium-term forecasting, the planning horizon is usually 12–18 months. During this period, some aggregation of data is done. For example, if an organization offers 15 variations of a product, the demand for the product is estimated at an aggregate level. Based on this information, capacity and material plans could be made. Since the forecasting is done for a slightly longer time, cyclical and seasonal patterns will make a significant impact and need to be incorporated in the analysis. The decisions taken using the forecasting information vary from purely tactical decisions such as annual production planning to somewhat strategic ones such as augmentation of capacity in specific areas of business. Forecasting techniques should be able to handle these requirements. Use of extrapolative methods, some subjective judgment and regression-based methodologies are often employed in medium-term forecasting.

> An organization uses forecasting as a starting point to the annual business planning exercise.

Long-term Forecasting

Long-term forecasts involve purely strategic decisions for a time period of about 5–10 years, so the forecasting processes need to cater to these requirements. For instance, an organization may be interested in projecting the future technology trends in their business and use it as the basis for developing new products, production technology, and human and other resources. Strategic decisions substantially draw subjective knowledge from the expertise of senior management personnel in an organization involved in the decision making. Furthermore, the level of uncertainty in the process tends to be high. Therefore, the forecasting methodology should be able to use this data and develop reliable estimates. Some amount of detailed modelling based on some macro-level assumptions is often required.

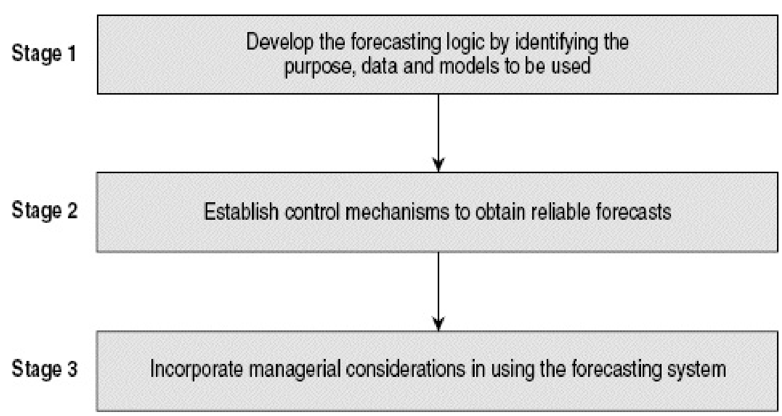
14.4 DESIGN OF FORECASTING SYSTEMS

Designing and using a forecasting system in an organization involves three important stages, as shown in Figure 14.1. In Stage 1, an organization needs to address the requirements for the forecasting system and identify an appropriate time horizon. On the basis of these, it needs to further identify a suitable technique, collect data, construct the forecasting logic using available tools and techniques, and test for logical and empirical validity using some past data.

> Designing and using a forecasting system in an organization involves three important stages: (i) identifying an appropriate time horizon, (ii) building and validating a forecasting model, and (iii) using the output from the forecasting model with managerial judgment.

Once the designer is satisfied with the forecasting logic, the next stage involves developing control mechanisms for using the forecasting system. This requires establishing some performance measures and subjecting the forecasts obtained from the system for reliability from time to time. If, after some time, the forecasting system is found to be consistently biased, then the basic logic may require a review. In the third stage, the focus is on using the estimates obtained from the forecasting system with a managerial perspective. It is not enough to merely take the output from a forecasting system and make decisions based on these estimates. On several occasions, managers need to understand the need for incorporating additional information not captured by the forecasting system. We shall look at each of these three stages in some detail in the rest of the chapter.

FIGURE 14.1 Designing and using a forecasting system: a three-stage process

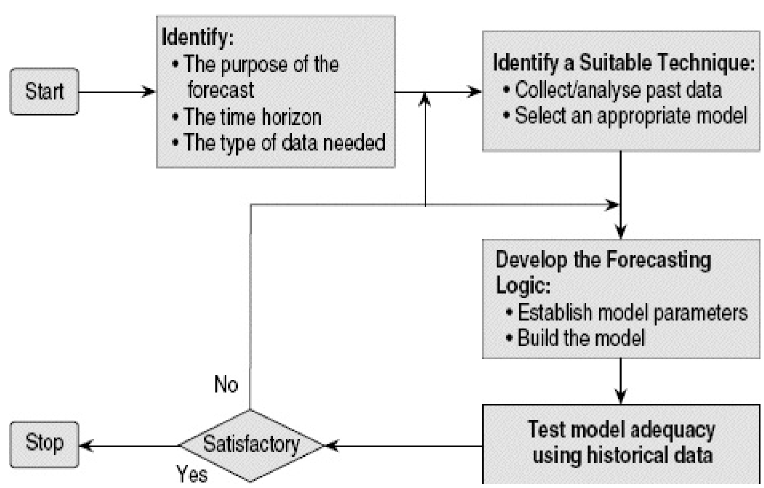


14.5 DEVELOPING THE FORECASTING LOGIC

Figure 14.2 describes the various steps involved in developing the forecasting logic. The first step in the process is to have clarity on the purpose behind developing the forecasting system. Why are we developing a forecasting model? Is the organization interested in launching new product lines in the near future? Is it trying to estimate the resources required to meet the production targets for the next year? Or is it analysing the impact of short-term changes in demand with a view to adjust the capacity to meet the demand? As we have already seen, much of the logic behind developing a forecasting system critically depends on these issues. In the first case, we are aiming at a long-term horizon, whereas in the second case we are addressing a medium-term requirement. In the last case we focus on short-term requirements. As we have already seen, the type of data required for developing a system in each of these cases and the nature of decisions to which the output from the forecasting system is put differs significantly.

Once the purpose, the time horizon, and the nature of data required are clearly identified, the next step in the process involves choosing an appropriate model from the available set. This is easily done by collecting sample data and analysing them using simple tools such as visual inspection and statistical measures. This is an important step to understand the specific requirements of the proposed forecasting system. For instance, let us assume that an organization is interested in developing a forecasting system for estimating the yearly demand of the equipment they manufacture for production planning purposes. Suppose a sample sales data for a year for the equipment is collected and plotted. From the plotted graph, the organization may get to know if there is a pronounced seasonal pattern. If there is a seasonal pattern, the model should be able to handle seasonality. Similarly, the plot of the data may also sometimes show the significant impact of business cycles. Understanding these patterns in the data will help in choosing an appropriate set of models as possible candidates for consideration. On the basis of these analyses, one can select an appropriate model for active consideration.

FIGURE 14.2 Steps in developing the forecasting logic



One can classify the various models available for forecasting into three categories: extrapolative methods, causal methods, and subjective judgments using qualitative data. **Extrapolative methods** make use of past data and essentially prepare future estimates by some method of extrapolating the past data. For example, the demand for soft drinks in a city or a locality could be estimated as 110 per cent of the average sales during the last three months.

Similarly, the sales of new garments during the festive season could be estimated to be a percentage of the festive season sales during the previous year. In both these examples, we are using past data and extrapolating it into the future on some basis.

> **Extrapolative methods** make use of past data to prepare future estimates.

Causal models analyse data from the viewpoint of a cause–effect relationship. For instance, in the process of estimating the demand for new houses, the model will identify the factors that could influence the demand for new houses and establish the relationship between these factors and the demand. For example, the factors may include real estate prices, housing finance options, disposable income of families, the cost of construction, and benefits derived from tax laws. Once the relationship between these variables and the demand is established, it is possible to use it for estimating the demand for new houses.

> **Causal models** analyse the data from the viewpoint of a cause–effect relationship.

Another set of models consists of subjective judgments using qualitative data. In some cases, it could be based on a set of quantitative and qualitative data. In several of these methods, special mechanisms are incorporated to draw substantially from the expertise of a group of senior managers using a collective decision-making framework. For instance, an organization such as the Indian Space Research Organisation (ISRO) would use this method to forecast the technology trends in space launch vehicles and the expertise that needs to be developed in the organization over the next 10 years. Similarly, several corporate planning exercises for the next ten years could often use this method for forecasting trends in their sector of operation.

The next stage involves developing the forecasting logic for the model selected. Each model has some parameters that are to be fixed. For example, if an organization wants to use a simple moving average technique for forecasting future demand, then the model parameter is the average number of periods for moving average. In other models there may be more parameters. Based on the sample data, the parameters of the selected models need to be established. Once the model parameters are established, the organization could use the logic for forecasting.

However, before putting it to use, the adequacy of the model and the forecasting logic needs to be tested. This could be done using historical data and comparing it with the forecasts obtained from the logic developed. If the forecasts obtained compare consistently and favourably with the actual data, then the model can be assumed to be adequate. In some cases, there may be significant deviations between these two. In such cases, the forecasting logic needs to be reexamined and some of the model parameters need to be adjusted. Alternatively, a completely new model may have to be considered.

After a few iterative procedures, the designer may be convinced that the model selected and the logic developed for forecasting are satisfactory. This would indicate that the organization has completed the first stage in the design and use of a forecasting system.

14.6 SOURCES OF DATA

Forecasting is often as good as the quantity and quality of data that is available with an organization performing a forecasting exercise. This is particularly true of forecasting exercises used for the purpose of planning. Therefore, it is important to know the type of data required and the normal sources through which such data could be collected.

> Forecasting is often only as good as the quantity and quality of data available.

Sales-force Estimates

For every organization, one of the most valuable sources of data is the sales force that operates in the field. Since the sales force spans the entire geographical range of operation, they have access to data on the actual consumption and the changing patterns in consumption. They may also have information on the performance of competitor brands and the overall patterns in market share and market growth. An organization will have to set up information-tracking mechanisms where the sales force can make periodic entries of actual consumption in the immediate past and projected trends. Using this data, organizations can make an end-use analysis to project emerging scenarios in market demand and one’s own share of the total demand. Moreover, the data obtained from the sales force is very valuable in short-term forecasting and mid-course corrections in production and sales planning.

Point of Sales (POS) Data Systems

Advances in information technology have enabled organizations to capture data at the point of sale using POS systems. Consider, for example, that you walk into a supermarket and buy a 500-gram Surf Excel pack. At the check-out counter, when the salesperson swipes the pack through a POS system, the data is captured and transmitted to the relevant database for the company to analyse. Using this technology, as a customer buys a unit of an organization’s product at a retail counter, the information is captured and instantaneously transferred to a common database. By developing systems to periodically analyse these databases, organizations could dramatically improve their planning, inventory management, and fulfilment systems. These translate into efficient consumer response and better supply chain management. In the United States, the success of giant retail chains such as Wal-Mart is attributed to the use of POS systems. You may find similar systems in use in Indian retail chains such as Big Bazaar, More, and Reliance Mart.

> Advances in information technology have enabled organizations to capture data at the point of sale using POS systems.

Forecasts from Supply Chain Partners

Obtaining POS data is often not easy. Distributors and retailers (also known as supply chain partners) hesitate to share information. They often perceive a threat arising out of erosion of their power. Hence, organizations often have to rely on their supply chain partners to obtain data on actual sales during a period. Moreover, supply chain partners provide vital information on market trends, competitor performance, and overall market sentiments and projections. These estimates are crucial for accurate forecasting of future demand, particularly during annual planning exercises.

Trade/Industry Association Journals

There are some useful sources of data for long-term forecasts. The most important among these are trade/industry association journals. These journals provide syndicated and researched data on the sector in which the organization is operating. Such journals serve as antennae to catch the buzz on future developments and long-term directions for the industry.

In addition to these, several market research firms such as ORG-MARG and management consultancy firms also provide syndicated sector-wise data on industry. This data is useful for forecasting purposes.

B2B Portals/Marketplaces

Another useful source of data in the era of the World Wide Web is the existence of industry portals and B2B marketplaces. These are the digital variations of trade/industry association journals. Consider, for example, an agro-portal such as. http://indiaagronet.com. This site provides a one-stop solution to the agricultural industry. It contains a vast amount of data on world agriculture, market news, commodity news, price movements of agricultural commodities, and some of the technology trends in the sector. In addition to these, B2B marketplaces and powerful search engines on the Web provide a vital source of data for the purpose of long-term forecasting.

Economic Surveys and Indicators

Studies conducted by research organizations on macroeconomic trends are good indicators of emerging trends in the consumption patterns of several classes of goods and services. Consider an organization interested in finding out the demand for high-definition TVs (HDTVs) over the next five years. Clearly, the demand for HDTVs is influenced by the income-level distribution in the population, the prevailing taxation policies, the level of disposable income, the growth of related technology, literacy levels, and the rate of urbanization. Economic research agencies such as the Central Statistical Organization (CSO) and the Centre for Monitoring Indian Economy (CMIE) provide useful data to model these situations and estimate the emerging demand for such products.

Subjective Knowledge

Several long-term forecasts enable strategic decision making. Since strategic decision making involves the use of considerable amounts of qualitative information, senior managers and subject experts are vital sources of such data. A forecasting system should be able to develop mechanisms to systematically collect and codify such data and put them to gainful use in situations involving long-term strategic decisions.

Once the forecasting system designer has identified the sources of data appropriate for his/her requirements, the focus shifts to building the forecasting logic. In order to do this, the forecasting designer could make use of several models available for developing a forecasting system. These models vary in terms of the nature of data employed, the manner in which future estimates are made, and the level of mathematical treatment the data is subjected to.

14.7 EXTRAPOLATIVE METHODS USING TIME SERIES

A *time series* is simply a collection of data at fixed time intervals over several years. Since extrapolative methods are estimates of future requirement on the basis of past data, the most important requirement for extrapolative methods is the existence of past data. Hence, this method is unsuitable for brand new products and new markets. For example, if Samsung wants to estimate the demand for the Galaxy Note 10.1, the latest version of tablet smart phone for the next two quarters, it is not possible to use this method. Established product lines will have several data points of the past that could be put to use. Extrapolative methods are very useful for short-term forecasts in an organization. This includes, for instance, predicting weekly/monthly demand for several fast-moving items and forecasts of capacity requirements in manufacturing and service organizations. Extrapolative models with some level of sophistication will also be useful for medium-term forecasts.

Extrapolative methods are very useful for short-term forecasts in an organization.

ideas at Work 14.2

A Forecasting Model to Improve Credit Card Business Performance at Commerce Bank

Commerce Bank is the princi pal subsidiary of Commerce Bancshares Inc., a regional bank holding company. It provides several financial services, including business and personal banking, wealth management, and estate planning. One of the major problems faced by Commerce Bank was losses out of its credit card operations mainly caused by non- payment of charges by the card holders. Since collection process is a core component in card operations and has direct impact on financial results, addressing this became a priority issue for Commerce Bank. With the economic slowdown, it assumed critical importance for financial institutions such as Commerce Bank.

Commerce Bank needed a system to analyze the financial risks on delinquent credit card accounts over six-month period. This information would reasonably project the amount of dollars at risk, provide indicators to establish a tolerance threshold as part of their financial planning, and allow the bank to place the appropriate personnel resources on accounts in each stage of delinquency, in order to optimize recovery efforts. A key element of the solution for Commerce Bank to address account recovery and reduce losses lies in the ability to accurately forecast delinquent accounts in a timely manner. Unfortunately, manual forecasting systems were in place and it was both time and resource consuming.

A new forecasting model was devised to address this issue. This model used Commerce Bank customer's data such as total of number of cardholders, balance, past due condition, and financial analyst data (for example, consumer price index, producer price index, and unemployment rate). The forecasting model analyzed these data and provided the much needed information. The forecasting model was implemented using Autobox, software developed by Automatic Forecasting Systems Inc. (AFS). Autobox provides a suite of forecasting methodologies by incorporating causal factors into the forecast such as sales of related products, cannibalization effects, and the price of competitors' products.

An automated forecasting tool combined with subject matter expertise, would allow Commerce Bank to adequately manage the delinquent credit card accounts and therefore minimize losses. By analyzing unemployment rate, number of cardholders at various stages of delinquency, balance, and other statistically significant variables, Commerce Bank can reasonably predict risk and establish a collection plan strategy. The other advantages that Commerce Bank can gain include improving resource planning in the collection department, minimizing credit card write off by earlier detection of delinquency accounts, and eventually optimizing resource productivity.

Source: Based on the case study available at http://www.autobox.com/cms/index.php/afs-university/intro-to-forecasting/cat_view/41-case-studies?orderby=dmdate_published&start=10. Last accessed on 31 May 2014.

Moving Averages

The simplest model for extrapolative forecasting is the method of simple moving averages. The model has a single parameter, that is, the number of periods to be considered for computing the moving average. For example, an organization may use a three-period moving average to estimate the demand of one of its fast-moving products. Table 14.2(a) presents a simple illustration of the methods of moving averages.

In the case of simple moving averages, as in Table 14.2(a), the forecast for the month of April is the average of the actual sales in the preceding three months. Similarly, the forecast for the month of September is the average of the actual sales during the months of June, July, and August. The moving average method is very simple to set up but has some limitations. If there is a significant change in the pattern, it reacts rather slowly. For instance, when there was a shift in the demand in June, it could react to the change only by September. This is because it weighs all the past periods of data equally. One way to take care of this limitation is to have a weighted moving average of the past data [see Table 14.2(b) for an illustration].

TABLE 14.2 Illustration of the Moving Average Method of Forecasting

(a) Simple Moving Average Method			**(b) Weighted Moving Average Method**		
Model Parameters:			**Model Parameters:**		
Number of periods for moving average: 3 months			Number of periods for moving average: 3 months		
			Immediate past: 0.45		
			Two periods before: 0.30		
			Three periods before: 0.25		
Month	**Actual Sales**	**Forecast***	**Month**	**Actual Sales**	**Forecast***
January	24,500		January	24,500	
February	27,000		February	27,000	
March	19,950		March	25,500	
April	26,000	23,817	April	26,000	25,700
May	21,200	24,317	May	21,200	26,100
June	18,900	22,383	June	18,900	23,715
July	17,500	22,033	July	17,500	21,365
August	19,000	19,200	August	19,000	18,845
September		18,467	September	18,525	

Note: *Forecasts in this illustration are rounded to units.

Therefore, the generalized formula for forecasting using the moving average method is:

$$F_t = \frac{D_{t-1}W_{t-1} + D_{t-2}W_{t-2} + D_{t-3}W_{t-3} + \ldots + D_{t-n}W_{t-n}}{W_{t-1} + W_{t-2} + W_{t-3} + \ldots + W_{t-n}} \tag{14.1}$$

where

F_t = The moving average forecast for Period t

n = The number of periods for moving average

D_i = Actual demand during Period i

W_i = Weight for the i^{th} period demand data

If different periods do not have different weights, the forecast obtained will be based on a simple moving average model. In this case, Eq. 14.1 reduces to a simpler form:

$$F_t = \frac{D_{t-1} + D_{t-2} + D_{t-3} + \ldots + D_{t-n}}{n} \tag{14.2}$$

There are pros and cons in using the simple and weighted moving average model. While the weighted moving average method may appear to be more useful, it results in an added burden of trying to fix appropriate values for the weights. How should one fix the weights in this example? Is the immediate past month more important than the one preceding that or is it the other way round? The other issue in using the moving average method is the logic behind the choice of *n*. How should one decide on *n*? In general, it can be seen that when demand is stable, larger values of *n* are appropriate. On the other hand, if the demand is not stable and has frequent tendencies to have significant shifts, then smaller values of *n* and the use of the weighted moving average model are likely to provide better results.

The Exponential Smoothening Method

Another popular method of extrapolative forecasting is the exponential smoothening method. In this method, the past data are weighed in an unequal fashion while estimating the future period's forecast. Moreover, there is a smoothening effect in this process as the weights of the past data die down in an exponential fashion. In this method, the forecast for the next period is computed on the basis of the forecast for the current period and the actual demand during the current period. Since there is likely to be a difference between the forecast and the actual demand, the difference is incorporated in the next period's forecast.

Let us suppose that

F_{t+1} = The exponentially smoothened forecast for Period $t + 1$

F_t = The exponentially smoothened forecast for Period t

D_t = Actual demand during Period t

α = The smoothening coefficient

Then,

$$F_{t+1} = F_t + \alpha(D_t - F_t) \qquad (14.3)$$

This equation is the simplest form of exponential smoothening. The smoothening effect does not become evident in this form of the equation. However, by recursively substituting F_t terms in Eq. 14.3, one can obtain an alternative equation as follows:

Rearranging the terms in Eq. 14.3, we get

$$F_{t+1} = \alpha D_t + (1-\alpha)F_t \quad \text{and} \quad F_t = \alpha D_{t-1} + (1-\alpha)F_{t-1}$$

Substituting the second equation into the first and proceeding in this fashion, one obtains alternate expression for F_{t+1} as:

$$F_{t+1} = \alpha D_t + \alpha(1-\alpha)D_{t-1} + \alpha(1-\alpha)^2 D_{t-2} + \ldots + \alpha(1-\alpha)^{t-1} D_1 + (1-\alpha)^t F_1$$

We see in this equation that the previous demand points are successively smoothened with a factor of $(1 - \alpha)$.

Table 14.3 presents an illustration of forecasting using exponential smoothening. The behaviour of the model parameter is of particular interest. A glance at Tables 14.3(a) and 14.3(b) clearly shows the impact of α on the forecast. A lower value of α indicates that the forecast is not responsive to the demand, whereas a higher value makes the forecast responsive to the demand. In other words, by choosing a higher value for α, the model weighs recent demand points more.

Figure 14.3—which is a plot of the forecast and the demand for various values of α—graphically portrays this phenomenon.

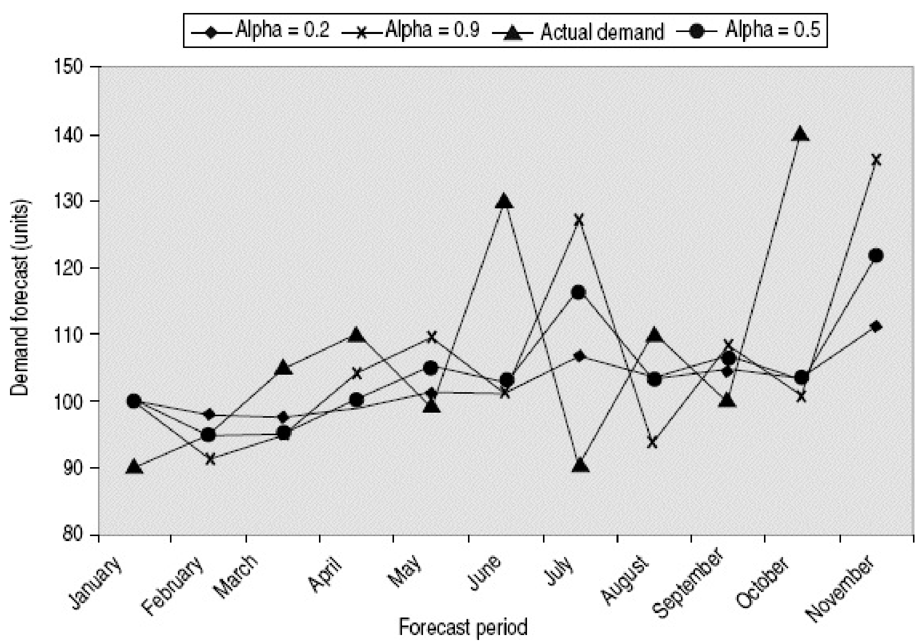
A lower value of α indicates that the forecast is not responsive to the demand.

TABLE 14.3 An Illustration of the Exponential Smoothening Method

(a) An example with α = 0.20			(b) An example with α = 0.80		
Period	**Forecast***	**Actual Demand**	**Period**	**Forecast***	**Actual Demand**
January	100	90	January	100	90
February	98	95	February	92	95
March	97	105	March	94	105
April	99	110	April	103	110
May	101	100	May	109	100
June	101	130	June	102	130
July	107	90	July	124	90
August	103	110	August	97	110
September	105	100	September	107	100
October	104	140	October	101	140
November	111		November	132	

Note: *Forecasts in this illustration are rounded to units; α = model parameter smoothening constant.

FIGURE 14.3 The impact of α on the forecast in exponential smoothening



Extracting the Components of Time Series

The two methods discussed so far provide a capability to project demand without any significant pattern. While they are useful for short-term forecasting, demand in the medium term of 12 months often has a significant pattern. Let us suppose that a manufacturer of stationery collects the actual demand for stationery items such as school notebooks by the month during the past several years. It is possible to decipher patterns in the demand by systematically analysing the past data and use the information for extrapolation of demand into the future. For example, the data may show that at certain points of time, the demand for the stationery is on the increase. Similarly, over the years, the demand could have steadily grown. Extracting components of a time series is a forecasting technique that employs time series data, deciphers the patterns in the demand in the past into distinctive components such as trend and seasonality, and uses it as the basis for forecasting.

There are four components of a time series. First is the *trend* (*T*), defined by the long-term secular movement in the pattern (see Figure 14.4). In our stationery example, we would have, for instance, detected a pattern that suggests that the demand has steadily increased in the last five years at a certain percentage. The second component is *seasonality* (*S*). There are fixed cycles in which the time series data often move from period to period. For example, the sale of stationery items such as notebooks is the highest during May–June–July when schools reopen and at other times it could be less. Similarly, the sale of consumer durables and home appliances peak during the festival season. The disposable income in the hands of salaried employees tends to be more during festival time due to bonus and other incentive payouts by organizations. All these examples suggest that during a year, there could be periods of high demand and periods of low demand. Further, this cycle could potentially repeat year after year (as is evident in Figure 14.5). This is characterized as seasonality in time series.

> There are four components of a time series: trend, seasonality, cyclical, and random.

The third component is the *cyclical* (*C*) component. Several sectors of the industry are influenced by business cycles that repeat over a much longer period, say, 10–20 years. The global meltdown of the economy is a case in point. Several developed economies in the west such as that of the United States are reeling under deep recession. Even in India, beginning from late 2008, we have experienced a slowdown of the economy. All these result in cyclic demand patterns for the business. Several factors influence business cycles and the business cycles in turn influence the demand for products and services. The last component is the *random* (*R*) component, also known as the “noise in the system”. There are several uncontrollable events happening in the short-term that could influence demand. For instance, a sudden development of inclement weather in the afternoon following a sunny morning could cause a slump in the number of people visiting the beach and can consequently influence the demand for snacks and beverages offered by a seaside restaurant. There are numerous such events that influence the business in the short run. Figure 14.5 shows the seasonal, cyclical, and random components of a time series. For instance, the seasonal factor for Month 6 in the figure is 1.10. This indicates that the demand during that month will be 110 per cent of the average demand due to high seasonality. The random component cannot be predicted, however, unlike the other three components.

FIGURE 14.4 The trend component in a time series

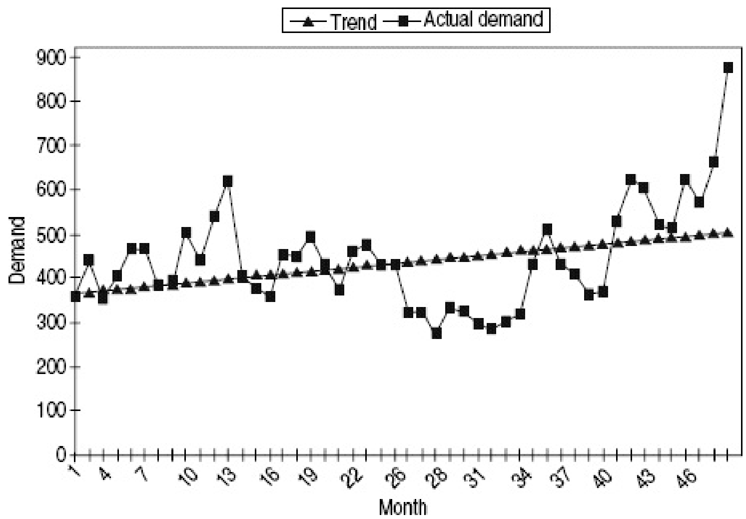
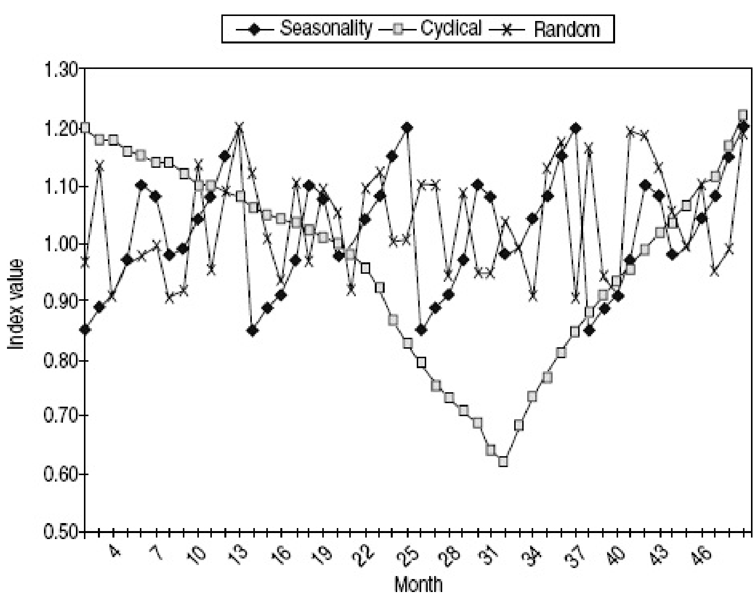


FIGURE 14.5 An extract of the seasonal, cyclical, and random components of a time series



The forecast for the demand is obtained by incorporating the components of the time series. In a multiplicative model, extrapolation is done using a multiplicative relationship among the four components. Thus, a forecast of future demand is given by $F = T \times C \times S \times R$. For example, the trend component for each period in Figure 14.4 could be multiplied by the other components for the same period in Figure 14.5 to obtain the demand forecast. The multiplicative model is more often employed and representative of several time series data used in business applications. In order to develop forecasts using time series data, an organization needs to identify the components of time series that require estimation of values and use these values to obtain the forecast. For example, an organization may choose to include trend and seasonal components of the time series data and accordingly estimate values of *T* and *S* to obtain the forecast.

> In a **multiplicative model**, the extrapolation is done using a multiplicative relationship among the four components.

Estimating the Trend Using Linear Regression

The simplest method to estimate the trend in a time series is to treat the time periods as independent variables and the actual demand as a dependant variable. Using the standard method of least squares, it is possible to estimate the trend component. Consider the following notations pertaining to a time series:

X_i = Time periods (in a monthly time series data for 2 years, X will vary from 1 to 24)
Y_i = Actual demand during Period X_i

Then, a simple linear regression of the form $Y = a + bX$ could be constructed to predict the demand Y for any value of X using the equation, where

a = Intercept (at Period 0)
b = Slope of the line
X = Time period
Y = Forecast for the demand Period X

The coefficients of the regression equation could be computed using the **method of least squares:**

$$b = \frac{\sum_i X_i Y_i - n\overline{X}\overline{Y}}{\sum_i X_i^2 - n\overline{X}^2} \tag{14.4}$$

$$a = \overline{Y} - b\overline{X} \tag{14.5}$$

where n is the number of periods,

$$\overline{X} = \frac{\sum_i X_i}{n}$$

$$\overline{Y} = \frac{\sum_i Y_i}{n}$$

Extracting the Seasonal Component

Extracting the seasonal component requires developing indices for seasonality. Seasonality indices adjust the forecast by scaling up the estimate during periods of high demand and scaling down during periods of low demand. The seasonality index could be estimated by taking a ratio of the actual period demand with the average demand for the period. Thus, if D_i is the demand during a period i and $\bar{D}_i$ is the average demand for the corresponding period, then the seasonality index S_i is given by:

$$S_i = \frac{D_i}{\bar{D}_i}$$

> The seasonality index can be estimated by taking a ratio of the actual period demand with the average demand for the period.

One can use a simple moving average method to obtain the average demand for every period in a time series data and use that for computing the seasonality index. Further refinement of the seasonality index is obtained by averaging the seasonality indices of the same period in the successive years in a time series. Example 14.2 illustrates the method of computing the seasonality indices for Example 14.1.

EXAMPLE 14.1

A manufacturer of critical components for two-wheelers in the automotive sector is interested in forecasting the trend of demand during the next year as a key input to its annual planning exercise. Information on the past sales is available for the last three years (see Table 14.4). Extract the trend component of the time series data and use it for predicting the future demand of the components.

TABLE 14.4 Actual Demand in the Last Three Years (In Thousands of Units)

Period	Actual Demand
Year 1: Q1	360
Year 1: Q2	438
Year 1: Q3	359
Year 1: Q4	406
Year 2: Q1	393
Year 2: Q2	465

Year 2: Q3	387
Year 2: Q4	464
Year 3: Q1	505
Year 3: Q2	618
Year 3: Q3	443
Year 3: Q4	540

Solution

The model for forecasting using linear trend is denoted by $Y = a + bX$.

From Table 14.4, we compute the following:

$$\bar{X} = \frac{78}{12} = 6.50 \quad \text{and} \quad \bar{Y} = \frac{5379}{12} = 448.25$$

TABLE 14.5 Computations for Trend Extraction Using the Method of Least Squares

Period	**X**	**Y**	**X × Y**	**X × X**
Year 1: Q1	1	360	360	1
Year 1: Q2	2	438	876	4
Year 1: Q3	3	359	1,078	9
Year 1: Q4	4	406	1,625	16
Year 2: Q1	5	393	1,965	25
Year 2: Q2	6	465	2,790	36
Year 2: Q3	7	387	2,709	49
Year 2: Q4	8	464	3,712	64
Year 3: Q1	9	505	4,545	81
Year 3: Q2	10	618	6,180	100
Year 3: Q3	11	443	4,873	121
Year 3: Q4	12	540	6,480	144
Sum	**78**	**5,379**	**37,193**	**650**

Therefore, using the values from Table 14.5, we can compute b from Eq. 14.4 as:

$$b = \frac{37193 - (12 \times 6.50 \times 448.25)}{650 - (12 \times 6.50 \times 6.50)} = \frac{2229.5}{143} = 15.59$$

Similarly, $a = 448.25 - 15.59 \times 6.50 = 346.91$

The linear trend for the time series is given by $Y = 346.91 + 15.59X$

The trend components of forecasts for the four quarters in Year 4 are obtained by substituting the values of 13 to 16 for X, respectively.

Forecast for Q1 of Year 4 = 346.91 + 15.59 × 13 = 550

Forecast for Q2 of Year 4 = 346.91 + 15.59 × 14 = 565

Forecast for Q3 of Year 4 = 346.91 + 15.59 × 15 = 581
Forecast for Q4 of Year 4 = 346.91 + 15.59 × 16 = 596

For the sake of simplicity, all the values are rounded to the nearest integer in this computation.

14.8 CAUSAL METHODS OF FORECASTING

These methods construct a forecasting logic through a process of identifying the factors that cause some effect on the forecast and building a functional form of the relationship between the identified factors. In other words, a set of independent variables are identified and associated with the dependent variable through a functional relationship. For example, let us consider the demand in the country for a new product such as direct-to-home receivers (DTH). Since this is a new product, we may not have adequate past data on the demand and may need other means of establishing the potential demand. Even in the case of an existing product, the number of factors that influence demand may be several, requiring us to understand the interactions among these. Let us return to the example of forecasting the demand for polyethylene in the case of Reliance Industries (see Ideas at Work 14.1). Several factors—including exchange rate fluctuation, installed capacity in the country, new product launches, customs tariffs, and the price of raw material at the international markets—influence the demand. Forecasting in these situations uses causal methods.

EXAMPLE 14.2

Extract the seasonal component and adjust the forecast obtained for seasonality for Example 14.1.

Solution
For Example 14.1, we first obtain the average demand for each quarter using the four-period moving average method. A four-period moving average value is centred between two quarters. For example, the average of Year : Q1 to Year 1: Q4 is centred between Year 1: Q2 and Year 1: Q3 (Column 3 in Table 14.6). Therefore, we once again take an average of such values obtained to finally centre the averages against each quarter (see Column 4 in Table14.6). By this method, we obtain the average demand for Year 1: Q3 to be 394.875. Taking a ratio of actual demand and this value provides the seasonality index for Year 1: Q3 (see the last column in Table 14.6). For example, the demand during Year 1: Q3 is lower than the average demand for the period and the demand for Year 1: Q4 is higher than the average demand.

We obtain more than one value of seasonality index for a particular quarter from the time series data. In our example, the seasonality indices of Year 2: Q1 and Year 3: Q1 are computed to be 0.960 and 1.007. An average of these values finally provides us the seasonality index for each quarter. Table 14.7 has the computations for obtaining the seasonality index for all the four quarters in this manner.

TABLE 14.6 Computation of Seasonal Index

Period	Actual Demand	Four-Quarter Moving Average of Demand	Average Demand for Period	Seasonality Index
Year 1: Q1	360			
Year 1: Q2	438	390.75		
Year 1: Q3	359	399.00	394.875	0.909
Year 1: Q4	406	405.75	402.375	1.009
Year 2: Q1	393	412.75	409.250	0.960
Year 2: Q2	465	427.25	420.000	1.107
Year 2: Q3	387	455.00	441.125	0.877
Year 2: Q4	464	493.25	474.125	0.979
Year 3: Q1	504	507.25	500.250	1.007
Year 3: Q2	618	526.25	516.750	1.196
Year 3: Q3	443			
Year 3: Q4	540			

TABLE 14.7 Computations for Obtaining the Seasonality Index in All Four Quarters

	Year 1	Year 2	Year 3	Average
Quarter 1		0.960	1.007	0.984
Quarter 2		1.107	1.196	1.152
Quarter 3	0.909	0.877		0.893
Quarter 4	1.009	0.979		0.994

The forecast after incorporating the seasonality index for the next four quarters is given by:

Year 4	Trend adjusted forecast*	Seasonality index	Seasonality adjusted forecast
Quarter 1	550	0.984	541
Quarter 2	565	1.152	651
Quarter 3	581	0.893	519
Quarter 4	596	0.994	592

Note: * These values were computed in Example 14.1.

In general, let us consider the forecast for a dependent variable Y using n independent variables $X_1, X_2, X_3, \ldots, X_n$. Then developing a forecasting logic requires establishing a relationship as follows:

$$Y = f(X_1, X_2, X_3, \ldots, X_n)$$

The use of the causal method to extract the trend component in a time series is a frequent application of the causal method. However, in the case of extracting the trend component in a time series, simplifying assumptions (including linear relationship between time and demand) are made. Other causal methods include econometric models, multiple regression models, and technological forecasting techniques.

Causal methods of forecasting require a greater degree of mathematical treatment of the data and a sound background in multiple regression techniques. Several computer packages such as SPSS are available today to help the forecast designer in this process. However, developing a good regression model requires considerable experience in using regression analysis and a good knowledge of the problem on hand. The inclusion of variables having spurious correlation among themselves and the dependent variable could result in forecasting models with poor explanatory power.

Computer packages such as SPSS help the forecast designer in developing causal models.

EXAMPLE 14.3

A manufacturer of tricycles for children in the age group of two to four years commissioned a market research firm to understand the factors that influenced the demand for its product. After some detailed studies, the market research firm concluded that the demand was a simple linear function of the number of newly married couples in the city. Based on this assumption, build a causal model for forecasting the demand for the product using the data given in Table 14.8 collected for a residential area in a city. Also estimate the demand for tricycles if the number of new marriages is 150 and 250.

TABLE 14.8 Data for Example 14.3

X	***Y***
New Marriages	**Demand for Tricycles**
200	165
235	184
210	180
197	145
225	190
240	169
217	180
225	170

Solution

Since the causal relationship is a simple linear regression, we make use of the method of least squares to determine the coefficients of the linear regression $Y = a + bX$ using Eqs. 14.4 and 14.5. The computation is shown in Table 14.9.

From Eq. 14.4, we have

$$b = \frac{303{,}225 - (8 \times 218.625 \times 172.875)}{384.073 - (8 \times 218.625^2)}$$
$$= \frac{866.25}{1697.875} = 0.5104$$

TABLE 14.9 Determination of Coefficients of Linear Regression *Y*

	X New Marriages	Y Demand for Tricycle	$X \times Y$	$X \times X$
	200	165	33,000	40,000
	235	184	43,240	55,225
	210	180	37,800	44,100
	197	145	28,565	38,809
	225	190	42,750	50,625
	240	169	40,560	57,600
	217	180	39,060	47,089
	225	170	38,250	50,625
Sum	1,749	1,383	303,225	384,073
Average	218.625	172.875		

From Eq. 14.5, we have

$$a = 172.875 - 0.5104 \times 218.625 = 61.29$$

Therefore the demand for tricycles is given by the relationship:

Number of tricycles demanded
= 61.29 + 0.5104 × Number of new marriages

If the number of new marriages is 150, then demand
= 138 tricycles

If the number of new marriages is 250, then demand
= 189 tricycles

Econometric Models

The primary use of causal methods lies in their usefulness in model building involving situations with unknown functional forms. For example, if we throw an object from a height, we can model the trajectory of the path and the time taken by the object to reach the ground from a certain height because known functional forms and relationships govern this process. On the other hand, a vast majority of business problems, including the problem of predicting the market for a new product or service or the likely acceptance of a new technology defy known functional relationships. Such a situation calls for collecting data from the market using pilot studies, eliciting information from subject matter experts, analysing related areas, or observing some patterns of behaviour and establishing the relationship. Often, these relationships can be established using principles of multiple regression analysis.

> In econometric modelling, macroeconomic performance is predicted for a variety of planning purposes using a large number of variables.

Two popular applications of this include econometric modelling and technology forecasting. In econometric modelling, macroeconomic performance is predicted for a variety of planning purposes using a large number of variables. These variables are typically included in a multiple regression model and the relationship between these variables and the dependent variable is established. Using such a relationship, several predictions are made at the macroeconomic level, and planning exercises are undertaken. In technological forecasting, a similar approach is taken to identify a host of variables pertaining to the alternative technology choices in question and a multiple regression model is developed to predict the impact and trends in using alternative technologies in the future.

Developing such causal models is not only time consuming but also expensive. They demand specialized skills of model building and analysis. The collection of a vast amount of data, use of extensive field trials, and pilot studies will precede the development of the model. Moreover, it will also require the use of powerful computing environments to handle complex and numerous mathematical relationships and regression analyses. Due to these features of causal models, they are mostly employed for analysing long-term forecasting and planning requirements in large corporations and economic and public policy institutions.

14.9 ACCURACY OF FORECASTS

So far, we have focused our attention on the various methods used for preparing forecasts. Forecasting models are useful only as long as their predictions are close to reality. If a forecasting model is found to be erroneous in predicting the demand for the future, managers lose their faith in using the system. Moreover, incorrect forecasts could create several problems in the organization as forecasting forms a key input to the planning function.

ideas at Work 14.3

Factors Affecting Fer tilizer Use in Punjab

As the population increases, foodgrain production also needs to increase. One of the methods to improve productivity per hectare of cultivable land is the judicious use of fertilizers. Farmers in the country continue to use fertilizers and therefore, firms manufacturing fertilizer need to understand the demand for fertilizer.

A study was conducted to identify the variables that influence the consumption of fertilizers per hectare. Data on different factors affecting the intensity of fertilizer use in Punjab during the period 1970–71 to 1997–98 was collected and analysed as a part of the study. The analysis revealed several variables that may explain the use of fertilizers. For instance, the price of fertilizers was important. When potash and phosphate fertilizers were decontrolled during the 1990s, the data showed changes in the usage pattern. Another factor was the gross cropped area. The increase in the consumption of fertilizer at a particular point in time was attributed to the intensity of fertilizer use rather than an increase in the gross cropped area. There have been some changes in this.

However, the analysis further showed that fertilizer consumption is also dependent on the gross cropped area of high-yielding varieties. For example, changes during the nineties reflect increased efforts in the research and development of high-yielding crops and their relationship to fertilizer use.

On the basis of this analysis, a causal model was developed to estimate the consumption of fertilizers in Punjab, as follows:

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3$$

where

Y = Fertilizer use per hectare (in kg)

X_1 = Percentage of gross cropped area under high yielding varieties

X_2 = Deflated price of fertilizers (in ₹)

X_3 = Percentage of irrigated gross cropped area

The regression analysis revealed that the value of b_3 was 2.38 and was significant. This indicated that gross cropped area had a positive effect on fertilizer use. Moreover, the area under high-yielding varieties also had a positive coefficient, whereas price had a negative coefficient, as expected. The negative and low price elasticity indicated that smaller price changes may not affect fertilizer use significantly.

Source: Based on K. Vatta and K.C. Dhawan, "Trends in Fertilizer Consumption in Punjab," *Productivity* 41, no. 3 (2000): 463–466.

Imagine that a forecasting model predicted the demand for a product in the next quarter to be 250,000 units. On the basis of this information, material procurement, production, inventory build up, and distribution activities will be organized. If the actual demand turns out to be only 100,000 units, then there could be an excessive build-up of raw material and non-moving inventory. On the other hand, if the demand was 350,000 units, severe shortages, last minute rescheduling of production, rush purchasing, and expediting deliveries could all result in excessive cost, compromise of quality, and severe strain in the operations system. Therefore, obtaining reliable forecasts is very important.

Various methods are available to assess the usefulness of the forecasting model. All these rely on alternative methods of comparing the actual demand with the forecast provided by the system for each period. The most popular among them are discussed here.

Forecast Error (FE)

In simple terms, forecast error for a period t, e_t denotes the difference between the demand, D_t, and the forecast, F_t, for the period. A positive value of e_t will indicate underestimation of demand and vice versa.

$$\varepsilon_i = D_t - F_t$$

The sum of errors (SFE) is merely the sum of errors during the period of consideration. For example, if we estimate the forecast error using the monthly data for a period of n months, sum of forecast errors is given by:

$$SFE = \sum_{i=1}^{n} \varepsilon_i$$

We know that forecast errors could be either positive or negative depending upon overestimation or underestimation of the demand. Therefore, even when the system is not performing well, one can expect a value close to zero for SFE. This happens when the system overestimates demand as much as it underestimates it.

Mean Absolute Deviation (MAD)

To overcome the limitation of SFE, one could take the absolute values of e_t and average it over the n periods to get an alternative and better picture of forecast error. This measure is known as the mean absolute deviation (MAD).

$$MAD = \frac{1}{n} \times \sum_{i=1}^{n} |\varepsilon_i|$$

Mean Absolute Percentage Error (MAPE)

An alternative way to represent the deviation is in relative terms rather than absolute terms. For example, each absolute error term could be expressed as a percentage of the demand and a new measure computed. This measure is known as mean absolute percentage error (MAPE) and is computed as:

$$MAPE = \frac{1}{n} \times \sum_{i=1}^{n} \frac{|\varepsilon_i|}{D_i} \times 100$$

Mean Squared Error (MSE)

As the name implies, this measure is obtained by taking the mean of the square of the error terms. Squaring of the error terms serves the important purpose of amplifying the forecast errors. Therefore, in situations demanding low tolerance for forecast errors it is desirable to make use of this measure. MSE is computed as follows:

$$MSE = \frac{1}{n} \times \sum_{i=1}^{n} \varepsilon_i^2$$

Tracking Signal (TS)

Another useful measure for assessing the performance of a forecasting model is the tracking signal. In addition to understanding the extent of deviation from the actual demand, managers will benefit from knowing if the forecasting system is drifting away. In order to know this, we need to find out if the forecasting system consistently under or over estimates the demand. Tracking signal is intended to detect this phenomenon and is obtained by taking a ratio of SFE with MAD.

> The tracking signal helps managers detect any drift in the forecasting system.

$$TS = \frac{SFE}{MAD} \tag{14.6}$$

In Eq. 14.6, we see that the denominator is always positive and is a fraction of the numerator value. But the numerator could be positive if the demand is more than forecast or negative if the forecast is more than the demand during successive periods. Therefore, the sign and magnitude of TS will indicate if and by how much the forecasting system is drifting away from the actual demand.

EXAMPLE 14.4

Table 14.10 has data pertaining to the actual demand and the forecast using a forecasting system for 18 time periods in the past. Compute the measures of forecast accuracy and comment on the usefulness of the forecasting system.

Solution
All the required computations are available in Table 14.11.

MAD for Period 6:
Cumulative absolute deviation up to Period 6 = 54

Number of periods = 6
Therefore, MAD = 54/6 = 9.00

MAPE for Period 12:

Cumulative absolute per cent error up to Period 12
= 9.2% + 3.5% + … + 0.0% = 92.0%
Number of periods = 12
Therefore, MAPE = 92/12 = 7.77%

TS for Period 15:

SFE for Period 15 = 96
MAD for Period 15 = 10.27
Therefore, TS = 96/10.27 = 9.35

MSE for Period 18:

Cumulative squared error up to Period 18
= 121 + 16 + … + 900 = 4106
Number of periods = 18
Therefore, MSE = 4106/18 = 228.11

TABLE 14.10 Actual Demand and Forecast Data for Example 14.4

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Demand	120	114	130	124	97	95	100	110	109
Forecast	109	118	132	110	110	105	98	95	104
Period	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Demand	123	127	119	130	125	119	120	90	95
Forecast	110	112	119	124	110	90	95	75	65

TABLE 14.11 Measures of Forecast Accuracy Based on Data Given in Table 14.10

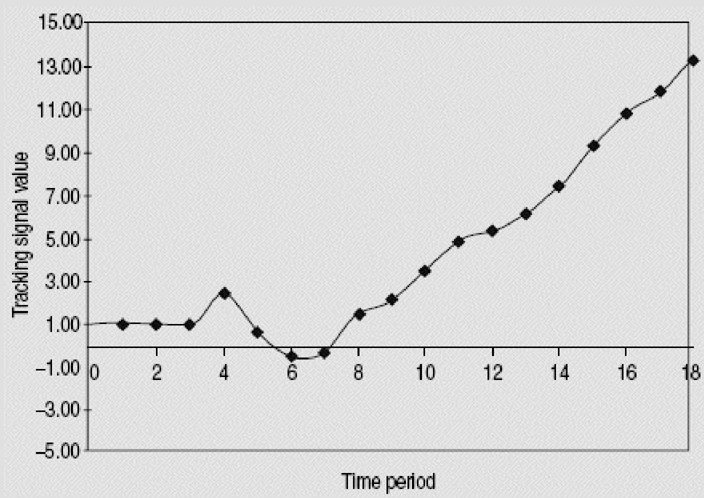
Key Inferences

The results in Table 14.11 bring out some of the salient features of the accuracy measures and the performance of the forecasting system. We shall begin by observing the results at the end of Period 6. The measure SFE tends to indicate that the system is performing well as the cumulative difference between the forecast and the actual demand is only 4 units. However, on looking at the demand, we realize that the system has deviated in all the periods from the demand. As it was overestimating during some periods and underestimating in other periods, we have not been able to detect this accurately. However, the cumulative absolute deviation during the period is 54 units. Therefore, MAD brings sharper focus to the performance of the forecasting system.

The MAPE measure does not indicate any significant change during the period of analysis. On the other hand, MAD has increased steadily beginning from Period 2. This indicates that the forecasting system is deteriorating in its performance over time. However, it still does not indicate if the system is consistently underestimating or overestimating the demand. The TS measure clearly shows that the forecasting system is consistently underestimating. This is because only in such a situation will the TS have a positive value of increasing magnitude. A graphical plot of the TS is available in Figure 14.6. It is evident from the graph that the forecasting system has been performing without introducing much bias during the first eight periods. One possibility of using the TS is to set some acceptable limits of positive and negative values. Once the TS value exceeds this limit, alerts could be set up to draw the attention of the management for some possible investigative and corrective measures.

An alternative perspective emerges from the MSE measure. The MSE measure clearly amplifies the error by an order of magnitude. Therefore, it has a tendency to alert the management much earlier on the impending poor performance of the forecasting system.

FIGURE 14.6 A graphical representation of TS



14.10 USING THE FORECASTING SYSTEM

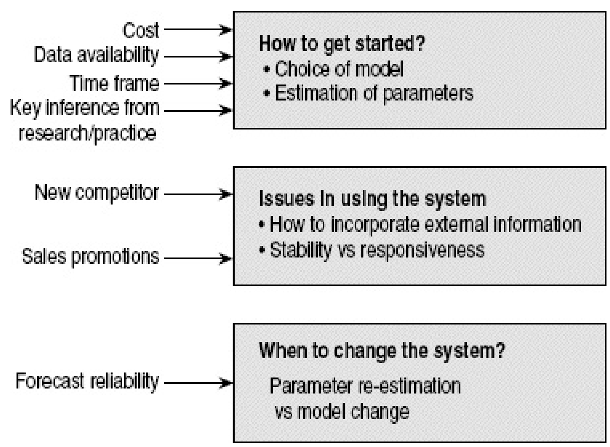
In addition to developing an appropriate forecasting model and establishing performance measures for obtaining reliable forecasts, it is important that managers focus on several issues pertaining to using the forecasting system. Figure 14.7 depicts the various issues involved in using a forecasting system. As shown in the figure, three aspects merit closer attention.

Getting Started

The issues of choosing the right model and estimating parameters depend on the cost, data availability, and the time horizon. These issues have been addressed. However, as we have seen already, forecasting models differ in terms of their level of complexity, and the degree of mathematical and analytical skills required in setting up and analysing the results from each forecasting system. Therefore, in the course of choosing an appropriate model, it is useful to draw from earlier experiences of practitioners and researchers. By doing so, it is possible to avoid reinventing the wheel. For instance, at the time of establishing the forecasting system, one can utilize other users' experiences of using alternative models. One interesting development based on this approach is the concept of *focus forecasting*.

> Choosing the right model and estimating the parameters for forecasting depend on the cost, data availability, and the time horizon.

FIGURE 14.7 Managerial issues in using a forecasting system



Focus Forecasting

An earlier research study involved testing of the appropriateness of several forecasting models for short-term forecasting using 1,001 actual time series.[1] The models included in the comparison ranged from simple moving averages to mathematically more involved auto-regressive moving averages (ARMA) and Box-Jenkins models. The study concluded that simple models consistently outperformed complex models, especially in situations requiring short-term forecasting.

> Simple forecasting models consistently outperformed complex models, especially in situations requiring short-term forecasting.

Encouraged by this result and the observed practice of using simple forecasting models, the concept of focus forecasting was developed. In focus forecasting, a set of five or six simple forecasting models is set up initially. During every period, forecasts are made using each of these models and the one with the least error (as per the forecasting performance measure chosen, for example, MAPE) will be used for forecasting the demand for the next period. Let us say we set up four simple forecasting models:

- Model 1: Forecasting for the next period is a moving average of the last three months' demand
- Model 2: Forecasting for the next period is 110 per cent of the actual demand during the same period last year
- Model 3: Forecasting for the next period is a moving average of the last six months' demand
- Model 4: Forecasting for the next period is the average of the forecast values obtained using Models 1 to 3

Forecasts for the period that just ended will be made using these four models and the model with the best forecast performance will be used for forecasting the demand for the next period. The procedure is repeated during every period.

Incorporating External Information

However sophisticated the forecasting system an organization has, there are still several issues that are to be dealt with before the organization uses the forecast information. Suppose a health research organization such as WHO releases a report pertaining to the use of coconut oil for cooking. If the report favours the use of coconut oil, the demand for coconut oil will shoot up. On the other hand, if the report shows coconut oil in poor light, the demand will fall. Similarly, consider the report brought out in September 2004 by the Centre for Science and Environment (CSE), an NGO, about high levels of pesticide in aerated drinks. As a result of this report, there was a drop in the demand for Pepsi and Coca-Cola. On the other hand, consider the arrival of a new competitor in a sector of industry. One example is the arrival of Jet Airways in air travel—an advent that caused changes that were only surpassed recently by the entry of several low-cost airlines including Spice Jet and Indigo. Several such examples abound in other sectors as well. A third type of information is regarding special sales promotion schemes announced either by the organization or by one of its competitors. As a result of these changes in the sector—either on account of new competition or some information that has the potential to modify the demand—the forecasts obtained may go wrong. This is simply because the forecasting model has not been built to take these issues into consideration.

In all the examples discussed so far, we see the distinct possibility of new information available in the market that can have an impact on the demand for one's own product or service. We categorize all these as external information because no forecasting system has in-built features or parameters to accommodate such information while estimating the demand. The critical issue in using a forecasting system is the ability of an organization to develop methods for incorporating external information as it becomes available from time to time. There are two ways of handling the situation arising out of this. One is to merely change the forecasts, and the other is to modify the forecasting system.

Although there are no set rules for deciding which one of the two is more appropriate, it is useful to question how permanent the changes introduced by the external information are likely to be. If the changes are only temporary, as in the case of special product promotions for a quarter, then it is prudent not to disturb the forecasting system. Using subjective expertise, the forecasts obtained from the system could be adjusted to account for the impact of the information. On the other hand, if the changes are likely to be permanent, then it calls for revisiting the forecasting model. In some cases, it may call for re-estimating the model parameters, and in other cases, the model itself may have to be replaced by a new one.

> The critical issue in using a forecasting system is the ability of an organization to develop methods for incorporating external information as it becomes available from time to time.

Forecasting Systems: Stability Versus Responsiveness

Our discussions so far bring out another important aspect of using forecasting systems. Depending on the choice of our parameters, it is possible that we make the system more responsive to recent changes. At the other extreme, we can ensure that the system ignores most of the recent changes and provides a stable output. It is also possible that one can tune the system to be more responsive at particular times and stable at other times. Recall our discussion on the exponential smoothening model in Section 14.7. We found that when the value of α is very low, the system is stable, and when α is very high, the system is responsive. Similarly, in the case of moving averages, by choosing a smaller number of periods, one can make the forecasting system more responsive and vice versa. Table 14.12 illustrates this idea using past data of eight periods for forecasting the demand for the ninth period, using alternative values for the model parameters for both moving averages and exponential smoothening method. As we can see, in the case of α = 0.80, the forecast is made using the previous three period data while in the case of α = 0.10, even after incorporating all the eight period data, only 57 per cent of the data is used collectively for the forecast.

TABLE 14.12 Stability Versus Responsiveness in Forecasting Models: An Example

Forecast Method	**Moving Averages**			**Exponential Smoothening**		
Model Parameter	**2 Periods**	**5 Periods**	**8 Periods**	$\alpha = 0.10$	$\alpha = 0.30$	$\alpha = 0.80$
Weightage Given to Actual Demand for Forecast of Period 9						
Period 1	–	–	12.50%	4.78%	2.47%	0.00%
Period 2	–	–	12.50%	5.31%	3.53%	0.01%
Period 3	–	–	12.50%	5.90%	5.04%	0.03%
Period 4	–	20.00%	12.50%	6.56%	7.20%	0.13%
Period 5	–	20.00%	12.50%	7.29%	10.29%	0.64%
Period 6	–	20.00%	12.50%	8.10%	14.70%	3.20%
Period 7	50.00%	20.00%	12.50%	9.00%	21.00%	16.00%
Period 8	50.00%	20.00%	12.50%	10.00%	30.00%	80.00%
Sum	100.00%	100.00%	100.00%	56.95%	94.24%	100.00%

Users of forecasting systems need to decide whether they need a responsive system or a stable system. Returning to our earlier example, during periods of significant happenings in the market (such as sales promotion schemes and the arrival of a new competitor), one may like to temporarily tune the system to be more responsive. After the effects of the external information diminish, the system could be resorted back to stability.

Finally, a good performance measurement system to identify errors in forecasts is valuable in helping the organization to periodically assess the need for either re-estimating the model parameters or changing the forecasting model itself.

SUMMARY

- *Forecasting* is an important planning tool in organizations. It helps to estimate future demand, predict certain events pertaining to operational planning and control, and provides useful information for the strategic planning exercise involving addition of new product lines, capacity, and technology.
- The forecasting context and methodology varies with respect to the time horizon. Consequently, the type of data required and the nature of analyses done also varies with the planning time horizon.
- Designing a forecasting system involves three steps.
    - Developing an appropriate forecasting logic
    - Establishing control mechanisms to obtain reliable forecasts
    - Incorporating managerial considerations in using the forecasting system
- *Extrapolative* and *causal methods* are the two generic classes of forecasting models available. While extrapolative methods devise methods of identifying some patterns in the past data and extend a similar logic into the future, causal methods identify cause–effect relationships between dependent and independent variables.
- By changing the model parameters in the moving averages and exponential smoothening methods, it is possible to create a responsive or a stable forecasting model.
- A time series consists of four components: *trend, seasonality, cyclical* and *random*. Developing time series models for forecasting involves estimating the parameter values for the first three components.
- Several methods are available to assess the accuracy of the forecasts obtained from a forecasting model. The *tracking signal* measure detects the impending tendency of a forecasting model to consistently overestimate or underestimate the demand.
- A sophisticated forecasting system is not enough; managers must use the forecasts obtained from the system in the context of external information.

FORMULA REVIEW

1. Weighted Moving Average forecast for period t,

$$F_t = \frac{D_{t-1}W_{t-1} + D_{t-2}W_{t-2} + D_{t-3}W_{t-3} + \cdots + D_{t-n}W_{t-n}}{W_{t-1} + W_{t-2} + W_{t-3} + \cdots + W_{t-n}}$$

2. Simple Moving Average forecast for period t,

$$F_t = \frac{D_{t-1} + D_{t-2} + D_{t-3} + \cdots + D_{t-n}}{n}$$

3. The exponentially smoothened forecast for period $t + 1$,

a. $F_{t+1} = F_t + \alpha(D_t - F_t)$ or

b. $F_{t+1} = \alpha D_t + \alpha(1-\alpha)D_{t-1} + (1-\alpha)^2 D_{t-2} + \ldots + \alpha(1-\alpha)^{t-1}D_1 + (1-\alpha)^t F_1$.

4. Method of least squares:

a. $\bar{X} = \frac{\sum_i X_i}{n}$

b. $\bar{Y} = \frac{\sum_i Y_i}{n}$

c. $a = \bar{Y} - b\bar{X}$

d. $b = \frac{\sum_i X_i Y_i - n\bar{X}\bar{Y}}{\sum_i X_i^2 - n\bar{X}^2}$

5. Forecast error, $\gamma_t = D_t - F_t$

6. Sum of forecast error, $SFE = \sum_{i=1}^{n} \varepsilon_i$

7. Mean Absolute Deviation, $MAD = \frac{1}{n} \times \sum_{i=1}^{n} |\varepsilon_i|$

8. Mean Absolute Percentage Error, $MAPE = \frac{1}{n} \times \sum_{i=1}^{n} \frac{|\varepsilon_i|}{D_i} \times 100$

9. Mean Squared Error, $MSE = \frac{1}{n} \times \sum_{i=1}^{n} \varepsilon_i^2$

10. Tracking Signal, $TS = \frac{SFE}{MAD}$

REVIEW QUESTIONS

1. For each of the following, identify an appropriate time horizon for forecasting:

a. A corporate mission plan
b. Preparation of an annual budget
c. Ordering material with suppliers
d. Building a new plant
e. Launching of GSLV rocket by ISRO
f. Hiring of contract labourers
g. Developing a new product line

h. Augmenting the capacity in a machine shop

2. What is the relationship between the forecasting time horizon and the choice of forecasting models?
3. Explain how forecasting helps an organization handle uncertainties.
4. Is there a relationship between the choice of data and the type of forecasting model that one wishes to use?
5. Suppose an organization wishes to forecast the demand for the next financial year to prepare its annual budget. What sources of data are useful for this exercise?
6. Identify a suitable forecasting methodology for each of the following situations:

   a. The moon mission project of ISRO
   b. Expanding production capacity
   c. Estimating the demand for apparels
   d. Manpower planning for a fast food joint
   e. Entering into contracts with suppliers of raw material
   f. Estimating the demand for white goods
   g. Identifying new markets
   h. Introduction of a new product into the market
   i. Estimating the demand for capacity during the next month
   j. Finalizing distribution plan for the next quarter
   k. Production planning for fireworks/crackers

7. What factors influence the choice of an appropriate forecasting model?
8. What are the different methods available for assessing the accuracy of forecasts? How should one select an appropriate measure?
9. What are the components of a time series? Explain with suitable examples.
10. Should forecasts be stable or responsive? Why?
11. How could an exponential smoothening model be made more responsive?

PROBLEMS

1. A manufacturer of television picture tubes has the following data (given in Table 14.13) pertaining to the actual demand for picture tubes (in thousands) during the period April to September in a year. Use a three-period moving average method to forecast the demand for October.

TABLE 14.13 Demand for Picture Tubes (in Thousands) Between April and September

Month	Demand
April	125
May	110
June	95
July	130
August	110
September	100

2. Ganesh Darshini is known for its specialty item, the Mysore Masala Dosa (MMD). Estimating the demand for MMD during the evening peak hours (6.00 pm to 8.00 pm) is crucial. Table 14.14 has data regarding the demand for MMD during the last six weeks.

   a. Use the exponential smoothening method to estimate the demand for the next week.

TABLE 14.14 The Demand for MMD for Six Weeks

Week	Demand
Week 1	80
Week 2	95
Week 3	75
Week 4	110
Week 5	100
Week 6	90

b. Compute the MAD and SFE at the end of Week 6. (**Hint:** Assume the forecast for Week 1 to be the same as the demand)

3. The demand for a certain raw material used in the manufacture of a piece of medical equipment varies from month to month. An organization engaged in the manufacture of this equipment wants to place orders with the suppliers for the next month. The inventory records for the component indicate the consumption pattern in the last six months (in metric tons), as shown in Table 14.15.

   a. Use the method of moving averages and forecast the demand for Month 7 using three periods as the model parameter.
   b. Suppose the three periods have the following weights: 0.50 for the immediate past, 0.30 for two periods before and 0.20 for three periods before. What will the forecast be?
   c. Change the number of periods for moving average to 2, 4, and 5 and obtain the forecast in each of these three cases.
   d. Compare the results obtained in (a), (b), and (c). What do you infer from this exercise?

4. Using the data given in Problem 3, compute the forecasts using the method of exponential smoothening when

TABLE 14.15 Consumption Pattern of Raw Material (Metric Tons)

Week	Demand
Month 1	15
Month 2	30
Month 3	45
Month 4	25
Month 5	50
Month 6	35

   a. $\alpha = 0.10$
   b. $\alpha = 0.20$
   c. $\alpha = 0.40$
   d. $\alpha = 0.60$
   e. $\alpha = 0.80$
   f. $\alpha = 0.90$
   g. Plot the forecasts obtained for various values of α. What do you infer from this exercise?
   h. Compare the forecasts obtained in each of these cases with those obtained in Problem 3. What are your inferences from this exercise?

5. An organization is in the process of setting up a forecasting system for short-term forecasting of the demand for their product. They have data on the actual demand in the last six months (Table 14.16). However, they are unsure regarding which model they should use and how to fix the parameters. Prepare a report on the various issues pertaining to the use of exponential smoothening and the moving average method of forecasting.

TABLE 14.16 Data On Demand for Six Months

Week	Demand
Month 1	75
Month 2	60
Month 3	55
Month 4	65
Month 5	80
Month 6	90

(**Hint:** Identify the parameters for each of these models, perform a series of tests to fix the model parameter, and prepare a report of inferences based on this exercise)

6. The sale of Bajaj two-wheelers in the last twelve months in a retail outlet in Chennai is given in Table 14.17. Assume that the demand has a linear trend.

   a. Establish the trend equation for the demand. What do you infer from the trend equation?
   b. Use the trend equation for estimating the trend of the demand during the first three months of the current year.
   c. Calculate MAPE and MSE at the end of December.

TABLE 14.17 Sale of Bajaj Two-Wheelers in Twelve Months in a Particular Outlet

Month	Demand
January	145
February	110
March	100
April	140
May	130
June	140
July	160
August	165
September	180
October	170
November	150
December	140

7. Sales of refrigerators in the past tend to have an element of seasonality in addition to the trend. The data in Table 14.18 shows the sale (in thousands) of refrigerators in the last three years. A manufacturer of refrigerators wants to forecast the demand for the next year by extracting the trend and seasonal components of this time series.

TABLE 14.18 Sales of Refrigerators (In Thousands of Units) in the Last Three Years

Month	Year 1	Year 2	Year 3
January	360	405	323
February	438	380	323
March	359	360	277
April	406	454	333
May	465	449	324
June	464	496	296
July	387	430	285
August	393	375	305
September	505	461	319
October	443	476	432
November	540	431	510
December	618	432	432

a. Extract the trend and seasonal components of the time series.
b. Using a multiplicative model, prepare estimates for the next year.
c. What could be the reasons for the actual demand varying from the forecast that has been prepared?

8. An organization is using the exponential smoothening method for preparing short-term forecasts for its product with an alpha value of 0.20. However, it is not clear if the forecasts obtained from the system are reliable enough. It is also not clear what the most appropriate measure is for assessing the forecast accuracy. Perform the following exercises using Table 14.19 and suggest a suitable course of action for the organization:

a. For the existing forecasting system compute the MAD and MAPE at the end of December.
b. Suppose you decide to change the value of α to 0.50, how will this impact forecasting accuracy?
c. On the other hand, if you replace the exponential smoothening model with a 3-period moving average model, will the forecasting accuracy improve?
d. Assume that a forecasting model with a linear trend will suit the system. Is it worthwhile to shift to this model?
e. Based on your computations, what will you finally recommend to the organization?
f. For the forecasting model that you have recommended, compute the tracking signal and plot the curve. What are your observations based on this plot?

TABLE 14.19 Demand Data for Problem 8

Month	Demand
January	65
February	80
March	90
April	100
May	110
June	80
July	75
August	55
September	50
October	60
November	50

December	45

9. A health services provider needs to estimate the demand for a certain type of service on a weekly basis. This information is important for planning manpower allocation decisions. Table 14.20 has data on the demand for the services in the last 8 weeks.

   The organization is currently using an exponential smoothening model with an alpha value of 0.25.

   a. Demonstrate the usefulness of the focus forecasting technology by forecasting the demand during Weeks 2 to 9.
   The focus forecasting system will consist of the following forecasting rules:
   Rule 1: Exponential smoothening with $\alpha = 0.25$ (existing)
   Rule 2: Moving average with 3 periods
   Rule 3: Forecast is 110% the average of last four period demands

TABLE 14.20 Data on Demand for Services in Eight Weeks

Week	Demand
Week 1	80
Week 2	90
Week 3	65
Week 4	110
Week 5	60
Week 6	80
Week 7	80
Week 8	100

   Rule 4: Forecast is 90% the average of last four period demands
   Rule 5: Forecast is 110% the average of demand 4 weeks before
   Rule 6: Forecast is the average of all forecasts obtained using Rules 1 to 5

   b. If the organization replaced the existing methodology with focus forecasting, would the forecasting accuracy improve? (Use MAD as the measure)

10. A market research firm was contracted by an organization manufacturing air conditioners (ACs) to forecast demand for their product. The market research firm conducted some studies in three prime markets in the country to understand what factors influence the demand for ACs. The study revealed that the demand is dependent on two factors—the average disposable income (in thousands of ₹) of the target customer segment and population (in thousands) in the city. The market research firm believes that a linear relationship will satisfactorily explain the behaviour. Use the data in Table 14.21 and build a linear regression model for the demand of ACs.

   a. How do these factors influence the demand for ACs?
   b. Assume that the parameters in a new city that the company proposes to enter are as follows: population: 275,000 and disposable income: ₹18,000. What is the sales revenue for the company if it prices the AC at ₹20,000 and ₹25,000?

TABLE 14.21 Demand for ACs With Respect to Population and Disposable Incomes

Demand for ACs (in Hundreds)	Population (in Thousands)	Disposable Income (Thousands of ₹)
115	240	12.0

125	230	18.5
110	155	14.0
120	260	11.0
160	340	9.0
90	165	11.5
120	125	15.5
125	140	17.0
90	110	16.0
105	200	11.5

11. A service provider has to make necessary arrangements for the work force to be employed in her service delivery system, which is a function of the expected weekly demand for her services. Table 14.22 has details for the actual demand for the last seven weeks.

   a. Develop a forecasting model using exponential smoothening which is very responsive to the demand and use it for forecasting the demand for week eight. Use week one demand as its forecast.
   b. Develop a forecasting model using exponential smoothening which is stable and use it for forecasting the demand for week eight. Use week one demand as its forecast.
   c. Use MAD as a measure of forecast performance. Which of the mentioned two models will you recommend?
   d. Will your recommendation change if tracking signal is the measure of forecast performance?

TABLE 14.22 Data on Demand for the Last Seven Weeks

Week	Demand for the Day
Week one	243
Week two	236
Week three	267
Week four	241
Week five	257
Week six	250
Week seven	242

12. The forecasts and the actual demand for an item are given in Table 14.23. Using the data, compute all relevant measures of forecast performance.

TABLE 14.23 Data on Forecast and Actual Demand for an Item

Period	Demand for the Item	Forecast of Demand
1	423	410
2	396	387
3	467	433
4	411	410
5	457	421
6	450	434

Week seven	442	436
Week eight	426	419

NET-WISE EXERCISES

1. Visit http://www.k2b.net/pdfs/k2b_resourcelibrary_forrester.pdf. Read the article, “Demand Forecasting Done Right.”

    a. What are the challenges in demand forecasting? How can you overcome some of them?
    b. How do organizations benefit from accurate demand forecasting data?

2. Visit http://www.hfma.org/Content.aspx? id = 1944 and read the article by Hugo J. Finarelli, Jr and Tracy Johnson, “Effective Demand Forecasting in 9 Steps: Shifts in Demand for a Hospital’s Services Can Occur Unexpectedly. Demand Forecasting Can Help You Prepare for these Shifts and Avoid Strategic Missteps”, *Healthcare Financial Management*, Nov 2004. Prepare a final report to answer the following questions:

    a. What are the key elements of data required to forecast healthcare services? Where do you find this data?
    b. What are the main steps involved in the demand forecasting exercise pertaining to the healthcare sector?
    c. Can you relate the ideas given in this paper to the issue of healthcare services in India?
    d. How can the policy makers make use of the demand forecasting done for the healthcare sector? Do hospitals and doctors find any use for this exercise?

MINI PROJECTS

Visit the local branch of any bank and collect statistics on the demand for the teller and savings bank facilities in the bank. Aggregate the data on a weekly basis. Use the data for a period of a quarter (12 weeks) and using this time series, identify the component of time series evident in the data.

a. For the components identified, extract the component values and use a multiplicative model to design a forecasting system.
b. Use your forecasting system and obtain the forecasts for the 12-week horizon that you have.
c. Choose an appropriate measure of performance for the system. Are you satisfied with the performance of the system?
d. If not, identify the problems in your forecasting system and improve the forecasting logic.
e. Once you have obtained a satisfactory result from the forecasting system, prepare the forecasts for the next four weeks.
f. Write a report and discuss the results with your instructor.

CASE STUDY

ABS Caterers

ABS Caterers operate from the Green Park area of Hauz Khas in New Delhi. Green Park is a posh locality in South Delhi and has a large number of restaurants serving the needs of the people in the locality. Though ABS has its main operations at Green Park, its also deals with the catering needs of educational institutions. ABS bagged the contract for catering in a well-known educational institution in South Delhi a few years back. They are responsible for the catering of the students and staff at the campus.

Campus Operations

At present, ABS has two units operating in the campus: “Green View”, which is on the seventh floor of the main academic building, and the second one, “ABS Café”, which is in the heart of the hostel zone. Green View operates between 10 a.m. and 5 p.m. during weekdays (Mon–Fri). It caters to the needs of the entire office crowd, students, and teaching and non-teaching staff. ABS Café operates between 4 p.m. and midnight on a daily basis and is mostly visited by students.

Though ABS has its main operation at Green Park, Mr Jain, the proprietor of ABS Caterers, considers the campus catering contract to be very important. There are quite a few educational institutions around. Jawaharlal Nehru University is near the campus. If ABS can prove its worth in their current operations, it is only a matter of time, according to Mr Jain, before they get contracts at other nearby institutions. This would mean a lot in terms of his business volumes.

At present, the volume of business at the campus is not substantial compared to the overall business of ABS, but the situation has certainly improved ever since ABS took over a few years back. ABS has registered a steady 20 per cent increase in sales and expects it to go up even further. This is primarily because ABS has been consistently maintaining a low price for its items.

Though the campus operations started with a small variety of food, ABS introduces new items whenever there is a demand for them. For example, two new South Indian dishes—Mysore Masala Dosa and Onion Uthappam—were introduced recently. They are now available only between 11 a.m. and 3 p.m. The management expects to introduce new items in the coming months. Serving a typical meal request takes nearly 20 minutes of one worker’s time.

ABS has a group of service personnel and two managers who take care of the needs of the two centres. The service personnel can move from one restaurant to another (i.e. from Green View to ABS Café and vice versa), if the need arises. In any case, the restaurants are not too far and they will not object to this. At present, the timings of the two centres are overlapping only between 4 p.m. and 5 p.m. Hence, resources management has not been a serious problem.

Future Plans

The immediate plan of Mr Jain is to keep ABS Café open between 1 pm and midnight. This would mean an additional three hours of service timing and overlap with Green View. He believes that this new arrangement will not only facilitate the students, but also increase his volume of business. However, Mr Jain has to have a relook into the resource management problem. Mr Jain has vast experience in the catering industry and particularly in an academic set-up. He has observed some patterns in the arrival of customers at the restaurants. Table 14.24 is a sample of his observation for the month of September 2007.

QUESTIONS FOR DISCUSSION

a. What are the potential advantages of forecasting requirements for the campus operations of ABS Caterers?
b. If Mr Jain wishes to develop a forecasting model, develop an overall framework for the same.
c. How should Mr Jain plan his weekly plan for deploying resource requirements? Can you estimate the number of service personnel that he needs?

TABLE 14.24 Number of Customers Served During September 2007

	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Week 1	345	310	385	416	597	706	653
Week 2	418	333	400	515	664	761	702
Week 3	393	387	311	535	625	711	598
Week 4	406	412	377	444	650	803	822

SUGGESTED READINGS

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CHAPTER 15

Operations Planning

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- Why do organizations engage in operations planning?
- What are the steps involved in an aggregate planning exercise?
- What are the alternatives available to an organization to modify demand and supply?
- What are the generic strategies adopted in an aggregate planning exercise?
- What are the heuristic and optimal methods used for solving the aggregate operations planning problem?
- What is master operations scheduling (MOS)? How is it related to aggregate operations planning?

Organizations often manage demand during peak times by shifting the demand to a non-peak period as capacity is far in excess of demand during non-peak periods. This is why hotel rates are high during the peak season and special off-season discounts are offered for summer resorts and hill stations.

ideas at Work 15.1

Operations Planning at Amazon to Improve Service Effectiveness

Amazon.com, started in 1995, is the largest internet retailer that offers new, used, and refurbished items in a number of categories, including books, music, food, apparel, kitchenware, and consumer electronics. Amazon's Customer Service Operations (CSO) provides service to customers through certain features on the company web site. These features allow customers to perform various activities, including tracking orders and shipments, reviewing estimated delivery dates, and cancelling unshipped items. Customers place orders and follow up on orders on the company web site. Customers who cannot resolve issues using the features on web site can either call the company's 800 number or send e-mail messages to customer service.

The e-mail messages and voice calls are annually estimated to be in millions with the peak just before and after Christmas. Operations planning to handle this requirement invariably amount to capacity planning of its contact centers . They must make decisions about hiring and training at internally managed centers and about the volume of voice calls and e-mail messages to allocate to external service providers.

The handling time for customer requests manifesting as voice calls and e-mail exchanges depends on attributes such as product type, customer type, and purchase type. Amazon uses these attributes to categorize customer requests to reflect the skill sets needed to resolve different issues. It has eight Planning Groups (PGs) dedicated to processing the requests. The internally managed contact centers are assigned to specific PGs and trained to handle both voice and e-mail contacts.

Operation planning begins with forecasting demand by product line, which is then converted into a forecast of orders. This would eventually determine the weekly forecasts of e-mails and voice contacts for the eight categories over the planning horizon. After the development of these contact forecasts, the capacity-planning team assesses the contact-handling capacity of each PG for each week of the planning horizon. If the capacity is less than forecast, resources are then hired externally.

Each week, the capacity-planning team in CSO employs a solution approach developed using an optimization model to address this operations planning problem. When the planning horizon is 52 weeks, the optimization model consists of approximately 134,000 constraints and almost 16,000 variables, where about 1,000 of these are both binary and integer.

With the optimization model the capacity-planning team is able to examine a number of scenarios and consider uncertainty by performing sensitivity analysis on the inputs to the planning process. After analyzing the output, they inform the HR team the number of new CSRs Amazon will need to hire. They are also able to estimate the transfers needed into and out of the PGs, and future quantum of customer request volumes for the external service providers.

Source: Adapted from Keblis, M.F. and Chen, M. (2006).'Improving Customer Service Operations at Amazon.com', *Interfaces*, 36(5), pp 433-445.

Operating systems in a business play the vital role of providing a continuous flow of goods and services to customers. For instance, a bicycle manufacturer may be producing at a daily rate of 10,000 bicycles in its factory. Similarly, an airline operating between the metropolitan cities of Mumbai and Delhi may be offering 2,000 passenger seats daily. However, these operating systems are not like a water tap, where, with a turn of the knob, the flow alters. Changing the daily production rate at the bicycle manufacturer to 15,000 or the seating capacity in the case of the airline to 2,500 are not simple and instantaneous decisions.

Operating systems are characterized by complex relationships between people, resources, market, and materials, and often involve lead time, affecting several of the processes. For example, if the order placed with suppliers is increased by 20 per cent, it requires considerable time at the suppliers' end to adjust the capacity to match the supply. Therefore, prior planning and strategies for dealing with real-time changes play a very important role in managing operating systems and ensuring a continuous flow of goods and services to the market. We address these issues in this chapter and several others in the book. In this chapter, we discuss planning methodologies that address capacity requirements in the medium term (typically a one-year period).

15.1 PLANNING HIERARCHIES IN OPERATIONS

It is important to understand that planning the operations in a manufacturing or a service system happens at different levels and at different time horizons. On the other hand, control of operations always happens in a short-term horizon (such as weekly, daily, or even on a shift-by shift-basis). Figure 15.1 graphically depicts the various steps involved in planning the operations in a hierarchical fashion.

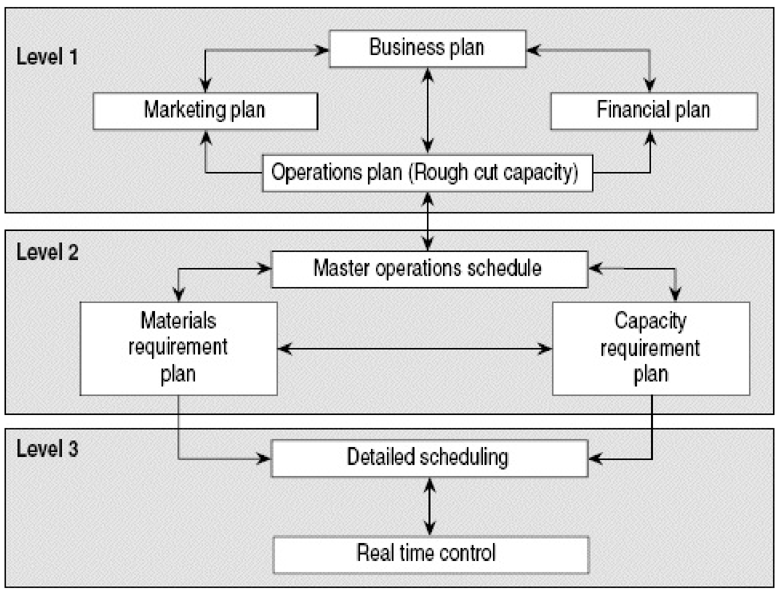
We saw in the previous chapter how demand for products/services is estimated using medium-level forecasting techniques. Based on this input, a firm needs to begin the planning exercise. At the highest level, business planning is done typically for a period of one year. For example, organizations following the financial year between April and March perform a detailed planning exercise between November and February and arrive at the plan for the next year. The business plan is strategic in nature and addresses the key level of resources to be committed to meet a targeted market segment by answering the following questions:

a. What is the likely demand for the next financial year?
b. Should we meet the projected demand entirely or a portion of the projected demand?
c. What are the implications of this decision on the overall competitive scenario and the firm's standing in the market?
d. How is this likely to affect the operating system and planning in other functional areas of the business, such as marketing and finance?
e. What resources should we commit to meet the chosen demand during the planning horizon?

These questions enable the top management to link the strategic intent to various operational choices to be made during the planning horizon. Moreover, they provide some clarity on the level of resources to be committed and the investments and policy decisions to be taken to execute the operational plans.

Once the level of resources to be committed is arrived at, rough-cut capacity planning needs to be done. During this stage, planning is done to adjust the demand and the available capacity on a period-by-period basis and ensure that the available capacity could match the demand. At this level of planning, information pertaining to products and resources is aggregated. For example, if a manufacturing organization is offering nine variants of a product, they are all aggregated into one "equivalent" model for the purpose of capacity calculations.

FIGURE 15.1 A hierarchical approach to planning



Consider for example the case of a fan manufacturer such as Crompton Greaves Limited (CGL). Suppose CGL manufactures three variations of fans: standard, deluxe, and premium. Assume that manufacturing a unit of standard fan requires 1 hour of machine capacity. Let us also assume that the deluxe model requires 1.5 hours and the premium one 2 hours. Then, this information could be used to convert the demand for all variants into a single measure of capacity. For example if the demand for standard is 100, deluxe is 200, and premium is 75, then the aggregated requirement in terms of machine-hours is $100 \times 1.00 + 200 \times 1.5 + 75 \times 2 = 450$ hours.

Similarly, if a service provider offers three levels of service—silver, gold, and platinum—that may place varying demands on the resources, they will be aggregated into one service version on some basis for the purpose of planning. Therefore, planning done at this level is only rough-cut and is usually done for a period of 9–12 months.

At the second level, detailed planning is done to ensure that capacity, material, and other resources are available to meet the projected demand on a period-by-period basis. The capacity, material, and resource requirements are linked to specific variations in the products to be manufactured and services to be offered during the planning horizon. In the earlier example of the service firm, assume that the projected demand for the three types of services is 300, 200, and 50, respectively. If they need six different labour skills and four different kinds of equipment in varying proportions, the planning exercise is done to ensure adequate availability of these labour skills and equipment. Clearly, such a detailed capacity planning is done at a time much closer to the planning horizon. Therefore, detailed planning is done typically for a period of 1–3 months duration.

The final level of detailed planning is done almost at the time the plan needs to be executed. During this exercise, decisions concerning the use of specific resources to manufacture goods as per plan are taken. For example, after deciding to manufacture 1,500 bicycles of a particular variety during a month, the exact scheduling will be done. This means that the set of machines to be used for manufacturing and the time when the "job" needs to be launched into the system in order to meet the targeted completion time are decided. This level of planning is usually done during a period of 1–4 weeks.

After the plans are worked out to this level of detail, the actual execution of the plan is done using an operational control system. Basically, the plans are monitored and resources are committed as per plan to complete the requirements. However, in real time, the plans get disturbed due to resource unavailability, breakdowns, absenteeism, quality problems, and so on. Any problems arising in real time are addressed to ensure the targets are met with. It may call for a certain degree of re-planning.

The hierarchy in planning offers several advantages to the planner. Splitting the decision-making framework into various stages enables the planner to reduce the complexity of the planning process. Moreover, as more information is available, it can be incorporated into the planning exercise. When doing the first-level planning, the planner tends to make several assumptions about markets, products, and the competitive scenario for the next 9–12 months. However, at the third level of planning, the planner gets recent information and uses it to validate and modify several assumptions. On this basis, the planner may perform a re-planning exercise for the next 1–3 months. Therefore, it is important to reaize that an earlier planning exercise invariably results in a certain level of re-planning at a later stage.

> An earlier planning exercise invariably results in a certain level of re-planning at a later stage.

15.2 AGGREGATE OPERATIONS PLANNING

As the name suggests, it is a planning exercise done for operations using data at an aggregate level. Aggregate operations planning serves the critical role of translating the business plans and strategic intent to operational decisions. Using an **aggregate operations planning (AOP)** exercise, firms arrive at the quantity and timing of resources to be committed to ensure continuous flow of goods and services to customers. Usually, the decisions involve the amount of resources (productive capacity and labour hours) to be committed, the rate at which goods and services need to be produced during a period, and the inventory to be carried forward from one period to the next.

For example, at the end of an aggregate operations planning exercise, a garments manufacturer may arrive at the following plan:

- Produce 9,000 metres of cloth everyday during the period January–March, increase it to 11,000 metres during April–August, and change the operations rate to 10,000 metres during September–December.
- Carry 10 per cent of monthly production as inventory during the first nine months of production.
- Work on a one-shift basis throughout the year with 20 per cent overtime during July–October.

An **aggregate operations planning (AOP)** decision deals with the amount of resources (productive capacity and labour hours) to be committed, the rate at which goods and services need to be produced during a period, and the inventory to be carried forward from one period to the next.

As we can see in this example, three critical decisions are made: the rate of production, the amount of inventory to carry, and the amount of resource (in terms of working hours) to be committed on a period-by-period basis. We shall see later that there are several options available for the planner and each has its own implications on cost and availability.

The entire planning exercise is done on the basis of some aggregate unit. There is no single basis on which the demand data is aggregated. The only requirement is the need to establish equivalences between variations. For example, suppose that one standard model of a bicycle takes 30 machine-hours to manufacture, a deluxe model takes 60 machine-hours, and a sports model takes 90 machine-hours. It is obvious that manufacturing one deluxe model is equivalent to manufacturing two standard models and manufacturing one sports model is equivalent to manufacturing three standard models from a resource-consumption perspective. Then a monthly demand of 1,000 bicycles of the basic model, 500 of the deluxe model, and 250 of the sports model can be aggregated as 2,750 basic models on the basis of machine-hours.

TABLE 15.1 Aggregate Units for Operations Planning: an Example

Product	Aggregate Unit of Capacity
Phenyl acetic acid	Metric tons
Data-entry systems	Numbers
Mini-computer	Value (ex-factory) in ₹
Printed circuit board	Square metres
Alloy iron castings	Metric tons
Cement	Metric tons
Multispeciality clinic	Patient-bed days
Bank	No. of accounts
Insurance Firm	No. of policies

Usually, the aggregated unit turns out to be some measure of the capacity. For example, a steel processing mill may make several variations of steel but may prefer to do the AOP on the basis of number of heats that can be extracted from a furnace.[1] A textile manufacturer may manufacture several varieties of cloth but may plan on the basis of metres of cloth production. Similarly, a PCB manufacturer may fabricate thousands of customised PCBs but may plan on the basis of square metres of board that it can process. Therefore, AOP can be viewed as a capacity planning exercise over the medium term of 9–12 months. Table 15.1 is an extract of the aggregate measures of capacity in manufacturing and service organizations.

15.3 THE NEED FOR AGGREGATE OPERATIONS PLANNING

There are several reasons for every organization, whether engaged in product manufacturing or service delivery, to plan operations at an aggregate level. The following ones merit some attention:

- *Demand fluctuations*: Organizations hardly experience stable or even demand. As we saw in the previous chapter, several sectors of the manufacturing and service industry experience a significant upswing in demand during certain periods. The demand for garments in India is high between August and October due to the festive season. Prior planning is required to meeting surges in demand.
- *Capacity fluctuations*: While demand fluctuations occur on account of seasonality, there are fluctuations in capacity too. The capacity available in the month of February will be 10 per cent lower than that in the month of May on account of fewer calendar (and working) days. Moreover, scheduled and unscheduled plant shutdowns have a significant impact on capacity availability.
- *Difficulty level in altering operation rates*: Operational systems are complex. Varying the rate of operation from one level to another requires some amount of prior planning and coordination with related systems on the supplier and distributor sides. Thus, an organization manufacturing diesel engines at the rate of 4,000 engines per day cannot unilaterally change it to 5,000 engines. It needs to ensure that the required material, capacity, and other resources are available for the incremental plan. Similarly, it needs to ensure that the distributors have the required capacity to handle the additional load on them. Similar is the case of a restaurant offering multi-cuisine menu.
- *Benefits of multi-period planning*: It is known that planning just for a particular period with no consideration of potential events in the near future amounts to a knee-jerk reaction than an attempt to reach optimal and cost-saving decisions. For example, while planning the production for a month, an organization is better off by taking into consideration the likely scenario in the next few months. If the estimates indicate a rising demand in the next few months, it is better to produce at a slightly higher, albeit even pace and accumulate inventory to handle the additional demand in the future than to react every month. Such month-by-month reactions to the market are not only expensive but also not feasible for the reasons discussed earlier.

It is evident that for several reasons, supply and demand may not match exactly on a period-by-period basis in an organization. For instance, during the festive season, a manufacturer of appliances, such as refrigerators, may experience higher demand than average since many employees might have received bonuses, special festival allowances, and advances. If the manufacturer has sufficient capacity to meet this demand, then there is no problem. On the other hand, if the capacity is less, then the organization has to either forego the unfulfilled demand or try to influence the demand or the supply.

Therefore, aggregate operations planning is done in an organization to match the demand with the supply on a period-by-period basis in a cost-effective manner. Matching the demand with the supply can be done in any one of the following ways:

a. For the supply capacity that an organization has during a period, ways by which the demand could be suitably modified are identified so that both are matched.

b. For the targeted demand to be fulfilled in every period, ways by which the supply is altered are identified so that both are matched.

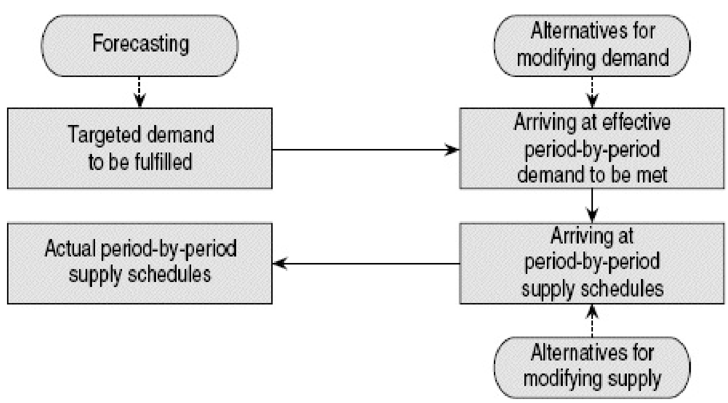
c. During every period, both the demand and the supply are adjusted in such a way that both are matched.

> Aggregate operations planning is done in an organization to match the demand with the supply on a period-by-period basis in a cost-effective manner.

Figure 15.2 provides a simple framework for the AOP exercise. The forecasting module in an organization merely indicates the likely demand for its product or service during a period. It does not throw light on the availability of sufficient capacity to meet the demand or the manner in which an organization needs to address issues pertaining to supply–demand mismatch. All these fall under the purview of the aggregate planning exercise.

The aggregate operations planning exercise begins by exploring alternative ways of modifying demand and arriving at the period-by-period net demand during the planning horizon. The second step is to further explore the possibilities of modifying the supply so that at the end of the exercise the demand and the supply are matched on a period-by-period basis. On the basis of this, various decisions on the level of inventory to be carried during every period, the rate at which goods and services are produced and the number of people to be engaged are arrived at. If required, additional arrangements for outsourcing and augmenting capacity are also made. In the final analysis, all decisions with respect to use of capacity are taken through an aggregate operations planning exercise.

FIGURE 15.2 An aggregate operations planning framework



15.4 ALTERNATIVES FOR MANAGING DEMAND

When you want to visit your doctor, don’t you take an appointment? Do you make use of differential tariffs and make long distance calls (STD/ISD) to your friends or family members late at night? Why do you think hotel rates are high in Darjeeling during the peak season? It is often the practice in organizations to manage demand using some strategies. These strategies basically aim at shifting the demand from one period to another without losing them for want of capacity. Normally, capacity is far in excess of demand during non-peak hours and vice versa during peak hours. Therefore, any attempt to even out the demand by shifting the demand from peak hours to non-peak hours is a desirable step. The aggregate operations planning exercise provides a few alternatives to achieve this goal.

Reservation of Capacity

One method used to manage demand is to moderate and shift the excess demand out of a busy period to any future period without completely losing it. Consider, for instance, a multi-speciality healthcare unit in which patients arrive for consultation. If there is no reservation of capacity (in this case, the doctor's time for consultation), some patients may go unattended and the hospital might lose the opportunity of servicing the demand. Therefore, an appointment system helps to capture the demand by scheduling the service on another day when there is sufficient capacity. Capacity reservation is a very popular method in service systems.

Influencing Demand

Another method to manage demand is to influence the demand during a particular period through some mechanisms and induce customers to voluntarily shift the demand count structures, and limited period product promotions. Consider the differential tariffs promoted by telecommunication companies in the country. The demand for bandwidth tends to be low during late night and early morning (10 p.m. to 9 a.m.). Therefore, to induce customers to use the bandwidth during this time, special rates (quarter–charges, for example) are applied. There are several examples similar to this, which induce customers to shift the demand from peak to non-peak periods. This includes special off-season discounts for several seasonal products such as summer resorts, raincoats, winter wear, and weekend tariff structures for airline tickets. Similarly, several years ago, white goods manufacturers such as Videocon and BPL used to offer a "wait–buy–save" scheme. In this scheme, customers willing to wait for a period of about five weeks would get a refrigerator with a substantial discount on the product price and it would also be home delivered according to the promised schedule. It is clear that strategies for influencing demand stem largely from a variety of initiatives in the marketing function in an organization. Therefore, close coordination and planning by operations planning and marketing functions is important to implement this set of strategies.

Although both these alternatives appear to be very similar there are some differences. In the case of reservation of capacity, there is an explicit approach to book capacity in the future. On the other hand, promotional schemes merely encourage the customers to use the capacity. There is still an element of uncertainty in the extent to which capacity is likely to be used during the promotional (non-peak) period. Therefore, an accurate capacity planning exercise could be done only in the case of the former. This explains why the appointment system is a useful tool for managing capacity in service systems efficiently.

Organizations have several options to modify supply to meet the demand during a period. In all these cases, the plan seeks to increase or decrease the available capacity to match the supply to the demand during the planning horizon. Supply can be modified through one of the alternatives: (i) inventory-based alternatives, (ii) capacity adjustment alternatives, or (iii) capacity augmentation alternatives.

In the case of inventory-related strategies, changes are made in the inventory levels to match the demand with supply whereas in the case of capacity related strategies, changes in capacity availability cause corresponding changes in the supply.

> Supply can be modified through one of the following alternatives: (i) inventory-based alternatives, (ii) capacity adjustment alternatives, or (iii) capacity augmentation alternatives.

Inventory-based Alternatives

Matching the demand with supply could be done in four ways using inventory. One is to *build inventory*[2] during periods of lean demand and consume them during periods of high demand. For instance, consider a textile manufacturer such as Arvind Mills. Suppose the forecast demand for denim during the months of April–June is 35,000 metres per month and during July–September is 55,000 meters per month. Let us also assume that the production capacity is 45,000 metres per month. Then, the firm could maintain the production at a level of 45,000 metres during April–September and carry inventory from the first three months to meet the demand during the next three months. Similarly, in a fast-food restaurant, a pre-processed inventory of certain food items is built in the preceding period in order to handle the high demand during peak periods.

Another option is to **back order** the current periods demand in a future period. **Back ordering** is a method of pushing an order to a future period on account of insufficient inventory and/ or capacity to supply during the current period. For example, in a watch-manufacturing firm, if the demand for watches during the month of October is 40,000 watches and if the firm has capacity to manufacture only 30,000 watches and has on-hand inventory of 5,000 watches, then the balance 5,000 watches is scheduled in the month of November, although the demand is for the month of October.

> **Back ordering** is a method of pushing an order to a future period on account of insufficient inventory and/or capacity to supply during the current period.

Another possibility is the *stock-out*. By stock-out, we mean a deliberate strategy of leaving a portion of the demand unfulfilled. In the above example, it is also possible that the watch manufacturer can go to its customers and express its inability to supply 5,000 watches.

The fourth variation is to *backlog* the orders. In this method, instead of promising the customer a due date and later incurring a back order or a stock out, the organization could specify a waiting time for supply. Thus, during periods of high demand, the backlog of orders could be large.

It is clear from the above that inventory-related alternatives ensure that an organization will continue to produce goods and services at a uniform rate. The demand–supply mismatch is absorbed through alternative plans, depending on the inventory availability. However, organizations incur several types of costs while implementing these alternatives. In the case of building inventory, carrying costs are incurred. Moreover, the organization could also incur costs of obsolescence. On the other hand, the back order/backlog/stock-out alternatives impose direct costs such as cost of shortage and other indirect costs pertaining to loss of customer goodwill. These costs are real, difficult to quantify and in some cases, significant too.

Capacity Adjustment Alternatives

Another possibility available to organizations is to adjust the available capacity to meet the demand during the planning horizon. Two factors affect capacity in any organization: the number of working hours and the number of people employed. Therefore, by varying these parameters one can adjust the capacity to match the demand. The variations include the following:

Hiring/lay-off of workers

In several service systems and in certain areas of manufacturing systems, it is possible to increase/decrease capacity and operations rate by varying the number of workers. For instance, in a construction project, employing more people on the site could hasten the completion of the project. This is true of several project-oriented situations such as maintenance, overhaul, new-product development, software development, and consulting. Similarly, in a service system, it is customary to hire temporary workers to augment capacity during peak hours. Therefore, hiring additional workers during periods of high demand and laying-off excess workers during periods of lean demand could help an organization match supply with demand. The cost of this includes cost of hiring, initial training, lost productivity due to learning effects, and severance costs during lay-off. Moreover, only semi-skilled and less-skilled workers can be frequently hired and laid off. Furthermore, frequent hiring and laying off causes low morale and motivational problems among the existing workers. These considerations limit the nature of jobs and the extent to which these options could be used.

Varying shifts

The actual capacity utilized could be different from the installed capacity in most organizations. For example, a CNC machine could theoretically work for 24 hours a day. If it can produce components at the rate of 1,000 pieces per hour, then the installed capacity for the machine is 24,000 components per day. However, in reality, the machine may be working for only one shift of eight hours. Therefore the realised capacity is only 8,000 pieces per day. If there is an increased demand for the component, then it is possible to add another shift of eight hours to increase the production to 16,000 components per day. Similarly, during periods of low demand, the number of shifts could be reduced.

Adjusting capacity by varying shifts is a feasible option only in the case of discrete manufacturing industries, as process industries work in a continuous fashion. Shift changes introduce additional costs in an organization. Several fixed and semi-fixed components of the overheads remain unchanged when the number of shifts is reduced. Moreover, the productivity levels decrease as the number of shifts increases. These costs need to be appropriately captured while analysing the suitability of this option. Service systems can also employ a similar strategy to match the supply to demand.

Varying working hours

Consider the example of submission of income-tax returns by individual tax payers. The last date for submission is 31 July. In order to meet the peak demand, it is possible to extend the working hours from the normal practice of 9 a.m. to 5 p.m. to perhaps 8.00 a.m. to 8.00 p.m. in the last week of July. The Income Tax Department and several other service systems employ such a practice to match the supply to demand.

From the above example it is clear that the other alternative for organizations to adjust the capacity is to vary the number of working hours instead of varying the number of shifts. This is normally achieved through overtime/undertime adjustments. In the overtime (OT) alternative, employees are allowed to work for additional time over and above the normal shift timing. Thus, a person working in a shift for eight hours will be permitted to work for another three hours on an overtime basis. Industrial regulations stipulate certain conditions for overtime working. This includes a certain premium to be paid to the employee and limits the number of hours permissible under overtime. Moreover, the productivity of the employee suffers on account of fatigue due to long working hours.

On the other hand, during periods of lean demand, organizations may require their employees to work less than the normal time, which is referred to as undertime (UT). The recessionary trends and slowing market conditions in the world over have forced many organizations to resort to undertime. Several global software firms required their employees to take a compulsory two-week annual vacation during December 2008–January 2009. Another example of undertime is retaining bench staff in several service organizations.[3] During UT, there is loss of productivity and employees continue to get their normal pay. Therefore, additional costs of the OT plan must include the OT premium, and those of the UT plan must include the opportunity costs of idle time and lost productivity.

Capacity augmentation alternatives

Another option for an organization to address the supply–demand mismatch is to augment its capacity. Capacity can be augmented by subcontracting (outsourcing) a part of the requirement during a period. Consider an organization such as Indian Telephone Industries (ITI). During a month, if the demand for PCB board fabrication is in excess of the available capacity, ITI can subcontract the work to an outside vendor for the excess requirement. In this case, the materials, process plans and drawings, production, quality, and inspection specifications are supplied to the chosen vendor with a due date for supplying the completed PCBs. Developing good sources for subcontracting and ensuring that they conform to quality and delivery norms is a critical process. This result in additional costs related to identifying, setting up the relationship, and transacting with an outside vendor for subcontracting.

TABLE 15.2 Alternatives for Aggregate Operations Planning

Alternatives	Description of the Alternative	Costs
For managing demand	Reservation of capacity	Planning and scheduling costs
	Influencing demand	Marketing-oriented costs
For managing supply	**Inventory-based alternatives**	
	(a) Build inventory	Inventory-holding costs
	(b) Backlog/backorder/shortage	Shortage/loss of good will costs
	Capacity adjustment alternatives	
	(a) Overtime/undertime	OT premium, lost productivity
	(b) Variable number of shifts	Shift-change costs
	(c) Hire/lay-off workers	Training/hiring costs, morale issues
	Capacity augmentation alternatives	
	(a) Subcontract/outsource	Transaction costs for subcontract
	(b) De-bottleneck	Annualized de-bottlenecking cost
	(c) Add new capacity	Annualized cost of new capacity

Other options for augmenting capacity include re-scheduling maintenance plans, launching de-bottlenecking projects and adding new capacity. In these cases, the annualized costs of these operations constitute the cost of the option. If the demand projections for the future indicate a growing trend, then capacity augmentation could be considered on a permanent basis. Otherwise, temporary capacity augmentation should be considered. In the case of service organizations similar examples can be found. When there was a huge pile up of IT returns to be processed, the Income Tax department outsourced the process to private players.

Table 15.2 lists all the available alternatives and the costs associated with each of these alternatives.

> An organization can augment its capacity by subcontracting (outsourcing), rescheduling maintenance, de-bottlenecking projects, and adding new capacity.

15.6 BASIC STRATEGIES FOR AGGREGATE OPERATIONS PLANNING

So far, we have identified several alternatives for bridging the supply–demand gap during the planning horizon. However, we are still uncertain about the specific combination of these that should be used, and the implications of these in practice. There are two generic approaches to AOP that can use a combination of these alternatives: *level strategy* and *chase strategy*. These two approaches represent alternative modes of thinking towards employing the available alternatives for AOP. Table 15.3 summarizes the key differences between these two strategies.

Level Strategy

In the **level strategy**, the emphasis is on not disturbing the existing operations at all. This implies that the system would employ a constant workforce and/or maintain constant working hours. In this strategy, inventory plays the vital role of linking one period with the other. Therefore, firms often employ inventory-related alternatives to address the supply–demand mismatch. During periods of lean demand, anticipation inventory is built and during periods of high demand, the anticipation inventory is consumed and other alternatives such as backordering/shortage are made use of to match supply with demand. Clearly, inventory-related alternatives are useful only when the risks of carrying inventory are low. Therefore, several sectors of industry operating in a made-to-stock environment and products with low technological obsolescence are suitable candidates for using this strategy.

In the **level strategy**, the emphasis is on not disturbing the existing operations at all.

TABLE 15.3 Two Generic Strategies for AOP

Strategy	AOP Alternatives	Key Features
Level strategy	Inventory-based alternatives	
	(a) Build inventory (b) Backlog/backorder/shortage	Inventory as the critical link between the periods; made-to-stock environments; products with low risks of obsolescence
Chase strategy	Capacity adjustment alternatives	
	(a) Overtime/undertime (b) Variable number of shifts (c) Hire/lay-off workers	No inventory carried from one period to another; made-to-order and project environments; several service systems
	Capacity augmentation alternatives	
	(a) Subcontract/outsource	
	(b) De-bottleneck	

In a constant workforce strategy, an organization having a certain number of workers may not hire new workers or lay off excess workers in response to changes in demand. They will utilize other means of addressing the supply–demand mismatch. This is especially true of highly skilled employees. In such cases, the high costs of hiring, training, and laying off may be responsible for several organizations resorting to a constant workforce strategy. A case in point is the recent experiences of firms operating in the information technology (IT) sector in India. As the global recession continues to affect several economies there could be a drop in the demand for IT services in the country. Firms such as Infosys and Wipro will resort to undertime strategy rather than laying off software engineers. At most, they may temporarily halt fresh recruitment of employees.

The other possibility is to maintain constant working hours. A constant operations rate is often achieved by maintaining constant working hours. For instance, a firm operating on a single-shift basis will continue to work in the same fashion. A constant operations rate is an appropriate method for achieving a level strategy in a highly automated and mechanized set-up. In such an organization, the operational rate is a function of the number of working hours. Process industries and highly mechanized batch-processing units fall under this category of such industries—they include two-wheeler and passenger-car manufacturing and petrochemical and pharmaceutical manufacturing.

In several organizations, level strategy is obtained only by maintaining constant working hours and a constant number of workers. These firms may employ a variety of automated and semi-automated set-ups for offering products and services.

Chase Strategy

At the other end of the spectrum is the **chase strategy**. In this method of AOP, very little or no inventory is carried from one period to another. Rather, the supply–demand mismatch is addressed during each period by employing a variety of capacity-related alternatives. For example, during periods of high demand, additional workers are hired, the number of working hours is increased, workers are permitted to do overtime, and more capacity is obtained by outsourcing the unmet demand. Similarly, during periods of low demand, some workers are laid off, others are permitted to go on undertime, and the number of working hours is reduced by reducing the number of shifts, and, in extreme situations, even the duration of the shift. Clearly, these strategies are more appropriate when it is not possible to stock inventory. Several service systems and made-to-order project type of organizations fall under this category. As we can see from our discussion of AOP alternatives, capacity augmentation and capacity adjustment alternatives are suitable for a chase strategy. However, for reasons already described (and due to the costs of these alternatives), organizations may prefer to exploit capacity adjustment alternatives before employing capacity augmentation alternatives.

> In the **chase strategy**, the supply–demand mismatch is addressed during each period by employing a variety of capacity-related alternatives.

Mixed Strategy

The chase and the level strategies represent two pure forms of aggregate operations planning. In reality, one can expect organizations to utilize a combination of the available alternatives to devise a strategy for aggregate operations planning. **Mixed strategy** is therefore defined as one that employs a combination of the available alternatives for AOP. The following examples illustrate this concept:

- *Mixed strategy 1*: Hire a certain number of workers at the beginning of the planning horizon, maintain a constant operations rate, and utilize inventory-based alternatives to match supply with demand.
- *Mixed strategy 2*: Do not hire or lay off workers, adjust the operations rate by varying the number of shifts, use inventory and subcontracting to match supply with demand.
- *Mixed strategy 3*: Do not hire or lay off workers, use subcontracting during periods of high demand and build inventory during periods of low demand.

In all these examples, we see that the strategy seeks to maintain level operations during periods of low demand by building inventory and chase the demand by additional alternatives during periods of high demand. Thus, the focus shifts between level and chase. The cost structure of the alternatives will determine the total cost of each of these strategies.

In reality, there can be numerous combinations of the AOP alternatives. Each combination could form one mixed strategy with a certain cost of the plan. Therefore, arriving at the best AOP strategy involves enumerating the pure as well as the numerous mixed strategies and choosing the one with the least cost. Aggregate planning methods seek to fulfil this requirement.

Mixed strategies employ a combination of the available alternatives for APP.

EXAMPLE 15.1

A manufacturer of electrical switchgears is in the process of preparing the aggregate production plan for the next year. Let us assume that a good measure of capacity is the number of working hours available per month. Table 15.4 presents details pertaining to the forecast demand for the “equivalent” model of switchgears and the number of working days available during the planning horizon.

The following relevant details are also available:

1. The manufacturer currently works on a single-shift basis and employs 125 workers.
2. One unit of switchgear requires 100 hours of production time.
3. It is expected that at the beginning of the planning horizon, there will be a finished-goods inventory of 200 switchgears.

TABLE 15.4 Forecast Demand for Models of Switchgears and the Number of Working Days

Month	Demand (in Units)	Number of Working Days
April	250	23
May	220	22
June	300	21
July	290	24
August	260	22

September	180	22
October	200	19
November	220	23
December	250	21
January	200	23
February	240	20
March	270	24

4. Inventory carrying costs are ₹1,000 per switchgear per month and unit shortage/backlogging costs are 200 per cent of unit carrying cost.

Devise a level production strategy with constant workforce and constant working hours and compute the cost of the plan.

Solution

Computing the Period-by-period Demand–supply Mismatch

The first step in AOP is to compute the demand– supply mismatch during the planning horizon. Using the information available this is computed and presented in Figure 15.3. Since the firm works for eight hours a day employing 125 people, the capacity available is 1,000 hours per day. Similarly, since each switchgear requires 100 hours, we can compute the number of hours required during a period. Figure 15.3 shows the relevant calculations.

Level Production Strategy

In this strategy, we use inventory-related alternatives only. During periods of low demand we accumulate inventory and during periods of high demand we consume the inventory built during lean periods. During each period we have an opening inventory.

After computing the excess/shortfall of inventory, we compute the closing inventory, which becomes the opening inventory for the next period. We compute the cost of the plan by computing the costs of holding inventory and backlogging/shortages. Figure 15.4 shows the relevant calculations and results.

We see from the computations that the opening inventory of 200 units has enabled the switchgear manufacturer to avoid shortages/backlogging until January. However, during February and March shortage/backlogging costs are incurred. The total cost of the plan is ₹830,000.

The costs related to backlogging/shortage are hard to quantify in practice. Therefore, enough care should be exercised in interpreting the usefulness of this strategy.

FIGURE 15.3 Computation of demand–supply mismatch period by period

Month	(A) Demand (in units)	(B) Hours required per unit of production	(C) = (A)*(B) Demand (hours)	(D) No. of Working Days	(E) Working Hours per Day	(F) No. of Workers	(G) = (D)*(E)*(F) Capacity Available (hours)	(H) = (G)–(C) Supply – Demand (hours)
April	250	100	25,000	23	8	125	23,000	(2,000)
May	220	100	22,000	22	8	125	22,000	-
June	300	100	30,000	21	8	125	21,000	(9,000)
July	290	100	29,000	24	8	125	24,000	(5,000)
August	260	100	26,000	22	8	125	22,000	(4,000)
September	180	100	18,000	22	8	125	22,000	4,000
October	200	100	20,000	19	8	125	19,000	(1,000)
November	220	100	22,000	23	8	125	23,000	1,000
December	250	100	25,000	21	8	125	21,000	(4,000)
January	200	100	20,000	23	8	125	23,000	3,000
February	240	100	24,000	20	8	125	20,000	(4,000)
March	270	100	27,000	24	8	125	24,000	(3,000)

FIGURE 15.4 Total cost of the level production strategy

Level Production Strategy

Month	(A) Demand (hours)	(B) Capacity Available (hours)	(C) =(B)–(A) Supply – Demand (hours)	(D) = (C)/100 Supply – Demand (units)	(E) Opening Inventory	(F)=(D)+(E) Closing Inventory	(G)=(E+F)/2 Average Inventory	Cost of Inventory
April	25,000	23,000	(2,000)	(20)	200	180	190	190,000
May	22,000	22,000	-	-	180	180	180	180,000
June	30,000	21,000	(9,000)	(90)	180	90	135	135,000
July	29,000	24,000	(5,000)	(50)	90	40	65	65,000
August	26,000	22,000	(4,000)	(40)	40	-	20	20,000
September	18,000	22,000	4,000	40	-	40	20	20,000
October	20,000	19,000	(1,000)	(10)	40	30	35	35,000
November	22,000	23,000	1,000	10	30	40	35	35,000
December	25,000	21,000	(4,000)	(40)	40	-	20	20,000
January	20,000	23,000	3,000	30	-	30	15	15,000
February	24,000	20,000	(4,000)	(40)	30	(10)	15	35,000
March	27,000	24,000	(3,000)	(30)	(10)	(40)	-	80,000
Total cost of the plan								**830,000**

EXAMPLE 15.2

Consider Example 15.1. Assume the switchgear manufacturer has no opening stock of inventory and chooses to devise a chase production strategy. The following additional information is available:

1. Overtime costs are ₹40 per hour and undertime costs are ₹20 per hour.
2. Temporary workers can be hired on a monthly basis. The relevant cost of this option including firing them at the end of the month amounts tò7,500 per worker.

Evaluate the following options for chase strategy and offer your suggestions to the switchgear manufacturer.

a. Utilizing overtime and undertime alternatives
b. Using hiring and laying-off alternatives for capacity adjustment

Solution

(a) Chase strategy using OT/UT

In this strategy, the demand–supply mismatch is addressed through use of OT during periods of high demand and UT during periods of low demand. For example, consider the computations in Example 15.1. During April, the demand for capacity is 25,000 hours and the available capacity is only 23,000 hours. Therefore, 2,000 hours of OT will be used at the rate of ₹40 per hour. Similarly, during the month of September, the demand is only 18,000 hours whereas the supply is 22,000 hours. Therefore, 4,000 hours of UT will be allowed during September at the rate of ₹20 per hour.

Since chase strategy does not result in carrying over inventory, there will be no inventory carrying costs. By computing the extent of OT/UT required and the costs associated with this in every period one can arrive at the cost of the plan. Figure 15.5 shows all the relevant calculations. The total cost of the plan is ₹1,440,000.

(b) Chase strategy using hire–lay-off

In the hire–lay-off alternative we compute the number of workers to be hired/laid off by examining the demand–supply mismatch. When the demand greater than the supply, we resort to hiring. For the given example, consider the month of April. The demand is in excess of supply by 2,000 hours. If we hire one worker, he/she will contribute 184 hours as there are 23 working days and each day we have eight working hours. Therefore, the number of workers to be hired during April is 2000/184 = 10.86 ≅ 11 workers. In the case of a lean period, we merely incur UT costs as we do not fire the enisting permanent workers. For example, in the month of january we incur UT cost of ₹60,000 (3,000 × 20).

Since the number of workers to be hired/laid off can only be integers, we round off the number to be hired to the next higher integer. In this process we also incur some idle time by retaining a little more capacity than needed. The cost of the plan takes all these into consideration. Figure 15.6 shows all the relevant details for the computation. The total cost of this plan is ₹1,572,420.

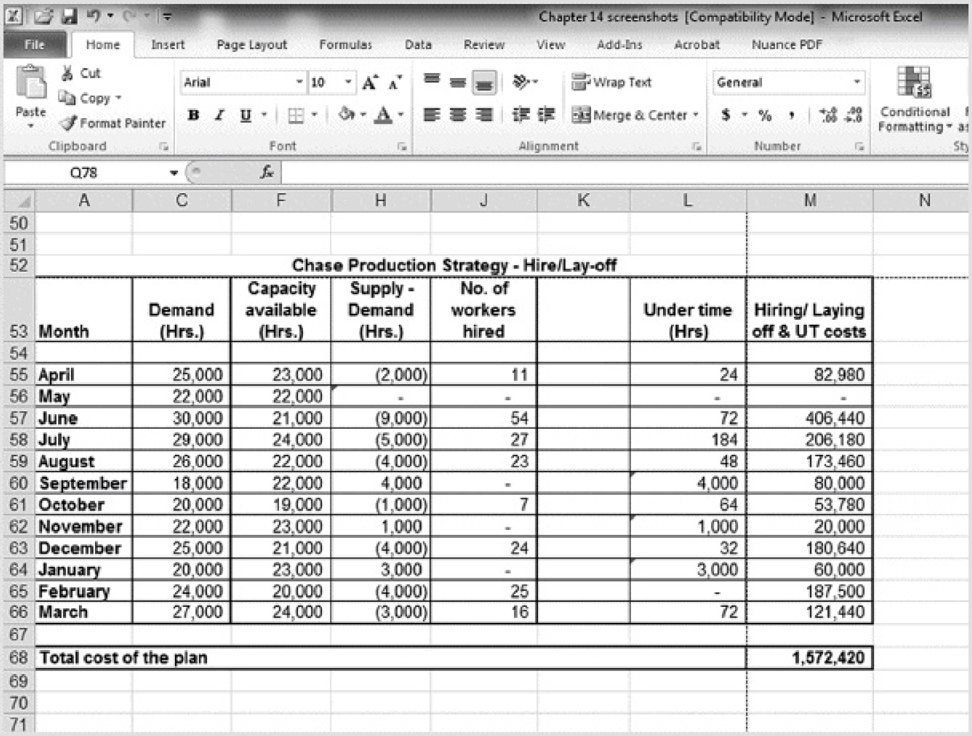
FIGURE 15.5 Total cost of the chase strategy using the OT/UT option

Chase Production Strategy Using OT/UT Alternatives

	(A)	(B)	(C)=(B)−(A)	(D)	(E)	(F)=(D)*40+(E)*20
Month	Demand (hours)	Capacity Available (hours)	Supply – Demand (hours)	Overtime (hours)	Undertime (hours)	OT/UT cost
April	25,000	23,000	(2,000)	2,000	0	80,000
May	22,000	22,000	-	-	0	-
June	30,000	21,000	(9,000)	9,000	0	360,000
July	29,000	24,000	(5,000)	5,000	0	200,000
August	26,000	22,000	(4,000)	4,000	0	160,000
September	18,000	22,000	4,000	-	4,000	80,000
October	20,000	19,000	(1,000)	1,000	0	40,000
November	22,000	23,000	1,000	-	1,000	20,000
December	25,000	21,000	(4,000)	4,000	0	160,000
January	20,000	23,000	3,000	-	3,000	60,000
February	24,000	20,000	(4,000)	4,000	0	160,000
March	27,000	24,000	(3,000)	3,000	0	120,000
Total cost of the plan						1,440,000

Clearly, the cost of the hire–lay-off plan is higher than the cost of the OT/UT plan. Moreover, there are other costs that are hard to quantify in the former case. For instance, frequent hiring/lay-off of workers may not be feasible in several sectors of industry involving skilled sets of workers. The training costs and lost productivity during the learning phase would have been grossly under-estimated. Moreover, such practices could result in low morale/motivation among the workers, leading to productivity and quality problems. These costs are difficult to quantify. Therefore, it is a good practice to deploy the hire–lay-off plan only as a last resort.

FIGURE 15.6 Total cost of the chase strategy using the hire/lay-off option



Chase Production Strategy - Hire/Lay-off

Month	Demand (Hrs.)	Capacity available (Hrs.)	Supply - Demand (Hrs.)	No. of workers hired		Under time (Hrs)	Hiring/ Laying off & UT costs
April	25,000	23,000	(2,000)	11		24	82,980
May	22,000	22,000	-	-		-	-
June	30,000	21,000	(9,000)	54		72	406,440
July	29,000	24,000	(5,000)	27		184	206,180
August	26,000	22,000	(4,000)	23		48	173,460
September	18,000	22,000	4,000	-		4,000	80,000
October	20,000	19,000	(1,000)	7		64	53,780
November	22,000	23,000	1,000	-		1,000	20,000
December	25,000	21,000	(4,000)	24		32	180,640
January	20,000	23,000	3,000	-		3,000	60,000
February	24,000	20,000	(4,000)	25		-	187,500
March	27,000	24,000	(3,000)	16		72	121,440
Total cost of the plan							1,572,420

EXAMPLE 15.3

Consider Example 15.2. Assume that on the basis of these computations, the switchgear manufacturer has come up with a plan that employs the following alternatives:

a. Hire 25 more workers at the beginning of April.
b. Lay off the 25 workers at the end of August.
c. Maintain constant working hours (1 shift of 8 hours) throughout the year.
d. Absorb the demand–supply mismatch by building inventory during periods of lean demand and by resorting to OT during periods of excess demand.

Assume the cost of hiring to be ₹7,500 per worker and the cost of firing to be ₹5,000 per worker. Evaluate the cost of this plan and compare it with the earlier alternatives. What are the key inferences?

Solution

The Impact of the Hiring–lay-off Decision

25 workers are hired at the beginning of April and laid off at the end of August. This would mean that during the months of April to August the number of workers available at the switchgear manufacturing facility is 150. The capacity available (in hours) during this time is computed on this basis. For example, during May the capacity available is (22 days × 8 hours

per day × 150) = 26,400 hours. The capacity available during the months of September to March is the same as computed in Example 15.1, as the number of workers remains at 125. Figure 15.7 shows these capacity calculations (see Column 5).

The decision affects the cost of the plan due to hiring charges at the rate of ₹7,500 per worker for 25 workers in the beginning of April and laying-off charges at the rate of ₹5,000 per worker for 25 workers by the end of August.

Absorbing the Supply–demand Mismatch through Inventory and OT

We first begin with the opening inventory and adjust the demand to get the net demand. For example, during the month of May, the opening inventory is 26 units. This means 2,600 hours of demand is already satisfied with this opening inventory (since each unit requires 100 hours). Therefore, the net demand is the period demand minus what is already available as inventory. If the net demand is more than the supply for the month, we resort to OT for the excess requirement. On the other hand, if the net demand is less than the available capacity, we maintain the production rate and build additional inventory. The calculations are shown in Figure 15.7.

FIGURE 15.7 Total cost of the mixed strategy

Mixed Strategy — OT, Inventory, Hire, Lay-off

Month	Opening Inventory	Demand (hours)	Effective Demand	Capacity Available (hours)	Overtime (hours)	Closing Inventory	Average Inventory	Cost of Inventory
April	0	25,000	25,000	27,600	-	26	13	13,000
May	26	22,000	19,400	26,400	-	70	48	48,000
June	70	30,000	23,000	25,200	-	22	46	46,000
July	22	29,000	26,800	28,800	-	20	21	21,000
August	20	26,000	24,000	26,400	-	24	22	22,000
September	24	18,000	15,600	22,000	-	64	44	44,000
October	64	20,000	13,600	19,000	-	54	59	59,000
November	54	22,000	16,600	23,000	-	64	59	59,000
December	64	25,000	18,600	21,000	-	24	44	44,000
January	24	20,000	17,600	23,000	-	54	39	39,000
February	54	24,000	18,600	20,000	-	14	34	34,000
March	14	27,000	25,600	24,000	1,600	-	7	7,000

Cost of hiring (25 workers at INR 7,500 per worker)	187,500
Cost of lay-off (25 workers at INR 5,000 per worker)	125,000
Cost of overtime (at INR 40 per hour)	64,000
Cost of inventory	436,000
Total cost of the plan	812,500

We find from Figure 15.7 that except during the month of March, there is an inventory build-up in all other periods. Only during the month of March are 1,600 hours of OT employed at the rate of ₹40 per hour. Figure 15.7 summarizes the total cost of this strategy. The total cost of the plan is ₹812,500.

Key Inferences

We first summarize the cost of each of the strategies that we analysed.

Cost of level strategy: ₹830,000
Cost of chase strategy (OT/UT): ₹1,440,000
Cost of chase strategy (hiring/lay-off): ₹1,572,420
Cost of mixed strategy: ₹812,500

It has been found in several situations that the cost of chase strategy is higher than other strategies. This is primarily due to the costs of disturbing the operating system, both at the manufacturer and at the supply-chain-members' level. Crash purchasing of material, uneven utilisation of resources, and payment of premium for making various resources available at the last minute are some of the reasons for high cost of chase strategy.

The examples we have discussed demonstrate the fact that levelling and chasing are two pure strategies; in reality, therefore, organizations should use a mixed strategy by utilizing several combinations of the available alternatives for AOP. It is interesting to note that for the given cost structure, a mixed strategy has resulted in the lowest cost. Therefore, it is worthwhile to explore all the available combinations of AOP alternatives and select the one with the least cost. Clearly, it requires robust models to accomplish this task.

EXAMPLE 15.4

A manufacturer of industrial motors produces four varieties of motors. The Type 4 motor requires a larger amount of customization than the other three. The production planning department has estimated the number of hours required for manufacturing one unit of motor of each variety. Type 1 requires 125 hours; Type 2, 175 hours; Type 3, 200 hours; and Type 4, 350 hours. The forecasts for the four varieties are given in Table 15.5.

TABLE 15.5 Forecasts for the Four Varieties

Month	Forecast of Motor Demand (units)			
	Type 1	Type 2	Type 3	Type 4
April	100	40	60	10
May	90	30	30	5
June	80	50	50	10
July	130	40	70	20
August	70	30	30	15
September	90	50	50	5
October	100	40	50	10
November	110	30	40	15
December	60	60	80	5
January	110	20	30	10
February	120	40	40	5
March	140	50	70	10

The overtime premium is estimated to be ₹20 per hour while undertime costs are 50 per cent of the OT premium. The cost of carrying inventory is ₹15 per hour per month and the backordering/shortage costs are 200 per cent of inventory carrying costs. The company can subcontract capacity from a reputed vendor and the additional costs related to subcontracting is ₹25 per hour of capacity.

Evaluate the following alternatives for AOP:

a. Prepare a level strategy. Use inventory/backlogging to absorb the demand–supply mismatch.
b. Use constant production rate for the first six months, change the production rate to another level and have a constant production rate for the next six months. Use inventory/backlogging to absorb demand–supply mismatch.
c. Maintain a production level of 31,000 hours per month and use OT/UT alternatives to chase the demand.
d. Maintain a production level of 31,000 hours per month. Build inventory during periods of low demand and use subcontracting when the demand exceeds available capacity.

Solution

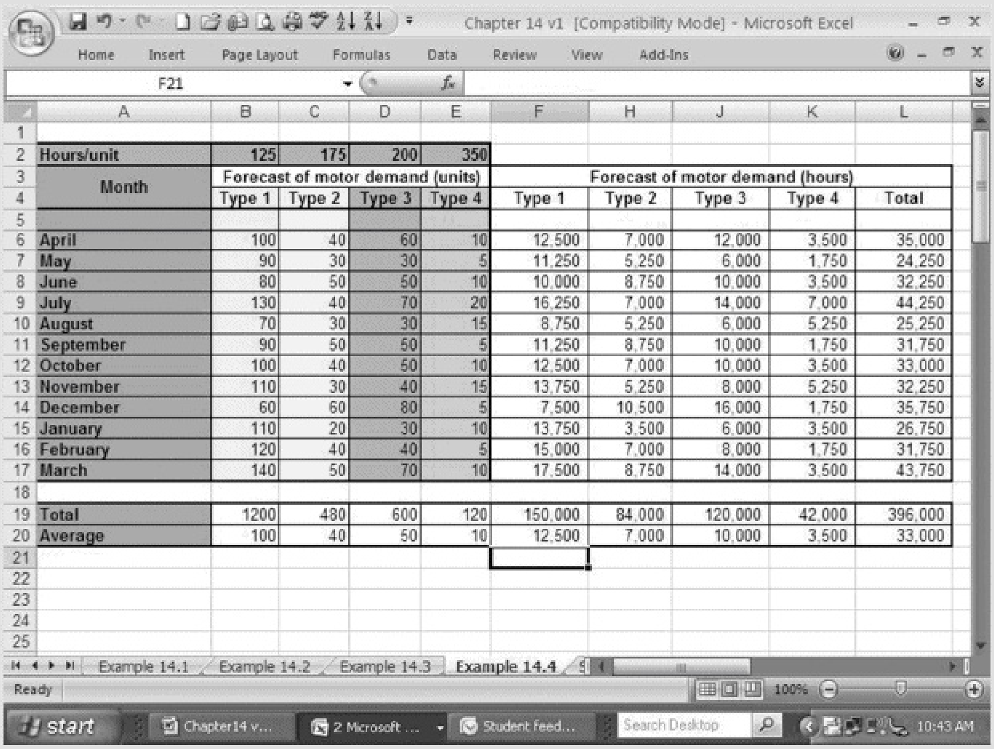
Aggregation of Product Demand

Since there are four products, we use the number of hours as the basis for aggregation and convert the demand in units of each variety to demand in hours. Figure 15.8 shows the details. Let us consider the month of October. Since the demand for the number of Type 1 motors is 100, and since it requires 125 hours for each unit, the demand for Type 1 in the month of October is 12,500 hours. Similarly, the demand for Type 2, Type 3 and Type 4 are 7,000 hours, 10,000 hours, and 3,500 hours, respectively. Therefore, the aggregate demand during October is 33,000 hours. All the values in Figure 15.8 are calculated in a similar fashion.

Plan A: Level strategy

A level strategy requires a constant production rate. From Figure 15.8, we find that the average requirement during the planning horizon to be 33,000 hours. Therefore, every month, the production will be 33,000 hours of motors. We then compute the demand– supply mismatch during each period (as in Example 15.1) and use inventory-related strategy. In the month of April, the demand is in excess of supply by 2,000 hours. Therefore, there will be a backordering cost of ₹60,000 (2,000 × 30). There will be no opening and finishing inventory and therefore no inventory carrying costs. Similarly, there will be no inventory carrying costs in the month of July. However, in the month of June, there will be an inventory carrying cost of ₹106,875 (15 × (6750 + 7500)/2). Figure 15.9 shows all the relevant computations. The total cost of the plan is ₹1,046,250.

FIGURE 15.8 Aggregate units of the forecasted demand



Hours/unit	125	175	200	350					
Month	Forecast of motor demand (units)				Forecast of motor demand (hours)				
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Total
April	100	40	60	10	12,500	7,000	12,000	3,500	35,000
May	90	30	30	5	11,250	5,250	6,000	1,750	24,250
June	80	50	50	10	10,000	8,750	10,000	3,500	32,250
July	130	40	70	20	16,250	7,000	14,000	7,000	44,250
August	70	30	30	15	8,750	5,250	6,000	5,250	25,250
September	90	50	50	5	11,250	8,750	10,000	1,750	31,750
October	100	40	50	10	12,500	7,000	10,000	3,500	33,000
November	110	30	40	15	13,750	5,250	8,000	5,250	32,250
December	60	60	80	5	7,500	10,500	16,000	1,750	35,750
January	110	20	30	10	13,750	3,500	6,000	3,500	26,750
February	120	40	40	5	15,000	7,000	8,000	1,750	31,750
March	140	50	70	10	17,500	8,750	14,000	3,500	43,750
Total	1200	480	600	120	150,000	84,000	120,000	42,000	396,000
Average	100	40	50	10	12,500	7,000	10,000	3,500	33,000

FIGURE 15.9 Computations for Plan A

Plan (a): Level Strategy with a Monthly Production of 33,000 Hours

Month	Demand (hours)	Production Rate (hours)	Opening Inventory (hours)	Production – Demand (hours)	Closing Inventory (hours)	Cost of Inventory/ Backorder
April	35,000	33,000	-	(2,000)	(2,000)	60,000
May	24,250	33,000	(2,000)	8,750	6,750	50,625
June	32,250	33,000	6,750	750	7,500	106,875
July	44,250	33,000	7,500	(11,250)	(3,750)	168,750
August	25,250	33,000	(3,750)	7,750	4,000	30,000
September	31,750	33,000	4,000	1,250	5,250	69,375
October	33,000	33,000	5,250	-	5,250	78,750
November	32,250	33,000	5,250	750	6,000	84,375
December	35,750	33,000	6,000	(2,750)	3,250	69,375
January	26,750	33,000	3,250	6,250	9,500	95,625
February	31,750	33,000	9,500	1,250	10,750	151,875
March	43,750	33,000	10,750	(10,750)	-	80,625
Average (12 months)	33,000			Total cost of the plan		1,046,250

Plan B: Two levels for constant production rate

Plan B differs from Plan A in the manner the production rate is fixed. In the case of Plan A, there is a single level at which the production rate is set. On the other hand, in Plan B, the production level is initially set at the average of the total requirement in the first six months and then changed to another level, which is set at the average of the total requirement of the next six months. The other calculations pertaining to the demand–supply mismatch, inventory holding, and backordering costs follow this as explained under Plan A.

Figure 15.10 presents the detailed computation. The total cost of the plan is ₹787,500.

By merely fine-tuning the production level with an alternative strategy, we were able to bring down the cost by nearly 25 per cent.

Plan C: Chase strategy with OT/UT

The chase strategy results in no carryover of inventory from one period to another. If the demand is in excess of supply, OT is employed (as in the case of July) and OT cost is incurred. On the other hand, if the demand is less than the supply, UT is employed (as in the case of August) and UT cost is incurred. The demand– supply mismatch computation and the computation pertaining to OT/UT costs are similar to those in the above examples. Figure 15.11 shows the complete computations for this plan. The total cost of this plan is ₹982,500.

FIGURE 15.10 Computations for Plan B

Plan (a): Level Strategy with a Monthly Production of 33,000 Hours

Month	Demand (hours)	Production Rate (hours)	Opening Inventory (hours)	Production – Demand (hours)	Closing Inventory (hours)	Cost of Inventory/ Backorder
April	35,000	33,000	-	(2,000)	(2,000)	60,000
May	24,250	33,000	(2,000)	8,750	6,750	50,625
June	32,250	33,000	6,750	750	7,500	106,875
July	44,250	33,000	7,500	(11,250)	(3,750)	168,750
August	25,250	33,000	(3,750)	7,750	4,000	30,000
September	31,750	33,000	4,000	1,250	5,250	69,375
October	33,000	33,000	5,250	-	5,250	78,750
November	32,250	33,000	5,250	750	6,000	84,375
December	35,750	33,000	6,000	(2,750)	3,250	69,375
January	26,750	33,000	3,250	6,250	9,500	95,625
February	31,750	33,000	9,500	1,250	10,750	151,875
March	43,750	33,000	10,750	(10,750)	-	80,625
Average (12 months)	33,000			Total cost of the plan		1,046,250

Expectedly, chase strategy is expensive. Due to knee-jerk reactions on a month-by-month basis, some opportunities for cost reduction are ignored. For example, we notice that there is 4,250 hours of UT in the month of January. By utilizing this, we could have avoided 750 hours of OT in February and 3,500 hours of OT in March. This would have resulted in a cost savings of ₹11,250.

Plan D: Mixed strategy

In the fourth plan, knee-jerks reaction are avoided to an extent by carrying inventory from a period of low demand to a future period of high demand. However, the cost of the plan is likely to be higher on account of the high cost of subcontracting. Also, the cost of carrying inventory is more than the cost of UT. Figure 15.12 shows all the relevant computations for the plan, which confirms this.

Key inferences

Example 15.4 points to a few important guidelines for aggregate operations planning.

- First, the chase strategy could prove to be more expensive than level strategy in situations involving items that are not made-to-order and vice versa. This is because some benefits of carrying inventory for a limited period and maintaining constant production rate are missed in chase strategy.
- It may be worthwhile to explore fewer production-level changes in a planning horizon even while implementing level strategy.
- Finally, mixed strategies provide a fertile ground for identifying the most appropriate AOP for an organization.

FIGURE 15.11 Computations for Plan C

Plan (c): Chase Strategy with OT/UT

Month	Demand (hours)	Production Rate (hours)	Opening Inventory (hours)	Production – Demand (hours)	Closing Inventory (hours)	Cost of OT/UT
April	35,000	31,000	-	(4,000)	-	80,000
May	24,250	31,000	-	6,750	-	67,500
June	32,250	31,000	-	(1,250)	-	25,000
July	44,250	31,000	-	(13,250)	-	265,000
August	25,250	31,000	-	5,750	-	57,500
September	31,750	31,000	-	(750)	-	15,000
October	33,000	31,000	-	(2,000)	-	40,000
November	32,250	31,000	-	(1,250)	-	25,000
December	35,750	31,000	-	(4,750)	-	95,000
January	26,750	31,000	-	4,250	-	42,500
February	31,750	31,000	-	(750)	-	15,000
March	43,750	31,000	-	(12,750)	-	255,000
				Total cost of the plan		982,500

FIGURE 15.12 Computations for Plan D

Plan (d): Mixed Strategy (Constant Production, Inventory, Sub-contracting)

	(A)	(B)	(C)	(D) = B+C–A		
Month	Demand (hours)	Production Rate (hours)	Opening Inventory (hours)	Net Capacity (hours)	Closing Inventory (hours)	Cost of Mixed Strategy
April	35,000	31,000	-	(4,000)	-	100,000
May	24,250	31,000	-	6,750	6,750	50,625
June	32,250	31,000	6,750	5,500	5,500	91,875
July	44,250	31,000	5,500	(7,750)	-	235,000
August	25,250	31,000	-	5,750	5,750	43,125
September	31,750	31,000	5,750	5,000	5,000	80,625
October	33,000	31,000	5,000	3,000	3,000	60,000
November	32,250	31,000	3,000	1,750	1,750	35,625
December	35,750	31,000	1,750	(3,000)	-	88,125
January	26,750	31,000	-	4,250	4,250	31,875
February	31,750	31,000	4,250	3,500	3,500	58,125
March	43,750	31,000	3,500	(9,250)	-	257,500
				Total cost of the plan		1,132,500

15.7 AGGREGATE OPERATIONS PLANNING METHODS

It is evident from these four examples that organizations need to devise a methodology to generate several alternatives for AOP and evaluate these alternatives before selecting the most appropriate one. In the absence of this, organizations may not be sure if the chosen strategy is the best. Moreover, they may not also know how much they could have improved by enumerating other strategies. Aggregate operations planning methods fulfil this objective. There are several methods available to the planner to evaluate alternative strategies before selecting one. Broadly, the available methods could be classified into heuristic methods and optimal methods.

Heuristic Methods for AOP

In heuristic methods, alternative strategies are generated on some basis and the alternatives are evaluated. The best among them is selected for implementation. Some of the known heuristic methods for AOP are the trial-and-error and search methods.

The trial-and-error method

In this method, a few options are considered. Each option employs a certain combination of AOP alternatives that we have already discussed. The total cost of each of these options is computed and the best one is chosen. Examples 15.1–15.4 illustrate this method for AOP. The trial-and-error method is simple to implement, particularly with the help of Excel-based spreadsheets. Since the method involves generating a limited set of alternatives, the usefulness of the method critically depends on the choice of the alternatives available for consideration. Managers with considerable experience in an organization and a good understanding of the cost structures of the AOP alternatives may be in a position to generate good candidates for evaluation.

Search methods

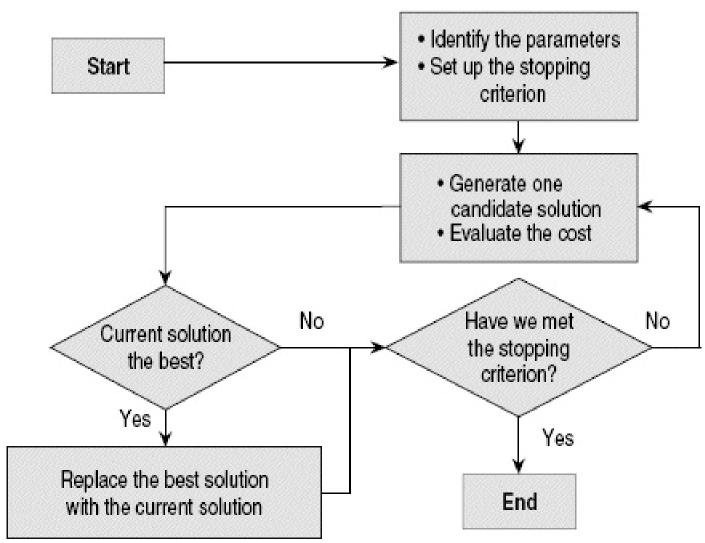
Search methods are useful in ensuring that “promising” candidates are not missed out in the enumeration process. In all the search methods, certain parameters are chosen and alternatives are generated by systematically varying the parameter values. As the parameter values are modified, newer alternatives are considered and the quality of the solution is evaluated. The search usually ends on the basis of some stopping criterion. The stopping criterion usually depends on the rate of improvement of the solution and/or the number of iterations done. At the end of the search, the best solution is identified.

A generalized search procedure is the random search process. In this process, sampling values for the parameters under consideration randomly creates alternative AOP plans. For example, suppose the parameters for consideration are desired production rate, number of employees, number of working hours and the inventory at the beginning of the planning horizon. Using a random number generator, a candidate solution for AOP could be sampled. As each plan is evaluated, the existing solution is updated. The procedure stops when the quality of the solution does not improve significantly and the best solution at the time of terminating the procedure is identified to be the solution to the AOP problem. Figure 15.13 illustrates the generalized search procedure for AOP.

Heuristic methods offer some advantages. First is the simplicity with which the method can be implemented. In several cases, one can set up the heuristic in a spreadsheet and quickly analyse the alternatives. It usually does not demand high levels of mathematical sophistication on the part of the user. However, the methods suffer from some drawbacks. Heuristic methods generally do not enumerate all the possible candidates in the solution space. Rather, they enable candidates with some knowledge of the problem to eliminate some from consideration. Therefore, the ability of the user to correctly identify the candidate solutions is critical to the usefulness of the method.

The other limitation of the trial-and-error method is that there is no guarantee of obtaining the best solution. Furthermore, users may not even know how far the best solution obtained from the method is from the optimal solution to the problem. Therefore, before using heuristic methods, users need to make a realistic assessment of these issues. With such a perspective, the use of heuristic methods could provide some promising solutions to the AOP problem.

FIGURE 15.13 Search procedure for AOP



Optimal Methods for AOP

Another method to develop the AOP is to build mathematical programming models of the problem and use the available solution procedures to solve the problem. Typical examples include the use of the linear programming (LP) and the transportation and dynamic programming (DP) models for AOP. We discuss some of the optimal methods for AOP in the Section 15.8.

Unlike heuristic methods, optimal methods systematically enumerate the entire solutions space and the optimal solution is obtained. While optimal methods guarantee the best solution, they may pose limitations arising out of the size of the problem that could be solved, the complexity of the solution procedure, and the nature of assumptions made in utilizing a model for solution.

> Optimal methods include the use of linear programming (LP) and the transportation and dynamic programming (DP) models.

15.8 OPERATIONS RESEARCH TOOLS FOR OPERATIONS PLANNING

Operations research (OR) was developed during the Second World War to systematically model and analyse several business problems. The optimum utilization of resources, maximization of profit, and minimization of cost were some of the pressing requirements of various government and private sector institutions at that time. Operations research tools provided them with a basis for meeting these requirements while taking several decisions. The application of OR tools in several areas of business happened in rapid succession in the post–World War scenario. Operations management problems are extensively addressed by OR researchers. In this section we will see how well known OR tools such as linear programming (LP) and transportation can be applied to operations planning problems.

Aggregate Operations Planning Using the Transportation Model

The transportation model is a special case of linear programming that deals with the issue of shipping commodities from multiple sources to multiple destinations. The objective is to determine a shipping schedule that minimizes the total shipping cost while satisfying supply and demand constraints. Table 15.6 shows the transportation table, which contains all the relevant information for solving the problem. *Ca1* is the cost of transporting one unit of the item from Supply A to Demand Point 1, and so on. *Sa* is the supply constraint of Supply Point A. Similarly, *D1* is the demand at Demand Point 1. The basis of the transportation model is the existence of multiple demand points and multiple supply points and the development of an optimum minimum cost method to satisfy the demand using the supply points. This structure is amenable for solving several other problems, like inventory control, operations planning, scheduling and personnel assignment.

TABLE 15.6 Generalized Representation of a Transportation Table

	Demand 1	Demand 2	Demand 3	Demand 4	Demand 5	Supply Constraints
Supply A	*Ca1*	*Ca2*	*Ca3*	*Ca4*	*Ca5*	Sa
Supply B	*Cb1*	*Cb2*	*Cb3*	*Cb4*	*Cb5*	Sb
Supply C	*Cc1*	*Cc2*	*Cc3* 900	*Cc4*	*Cc5*	Sc
Supply D	*Cd1*	*Cd2*	*Cd3*	*Cd4*	*Cd5*	Sd
Demand Requirements	D1	D2	D3	D4	D5	

ideas at Work 15.2

Use of Spreadsheets for Aggregate Production Planning

The complexity of production planning increases with variability in demand. The problem would have been much simpler if all the customers were to confirm their order well in advance. As discussed in the chapter, to avoid shortage, a company can either build inventory in anticipation or have additional capacity. As the numerical examples demonstrate, the best plan is a combination, allowing some backlog to accumulate, building anticipation inventory and providing variable capacity.

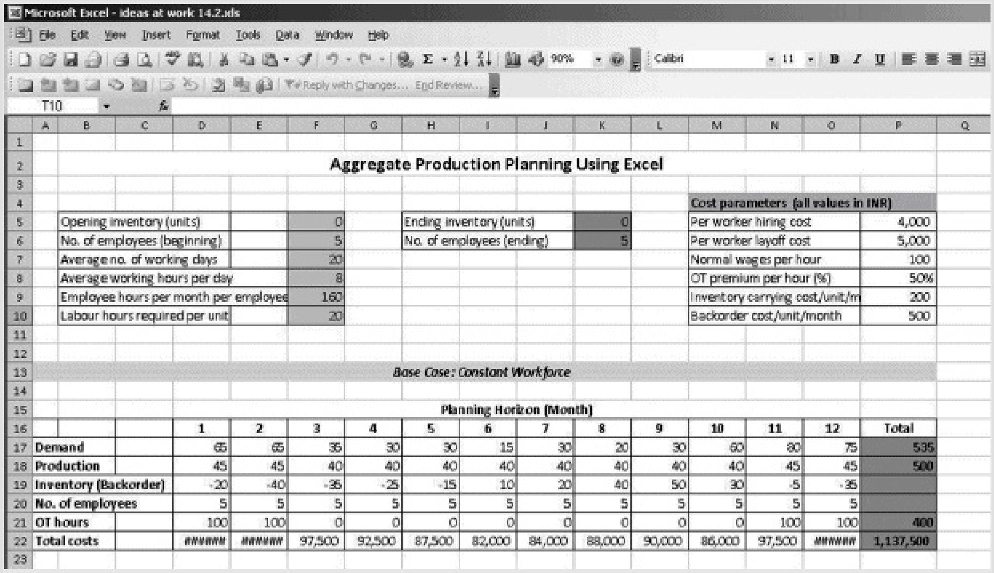
Use of spreadsheet software such as Microsoft Excel makes it easier to study the various alternatives that an organization may have in order to obtain the best plan. Furthermore, the Solver, an add-on utility, can help in building useful linear programming models and exploring optimal solutions. Figure 15.14 shows one such application of Excel for aggregate production planning.

Since variations in demand and cost parameters are very common, spreadsheet modelling of the aggregate production planning problem will allow the user to perform “what if” sensitivity analysis on the base case. The figure shows the effect of introducing hiring–lay-off costs in the aggregate production planning problem. It is evident from the figure that in the base case with a constant workforce of five employees, the best plan was to allow back orders in the first three months, whereas in the case of introduction of hiring–lay-off costs, the back orders were minimal. Instead, the workforce varied from three to seven.

The discussed example demonstrates how spreadsheets could be used to solve aggregate production planning problems. With the easy availability of computers and increase in the computing power, modern-day operations management will invariably have several such tools that help the operations manager make quick and sensible decisions to solve the problems that he/she faces.

Source: Based on Crandall, R.E., “Production Planning in a Variable Demand Environment,” *Production and Inventory Management Journal* 39, no. 4 (1998): 34–41.

FIGURE 15.14 Application of Microsoft Excel to aggregate production planning



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Aggregate Production Planning Using Excel

Opening inventory (units)	0
No. of employees (beginning)	5
Average no. of working days	20
Average working hours per day	8
Employee hours per month per employee	160
Labour hours required per unit	20

Ending inventory (units)	0
No. of employees (ending)	5

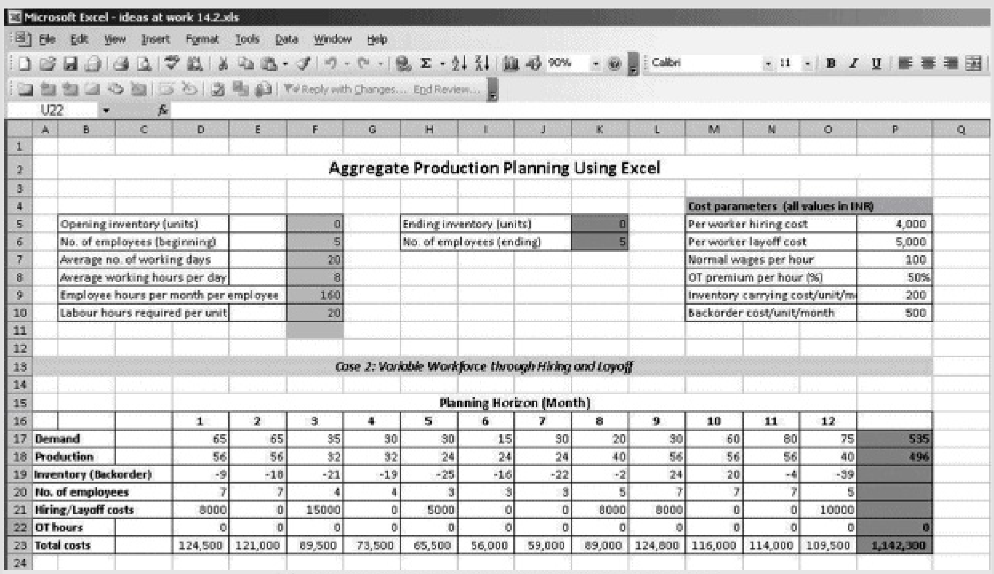
Cost parameters (all values in INR)	
Per worker hiring cost	4,000
Per worker layoff cost	5,000
Normal wages per hour	100
OT premium per hour (%)	50%
Inventory carrying cost/unit/m	200
Backorder cost/unit/month	500

Base Case: Constant Workforce

Planning Horizon (Month)

	1	2	3	4	5	6	7	8	9	10	11	12	Total
Demand	65	65	35	30	30	15	30	20	30	60	80	75	535
Production	45	45	40	40	40	40	40	40	40	40	45	45	500
Inventory (Backorder)	-20	-40	-35	-25	-15	10	20	40	50	30	-5	-35	
No. of employees	5	5	5	5	5	5	5	5	5	5	5	5	
OT hours	100	100	0	0	0	0	0	0	0	0	100	100	400
Total costs	######	######	97,500	92,500	87,500	82,000	84,000	88,000	90,000	86,000	97,500	######	1,137,500

(a) Base case: constant workforce



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Labour hours required per unit	20

Ending inventory (units)	0
No. of employees (ending)	5

Cost parameters (all values in INR)	
Per worker hiring cost	4,000
Per worker layoff cost	5,000
Normal wages per hour	100
OT premium per hour (%)	50%
Inventory carrying cost/unit/m	200
Backorder cost/unit/month	500

Case 2: Variable Workforce through Hiring and Layoff

Planning Horizon (Month)

	1	2	3	4	5	6	7	8	9	10	11	12	
Demand	65	65	35	30	30	15	30	20	30	60	80	75	535
Production	56	56	32	32	24	24	24	40	56	56	56	40	496
Inventory (Backorder)	-9	-18	-21	-19	-25	-16	-22	-2	24	20	-4	-39	
No. of employees	7	7	4	4	3	3	3	5	7	7	7	5	
Hiring/Layoff costs	8000	0	15000	0	5000	0	0	8000	8000	0	0	10000	
OT hours	0	0	0	0	0	0	0	0	0	0	0	0	0
Total costs	124,500	121,000	89,500	73,500	65,500	56,000	59,000	89,000	124,800	116,000	114,000	109,500	1,142,300

(b) Variable workforce through hiring and lay-off

Recall our discussion on aggregate operations planning. The central issue in AOP is to balance the supply with the demand on a period-by-period basis. This structure of AOP lends itself to straightforward application of the transportation model for solving AOP problems. Let us consider the various supply options for satisfying each period demand. These options are nothing but the various AOP alternatives that we discussed in the chapter. For instance, for a period *i* the supply options that an organization may consider are regular time production (RP), overtime production (OP) and subcontracting (SC). Each of these alternatives has differential cost and limits of production. Using this information, one can construct a transportation table. Example 15.5 illustrates how one can model the AOP using transportation.

> The central issue in aggregate production planning is to balance the supply with the demand on a period-by-period basis. This structure of APP lends itself to a straightforward application of the transportation model for solving APP problems.

The Linear Programming Model for AOP

The transportation model we just discussed cannot include AOP alternatives such as hiring and lay-off of workers. Furthermore, a linear programming (LP) model is a more generalized version of the transportation model and therefore can accommodate all AOP alternatives. In the LP model for average production planning, an inventory balance equation and the regular operations rate balance equation links each period with the succeeding period. During every period, there will be an increase in the inventory level due to regular operations and subcontracting. On the other hand, the inventory level decreases due to demand for the product. Similarly, the regular operations rate increases due to the additional hiring of workers and decreases due to laying off workers. Using this logic, it is possible to construct a set of equations pertaining to every period in a planning horizon. There are also other constraints such as minimum quantity for subcontracting capacity and restrictions on the extent to which overtime can be utilized in a system. The LP model formulation using such information is discussed here.

EXAMPLE 15.5

A manufacturer needs to perform AOP and has the following information about to the problem:

- *Demand information*: The demand forecast for the next four quarters is 100,000, 50,000, 70,000, and 60,000 units respectively. It is the company’s policy to plan for an additional inventory of 10 per cent of next period’s forecast. Moreover, planning needs to take into consideration that 25,000 units of inventory will be available at the beginning of Period 1 and 40,000 units must be made available at the end of Period 4.
- *Supply options and costs*: The manufacturer can produce 80,000 units through regular production and add another 20 per cent through overtime. Adequate capacities are available with the supply base and it is estimated that up to 100,000 additional units can be obtained through subcontracting. Regular production costs ₹80 per unit while overtime production costs ₹120 per unit. The cost per unit if subcontracted is ₹105 per unit. It is also possible to carry over inventory from one period to another at a cost of ₹2 per unit per period.

Use the transportation method to model the problem.

Solution

Requirements for Each Period

Period 1: 100,000 + 10% × 50,000 = 105,000 units

Period 2: 50,000 + 10% × 70,000 = 57,000 units

Period 3: 70,000 + 10% × 60,000 = 76,000 units
Period 4: 60,000 + 10% × 100,000 = 70,000 + ending inventory of 40,000 = 110,000 units

(Since no information about the next period forecast is available, to simplify the process we use the current year's Period 1 forecast as a substitute)

Cost of AOP Alternatives
Regular time: ₹80
Overtime: ₹120
Subcontracting: ₹105

Inventory can be carried at the rate of ₹2 per unit per period. For example, a regular time production during Period 1 costs ₹80 per unit in that period, ₹82 per unit in Period 2, ₹84 per unit in Period 3, and ₹86 per unit in Period 4 on account of carrying inventory. Similar costs are incurred in the case of the other alternatives.

Based on the above information and the supply constraints of the AOP alternatives, the transportation table can be constructed as shown in Table 15.7.

TABLE 15.7 The transportation table

	Period 1	Period 2	Period 3	Period 4	Supply Constraints
Initial Inventory	0	2	4	6	25,000
Period 1 RP	80	82	84	86	80,000
Period 1 OP	120	122	124	126	16,000
Period 1 SC	105	107	109	111	100,000
Period 2 RP		80	82	84	80,000
Period 2 OP		120	122	124	16,000
Period 2 SC		105	107	109	100,000
Period 3 RP			80	82	65,000
Period 3 OP			120	122	13,000
Period 3 SC			105	107	100,000
Period 4 RP				80	80,000
Period 4 OP				120	16,000
Period 4 SC				105	100,000
Demand Requirement	105,000	57,000	76,000	110,000	

Some portions of the table have been excluded from consideration. This is because there are no feasible AOP alternatives available in those cells. For example, the items obtained from Period 2 AOP alternatives (RP, OP, and SC) cannot be used to meet the demand for Period 1. By introducing backorders as another AOP alternative one can make these cells feasible. One can solve Table 15.7 using the standard solution procedures available.[4]

Notations for the model

The notations for the LP model are as follows:

Cost parameters:

C_r = Per unit cost of regular production
C_o = Per unit cost of overtime production
C_s = Per unit cost of subcontracted units
C_h = Per unit cost related to hiring of workers
C_l = Per unit cost related to laying off workers

C_i = Per unit costs related to inventory

Decision variables for the time period *t*:

R_t = Number of units produced in regular time
O_t = Number of units produced using overtime
S_t = Number of units obtained through subcontracting
H_t = Number of additional units obtained though hiring of workers
L_t = Number of units reduced through laying off workers
I_t = Inventory during the period

Other parameters:

D_t = Projected demand during the period
K = Minimum amount to be subcontracted
α = Maximum allowable overtime as a proportion of regular production

Objective function:

$$\text{Min } TC_{\text{APP}} = \sum_{t=1}^{N} (C_r R_t + C_0 O_t + C_s S_t + C_h H_t + C_l L_t + C_i I_t) \qquad (15.1)$$

Subject to the constraints:

Amount produced in regular time during a period is:

$$R_t = R_{t-1} + H_t - L_t \qquad \forall t = 1, 2, 3, \ldots, N \qquad (15.2)$$

The inventory balance equation is:

$$I_t = I_{t-1} + (R_t + O_t + S_t) - D_t \qquad \forall t = 1, 2, 3, \ldots, N \qquad (15.3)$$

The overtime constraint is:

$$O_t \leq \alpha R_t \qquad \forall t = 1, 2, 3, \ldots, N \qquad (15.4)$$

The subcontracting constraint is:

$$S_t \geq K \qquad \forall t = 1, 2, 3, \ldots, N \qquad (15.5)$$

$$R_t, O_t, H_t, L_t, S_t, I_t \geq 0 \qquad \forall t = 1, 2, 3, \ldots, N \qquad (15.6)$$

In this model, the total cost of aggregate planning is minimized subject to the meeting of the constraints. Equation 15.1 shows all the cost components associated with APP. Equations 15.2 and 15.3 are the production rate balance and the inventory balance. Equations 15.4 and 15.5 pertain to the constraints for the subcontracting and overtime alternatives of APP. Equation 15.6 is the non-negativity constraint. For a planning horizon of one year split into 12 months, the above formulation will result in 48 constraint equations and 72 variables. As this is a linear programming model, the most important assumption that we are making is that all costs are linear in the decision variables. In certain circumstances, this assumption many not be appropriate.

The Linear Decision Rule (LDR)

An interesting approach to the AOP is the linear decision rule proposed by Holt, Modigliani, Muth, and Simon.[5] In the LP formulation, the assumption was that all costs are linear. However, in reality, this could be a restrictive assumption. In the case of LDR, they assume that all the relevant costs, including inventory costs and the costs of changing production level and number of workers, are represented by quadratic functions. The decision variables in LDR are the production rate (P_t), workforce (W_t) and the inventory (I_t) during every period. Four types of costs are captured—the cost of regular production (C_{RP}), cost of hiring/lay-off (C_{HL}), cost of overtime (C_{OT}) and cost of inventory (C_{IN}). The formulation is as follows:

$$\text{Min } TC_{\text{LDR}} = \sum_{t=1}^{N} C_{RP} + C_{HL} + C_{OT} + C_{IN}$$

Where the four components of the costs are modelled as:

$$C_{RB} = (c_1 W_t)$$
$$C_{HL} = c_2(W_t - W_{t-1})^2$$
$$C_{OT} = c_3(P_t - c_4 W_t)^2 + c_5 P_t - c_6 W_t$$
$$C_{IN} = c_7(I_t - c_8 - c_9 D_t)^2$$

Subject to the constraint:

$$I_t = I_{t-1} + P_t - D_t \qquad \forall\, t = 1, 2, 3, \ldots, N$$

In the above formulation, there are 9 different cost coefficients. Depending on the specific cost structure and the nature of operations of a manufacturing set-up, these coefficients are to be arrived at. As mentioned before, D_t is the expected demand for the period. The most appealing feature of LDR is that the optimal policy for P_t and W_t has a simple form involving a linear equation. However, the computational advantage of this simple policy structure is less significant today than at the time this procedure was proposed. This is primarily due to improvements in availability of computing power and software packages for solving LP and NLP problems today. However, LDR is useful for the insights it offers with respect to solving AOP problems using mathematical modelling methods.

15.9 MASTER OPERATIONS SCHEDULING

Master operations scheduling (MOS) represents the critical linkage between planning and execution of operations. It is the next stage in the operations planning process in any organization after aggregate operations planning is done. Aggregate operations planning is a rough-cut capacity planning exercise on the basis of forecast quantities of products and services.

MOS makes use of actual customer orders for the purpose of capacity planning and resource allocation to specific customer orders. While aggregate operations planning ensures that adequate capacity is available in a period-by-period basis, organizations need to relate the capacity needs of specific varieties of products and services that they offer to the overall capacity available. MOS is the process by which disaggregation of varieties is done. Using this information, additional planning is carried out to assign the required capacity to each variety. At this stage, planning for the material required for operations during each period is also done.

Master operations scheduling is required for a variety of reasons:

- The most important reason is that at the stage of aggregate operations planning, the forecast demand is normally taken for the purpose of estimating the capacity required. However, when actual orders are received, this information provides a better input and another opportunity for the planning exercise.
- Moreover, the AOP exercise is to ensure availability of capacity in broad terms. However, as we approach the planning horizon, it is important to relate material and capacity availability to specific varieties of products and services that an organization plans to produce during a planning horizon. Therefore, MOS uses actual and the most recent information while revisiting the planning problem and ensures specific material and capacity availability in a particular time period.
- As customer orders get amended and/or cancelled, the information has a bearing on capacity availability. Therefore, as order inflow happens in real time, the marketing department may want to know if there is scope for accepting newer order inquiries. The marketing department may also want to know if delivery commitments can be made to customers while accepting orders. The MOS module serves the important purpose of computing capacity available to promise.

The critical linkages between MOS and other planning processes in an organization are shown in Figure 15.15. As shown in this figure, MOS takes inputs from the order inflow system and AOP to perform the disaggregation exercise. Based on the disaggregation, capacity planning and materials planning are performed to ensure their adequate availability. If there is some infeasibility in either capacity or material availability, the plans are altered to arrive at feasible production plans. Therefore, MOS determines *what needs to be ultimately produced, not what is demanded*.

> Master production scheduling (MOS) is the process by which disaggregation of varieties is done.

There are two stages involved in MOS. The first step is to update the projected demand based on earlier forecast and current market information. The second step involves disaggregation of information and relating it to specific material and capacity requirements. After the disaggregation process, it is possible to accurately estimate the amount of material and capacity required for planned units of production of each variety. If either capacity or material is not available, that information is made use of in MOS and plans are re-worked. This is an iterative process and the actual plan is finally arrived at. The two steps are explained in some detail here.

> MOS determines *what needs to be ultimately produced and not what is demanded.*

FIGURE 15.15 Master operations scheduling: a planning tool

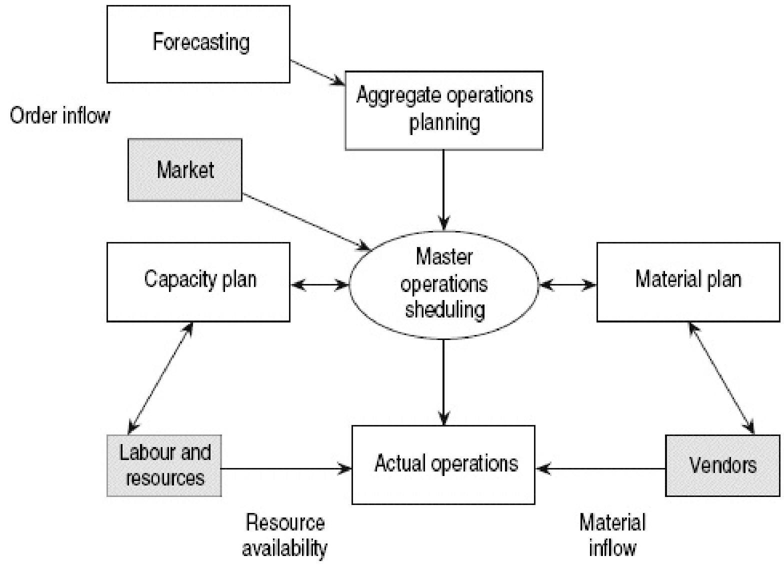

TABLE 15.8 Disaggregation Process in MOS

Capacity Planned Using AOP		18,000
Capacity required/unit	Silver	20
	Gold	40
	Platinum	70

Type of Service	Demand Status	Planning Horizon		
		Month One	Month Two	Month Three
Silver	Forecast	100	120	140
	Firm order	120	90	30
Gold	Forecast	200	240	180
	Firm order	180	200	60
Platinum	Forecast	80	100	90
	Firm order	50	110	20
MOS Quantity		Shaded area represents MOS quantity.		
Capcity required (for MOS quantity)		16,000	19,700	16,300

Step 1: Incorporating current market information into the operations plan

MOS exercise is normally done several times during the planning horizon. Therefore, at each instance it is possible that additional information is available to the planner. Let us assume that the AOP exercise was done during September– October for the next financial year beginning April. At that point in time the demand for June, July and August would have been based on some forecasting. If the MOS exercise was carried out in the month of April it is possible that some customers would have already placed firm orders. Therefore, while planning is done at that time it is important that firm orders are also taken into consideration. If the forecast quantities are higher than the firm orders it is a normal practice to work on the basis of forecast quantities. On the other hand if the firm orders are more than the forecast quantity, then it is desirable to incorporate this information for the purpose of planning. Moreover, between one MOS exercise and the other order cancellations, order amendments and new orders are received. Therefore, the MOS exercise must include all this information at the time of planning. Table 15.8 presents an example that illustrates this.

Step 2: Disaggregation of information

You may recall that at the time of AOP an aggregate unit was chosen and different varieties of a product or service were converted to an "equivalent" product/service. Therefore, it is imperative that the process be reversed at the time of detailed planning. The MOS exercise performs this process known as disaggregation. Let us revisit the example in Section 15.1, where we described three different service levels offered by a service provider. Assume that one unit of the "silver" category of service requires 20 man-hours, one unit of the "gold" category requires 40 man-hours and one unit of the "platinum" category requires 70 man-hours. Table 15.8 provides information on forecast and firm orders status for the next three months for each category of service. Using this information, one can disaggregate the total requirement and relate specifically to each category of service.

Aggregate operations planning and master operations scheduling are the first two steps in every planning and control activity in an organization. These form the critical inputs for further planning and control of operations, as we will see in the next chapter.

SUMMARY

- *Operations planning* serves to translate business plans into operational decisions. The decisions include the amount of resources (productive capacity and labour hours) to commit, the rate at which to produce, and the inventory to be carried forward from one period to the next.
- AOP is done to match the demand and the available capacity on a period-by-period basis using a set of alternatives available to an organization to modify the demand and/or the supply.
- Alternatives for modifying demand include the reservation of capacity and methods of influencing (changing) the demand during a period.
- Alternatives for modifying the supply include inventory variations, capacity adjustment, and capacity augmentation.
- The AOP exercise employs two generic strategies: *chase* and *level production*. A chase strategy is often found to be expensive and hard to implement in organizations.
- In reality, a *mixed strategy* using a combination of alternatives is employed in an AOP exercise. It uses a variety of alternatives for modifying supply.
- The structure of a transportation model lends itself to studying the AOP problem. Linear programming can also be used to model the AOP problem.
- MOS involves disaggregation of information and ensuring the required capacity and material are available as per the plan.

REVIEW QUESTIONS

1. Why do you need aggregate units while planning for operations?
2. Give three examples each from the manufacturing and service sectors of industry for aggregation of products and services.
3. Assume that you are a garment manufacturer. Your current production rate is 20,000 pieces per day. If you want to increase it to 30,000 per day, what problems do you envisage in making this change?
4. Identify a suitable aggregate unit for each of the following situations:

    a. A business school offering four different long-duration academic programmes and three different short-duration programmes
    b. A manufacturer of colour televisions of 30 different varieties
    c. A service provider offering inter-city transport facility using six different classes of vehicles
    d. A multi-specialty hospital
    e. A financial supermarket such as ICICI Bank
    f. A fast-food restaurant offering North Indian and South Indian dishes
    g. A law firm offering a variety of legal services
    h. A manufacturer of custom-made PCBs
    i. A BPO service provider offering back-office services to a variety of domestic and MNC clients

5. What do you mean by hierarchical operations planning? Are there any benefits in this exercise? Use an example to demonstrate hierarchical operations planning.
6. How does aggregate operations planning impact each of the following functional areas in an organization?

    a. Marketing
    b. Finance
    c. Strategy
    d. Materials and procurement

7. What considerations will you bear in mind while selecting either demand-oriented alternatives or supply-oriented alternatives during an AOP exercise?
8. Which AOP alternatives are more suited to a service organization? Why?
9. What are the key differences between level strategy and chase strategy in AOP formulation?
10. Identify suitable AOP alternatives for an organization manufacturing made-to-order items. Will your recommendation change if the items are made-to-stock?
11. “Mixed strategies are always superior to pure strategies in an AOP exercise.” Comment on this statement.
12. What are the pros and cons of using optimal methods for solving the AOP problem?
13. How is the master production scheduling exercise different from an AOP exercise?
14. How are materials planning and capacity planning related to MOS?

PROBLEMS

1. A manufacturer of ceiling fans offers three different versions of the product to its customers: basic (three blades), improved (four blades) and deluxe (enhanced performance features). Table 15.9 has information on the machine-hours required for each of these variations and the number of fans to be manufactured in the next quarter. Assume 25 working days per month.

TABLE 15.9 Data for Problem 1

Fan Type	April	May	June	M/c hours per unit
Basic	140	160	160	9.50
Improved	110	150	150	12.00
Deluxe	120	120	140	18.50

a. Choose an appropriate aggregate unit for planning the production.
b. For the chosen aggregate unit, estimate the capacity required.
c. If the manufacturer operates two shifts each of eight hours, how many machines are required for meeting the demand during the next quarter?

2. A manufacturing organization employs 220 people in the factory. The manufacturing is largely manual; therefore, man-hours are a good measure of the capacity of the system. The factory currently works for a single shift of eight hours. The number of working days for the next six months is as follows: 24, 22, 25, 19, 21, and 23. The company uses this information to plan its capacities. The demand for its product during the next six months is such that with the current level of employment, the company will have 80 per cent capacity utilization. During the next six months, the number of working days remains the same but the demand is likely to go up by 35 per cent. Under these circumstances, analyse the situation and answer the following questions:

   a. What is the total capacity available in the factory as of now?
   b. The company is considering three options to meet the impending demand for capacity:
      i. Introduce two hours of overtime for the next six months
      ii. Introduce one hour of overtime for the next six months
      iii. Introduce two hours of overtime for the first three months and two hours of idle time thereafter

   Evaluate these options from the capacity perspective and suggest a suitable option for the company.

3. Suppose, in Problem 2, the following are the costs pertaining to overtime, inventory and shortage and idle time:

   a. Overtime premium: ₹4 per hour
   b. Idle time costs: ₹2 per hour
   c. Cost of holding inventory: ₹10 per hour
   d. Cost of shortages is 200 per cent of cost of holding inventory.

   Use this additional information and suggest an appropriate option to the management.

4. Hot Spot is a fast-food restaurant located in a prominent locality in the city of Bangalore. Hot Spot offers three different menus for breakfast: standard, extended, and custom-made. The standard offering takes nearly 20 minutes of one worker and the extended requires 30 minutes. On the other hand, custom-made requires three workers to spend 25 minutes each. Hot Spot is interested in identifying the right number of workers required in its restaurant. Using the data given in Table 15.10, estimate the aggregate capacity required at Hot Spot during the next four weeks.

TABLE 15.10 Data for Problem 4

Type of Service Offered	Demand During the Next 4 Weeks			
	1	2	3	4
Standard	2,000	2,200	2,800	2,500
Extended	1,700	1,600	1,300	1,000
Custom-made	500	600	200	400

5. Assume that Hot Spot currently employs twenty nine workers in its restaurant. If Hot Spot works for six days a week, 10 hours a day compute the following:

   a. What is the capacity available at Hot Spot in its current level of working?
   b. Is the capacity adequate to meet the demand? If not, how much additional capacity do they need?
   c. What alternatives would you recommend to Hot Spot to solve their capacity problem?
   d. If Hot Spot is ready to recruit new workers, how many should they recruit?

6. A manufacturing firm is performing an AOP exercise for its product. One unit of product requires 100 hours of the capacity. An extract of the aggregate planning exercise for the firm is given in the table. Table 15.11 has details on the number of working days, number of people employed and working hours per day. Complete the table and answer the following questions:

TABLE 15.11 Data for Problem 6

Month	Demand (in Units)	Demand (Hours)	No. of Working Days	Working Hours Per Day	No. of Workers	Capacity Available (Hours)	Supply-Demand (Hours)
April	160	16,000	23	8	90		
May	150	15,000	22	8	90		
June	140	14,000	21	8	90		
July	160	16,000	24	8	90		
August	120	12,000	22	8	90		
September	150	15,000	22	8	90		
October	160	16,000	19	8	90		
November	180	18,000	23	8	90		
December	160	16,000	21	8	90		
January	180	18,000	23	8	90		
February	190	19,000	20	8	90		
March	150	15,000	24	8	90		
Total							
Average							

   a. What is the capacity required for the planning horizon? Does the company have adequate capacity to meet the demand?
   b. Will the company fall short of capacity if you analyse on a period-by-period basis? By how much does it fall short?
   c. If the cost of shortage is ₹5 per hour of capacity falling short, what is the cost that the company may incur on account of shortages?
   d. If the cost of having excess capacity is ₹1 per hour, what will the cost of excess capacity be?
   e. If the company chose to adopt this plan, what is the total cost of the plan? Identify the AOP alternatives and the AOP strategy that the company has deployed in this plan.

7. A manufacturer of garments is interested in making an aggregate production plan for its range of products manufactured. From the perspective of capacity usage, the range of products could be divided into three: basic garments, office wear and trendy garments. A basic garment required on an average 2 hours. The ratio of the time required for the office wear and trendy garment to the basic garment is 2 and 4, respectively. The company can source 20 per cent additional capacity through overtime. The overtime premium to be paid for the labour is 50 per cent. Material cost is 125 per cent of labour cost. Currently the company is operating at a capacity of 20,000 hours. The labour charges are paid at the rate of ₹40 per hour.

   The company can also subcontract the work to nearby units for a premium of 20 per cent. However, every time a subcontracting arrangement is made, it involves a fixed cost of ₹3,000 also. Short term funds for working capital at 24 per cent per annum is available for the company without any restrictions. The company cannot afford to run into shortages as it is a competitive industry. The forecasted demand for the next six periods is as shown in Table 15.12.

TABLE 15.12 Demand Forecast for the Next 6 Periods

	Basic	Office wear	Trendy
Period 1	5,000	2,000	1,500
Period 2	4,500	1,800	1,900
Period 3	5,500	2,200	2,000
Period 4	5,200	2,100	1,750
Period 5	5,500	1,600	1,800
Period 6	5,000	1,900	1,500

a. Set up a transportation table for the given problem.
b. What is the least cost plan for the company?
c. Suppose the premium for subcontracting is only 12 per cent, will the plan change?

8. A major manufacturer of vacuum cleaners is preparing the AOP for the four quarters of the next year. They are currently operating at a production level of 24,000 vacuum cleaners per quarter. The number of employees working now is 480. The current capacity represents the regular time production. The company can additionally produce a maximum of 2,000 vacuum cleaners per quarter through overtime. Subcontracting capacity to the extent of 750 vacuum cleaners per quarter is also available. The cost of production (including materials) through regular time, overtime, and subcontracting are ₹7,300, ₹8,000 and ₹10,000 respectively. Unused regular time capacity costs ₹800 per vacuum cleaner. The company plans to start the planning horizon with an opening inventory of 2,700 vacuum cleaners and wants to end with an inventory of 2,500. No back orders are allowed and the cost of carrying the vacuum cleaners is ₹1,000 per quarter. It costs ₹9,000 to hire a worker and ₹6,000 to lay off. The demand for the planning horizon (next four quarters) is 6,700, 28,000, 49,000, and 30,000 respectively.

   The company is considering two options with respect to the workforce, as shown in Table 15.13.

TABLE 15.13 The Two Plans Under Consideration

Quarter	1	2	3	4
Plan 1	480	520	620	480
Plan 2	570	570	570	570

a. Advise a suitable course of action for the company.
b. The company wants to evaluate the policy of having opening and closing inventories. Help them with some computations that provide some implications of carrying inventory.

9. Channapatna near Bangalore is well known for specialized wooden toys. A toy manufacturer in Channapatna has determined the demand (in units) to serve the forecasted demand for the next year. This data is shown in Table 15.14.

TABLE 15.14 The Demand for the Toys (in units)

Month	1	2	3	4	5	6
Demand	500	800	1,000	1,400	2,000	1,800
Month	7	8	9	10	11	12
Demand	1,350	1,100	900	2,400	2,900	1,000

Each worker is paid a monthly salary of ₹8,000 and can produce 10 toys per month. The owner does not resort to overtime, instead, he prefers to hire and fire workers depending on his requirement. He can hire and train a new employee for ₹8,000 and lay off for ₹2,000. In this way, he enables the local community to acquire some skills and gainfully employ themselves over time. The cost of holding inventory is ₹125 per month. At present there are 130 employees in the manufacturing unit.

a. Prepare a level production strategy for the toy manufacturer.
b. Can you also develop a chase strategy for the toy manufacturer?
c. Identify two more options for the toy manufacturer.
d. Prepare a comparative analysis of the plans and suggest a suitable course of action for the toy manufacturer.

CASE STUDY

New Age Electronics Limited

Bala Athreya, the director (operations) of a popular brand of electronic voltage stabilizer, was on the verge of finalizing the aggregate production plan for his manufacturing plant when he received a letter from his marketing director about a new marketing and promotional campaign that he plans to launch to boost the sales of voltage stabilizers. What is the implication of this to him? Should he re-plan the campaign, or should he convince the marketing director about the need to take another look at his plan?

Introduction

New Age Electronics Limited (NAEL) is a Hyderabad-based manufacturer that specializes in the manufacture of electronic voltage stabilizers. Electronic voltage stabilizers are increasingly popular on account of better performance, longer working life, light weight, and low cost. NAEL was promoted by Bala Athreya, an electronics engineer with about 15 years' experience prior to starting NAEL with two other friends. NAEL manufactures three variations of voltage stabilizers, primarily differing on account of the type of application they are put to and the rating. These three can be designated as VS-TV, VS-RF and VS-IN. One unit of VS-TV requires two hours of labour. For the other two models VS-RF and VS-IN the labour hours required are 2.5 hours and 3.25 hours, respectively. Due to their early entry into the market, NAEL has been enjoying a good market share of the electronic voltage stabilizers.

Production of Voltage Stabilizers

The factory is currently working on a single shift with a capacity equivalent to 60,000 hours of labour. Over the last six months, the order inflow has been on the rise at NAEL, and Bala had to schedule overtime since the demand was in excess of 60,000 hours. The factory can increase the production up to 80,000 hours through overtime although it means paying more by way of overtime (OT) premium. By resorting to a second shift, NAEL can produce anywhere between 60,000 hours and 120,000 hours. A second shift has certain benefits. Instead of paying an OT premium of ₹15 per hour, it is enough if NAEL pays ₹3 per hour as shift allowance. After carefully analysing the demand trend in the past six months, Bala recently took a decision to operate the factory on a two-shift basis and made the change two months back. However, by changing over to two shifts from one, NAEL incurred a one-time shift change cost of ₹50,000. Henceforth, Bala plans to operate only on a two-shift basis for the coming year as the demand is likely to go up.

Costs Pertaining to Production and Inventory

NAEL incurs several types of costs, just as any manufacturer would. The first set of costs relate to inventory. As it manufactures an electrical product, NAEL does not wish to carry too much inventory of finished goods. There are frequent changes in the components that NAEL uses in its products. Therefore the cost of carrying inventory is ₹18 per hour of average inventory held. Shortage costs are double the average inventory carrying costs at NAEL. The second element of cost is the cost of changing the production level. Changing the production level (either up or down) requires NAEL to make several adjustments with its suppliers, the internal departments. It also calls for re-planning and manpower scheduling adjustments to suit the revised production plan. The costing department recently did an elaborate exercise and estimated the cost of change in production level to be ₹12 per hour.

Production Planning

NAEL is currently in the process of developing an aggregate production plan for the next financial year. Detailed estimates of the demand were made and based on this a strategic planning exercise at the corporate level was done to arrive at the potential demand for the next year. During the strategic planning exercise the marketing department highlighted the increased competition as more players are bringing similar products to the market. According to some market information, a number of new players were planning to launch major marketing campaigns with a view to capture some share of the market. According to NAEL top management, these new entrants would not make significant inroads into their market share. The new competitors were most likely to take away the market from traditional voltage stabilizer manufacturers. After detailed discussions, the final projections for the next year were finalized. Table 15.15 has the demand projection for the next year.

TABLE 15.15 Demand Projection for the Next Year

Month	VS-TV	VS-RF	VS-IN
1	12,150	12,750	6,100
2	9,050	18,700	5,600
3	22,900	15,000	11,000
4	6,750	8,900	4,100
5	10,750	11,550	4,200
6	10,250	17,500	6,100
7	26,550	19,200	9,200
8	6,950	11,200	6,800
9	11,250	12,400	5,700
10	9,950	15,500	7,500
11	28,750	20,000	9,100
12	7,050	11,000	7,200

Bala and his team analysed the demand pattern for the next year and came up with certain observations. For instance, the demand for the stabilizers had pronounced seasonality and peaked during Months 3, 7, and 11. Further, being an electrical product, the cost of carrying inventory was high, therefore the amount of inventory build-up they could do to meet the peak demand was a question that they needed to answer. After some discussions, they came with two possible production plans:

a. To maintain a constant production level of 80,000 hours except during peak periods when it would be increased to 100,000 hours
b. To maintain the production at the level of the monthly demand, but to increase it to the peak production level of 120,000 hours during the peak months in order to meet the demand

They were not clear about which one to choose as there are different implications for each of these choices. One of the major constraints for NAEL is the ability of their supply chain partners to respond to the changes in production plan. Up to 5 per cent increase or decrease is generally accepted without any discussion. Mere e-mail communication will do. Another 5 per cent change (both increase and decrease) requires that NAEL discusses this with them, have a mutual agreement, and give them at least 45 days notice. Any larger magnitude of change in excess of 10 per cent is generally resisted. It also requires a much longer time frame to respond.

Later Development

While Bala and his team were working on finalizing the production plan for the next year, the marketing director informed them that they would like to launch a promotional campaign to counteract the new entrants. The specifics of the plans are as follows. The marketing plan would cost ₹2 million and the budget will be spent during Months 2 to 5. Due to this the increase in sales (across all the three variations) expected would be Month 3: 10 per cent; Month 4: 15 per cent, Month 5: 18 per cent, Month 6: 12 per cent and Month 7: 5 per cent.

QUESTIONS FOR DISCUSSION

a. What is your advice to Bala Athreya with respect to production planning for the next year? Which of the two plans would you recommend? Why?

b. What are the practical difficulties that Bala and his team will face while implementing the plan? How should they handle them?

c. What are the implications of the marketing plans at NAEL? Bala needs to attend a meeting to discuss this issue. Prepare a brief for the meeting.

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SUPPLEMENT 15: LINEAR PROGRAMMING

One of the issues that an operations manager often faces is with respect to the effective use of resources such as labour, material, machine capacity, and other similar resources. Typically, in any business situation, the managers face constraints with respect to several of these resources. For example, in a manufacturing organization the availability of machines is limited. Therefore, an operations manager would like to understand how best to make use of the available machines while meeting certain objectives such as maximizing the production or minimizing the waiting time for the machine. Similarly, in a service system such as a hospital or restaurant, one of the issues for planning would be to make the best use of available resources while minimizing the waiting time of the customers in the system. *Linear* *programming* is a methodology which helps an operations manager to address such problems that he/she faces in planning the operations in the system.

Linear programming (LP), as the name implies, is a methodology in which linear relationships between various elements in the system can be modelled to study the behaviour of the system and to identify the best set of decisions that one should make in order to optimize the performance of the system while taking into consideration the constraints that one faces in the system.

LP Modelling Fundamentals

An LP modelling exercise begins with the mathematical formulation of the problem that one wishes to study. Before formulating the problem, it is important to understand the decisions to be made, the relationships between various elements of the system, and the performance measures for which the decision is being made. In an LP modelling exercise, these aspects are represented in a structured fashion. The following terminologies describe them in some detail:

- *Decision variables*: The purpose of LP modelling is to arrive at a decision with respect to the problem under study. For example, the problem could be to identify the number of machines required in order to meet a certain targeted production in a manufacturing system. In this case, the number of machines required becomes the decision variable. Another example is to decide on an appropriate production plan given a set of machines and other resources so that the profit could be maximized. Similarly, in the design of a restaurant, the number of waiters to be employed could be a decision variable.

  If the decision on hand is the number of machines of Type A, Type B, and Type C to be procured, one can denote this decision using three decision variables as illustrated below:

  Let X_A be the number of machine of Type A to be procured

  Let X_B be the number of machine of Type B to be procured

  Let X_C be the number of machine of Type C to be procured
- *Objectives*: The operations manager analyses the problem with specific objectives in his/her mind. The objective could be to maximize certain parameters of interest such as production, profit, availability of resources etc. Alternatively, it could be to minimize certain parameters such as investment, waiting time, cost etc. In an LP modelling exercise, the objectives need to be specified *a priori*. In the preceding example of the manufacturing system, our objective could be to minimize the investment to meet a certain targeted production or to maximize the production given a certain availability of machines. Similarly, in the case of the restaurant, the objective could be to maximize the daily revenue or to minimize their cost of human resources while meeting a certain demand.

  For example, in the case of the manufacturing system, if the objective is to minimize the investment, then one can represent the objective function as follows:

  Let C_A be the cost of one unit of machine of type A to be procured

  Let C_B be the cost of one unit of machine of type B to be procured

  Let C_C the cost of one unit of machine of type C to be procured

  The cost of the decision $Z = X_A \times C_A + X_B \times C_B + X_C \times C_C$

  The objective function is **Minimize *Z***.
- *Constraints*: Any management problem is solved in the context of certain constraints that the manager faces. If we consider the examples discussed earlier, in the case of the manufacturing system, the constraint could be the need to meet with a certain daily production. Another constraint could be the availability of raw materials for production. A third constraint could be the demand for the product for which the production system is being designed. A fourth could be the funds available for the procurement of machines. Similarly, in the case of the restaurant, the constraints could be the demand for the service, the productive capacity of the kitchen, the skill requirements for the service, and the availability of such skilled personnel in the market.

  Using LP as a modelling tool also implies certain important assumptions behind the modelling exercise. These include the following:

a. ***Linearity:*** All relationships between various elements that are being studied using an LP model are assumed to be linear. Similarly, the objective function is also assumed to be linear.
b. ***Non-negativity:*** It is also assumed that all decision variables used in an LP modelling exercise are strictly nonnegative. In other words in the above example this implies that X_A, X_B, and X_C are greater than or equal to zero.

Once these conditions are satisfied, there are well-known methodologies to obtain a solution set for any LP problem. The solution methodologies also indicate whether a feasible solution exists for the problem formulated, and if so, whether it is unique. The solution methodologies also enable us to analyse the sensitivity of variables and constraints of the problem.

Mathematical Formulation of the Problem

The first step in LP modelling is to represent the problem to be studied in a format amenable for solving using known solution methodologies. A number of computer packages are available today to solve a well-formulated LP problem. Therefore, developing adeptness in formulating the problem will be more valuable than developing skills in actually solving the problem using a known solution methodology.

Based on this discussion, it is obvious that mathematical formulation of the problem begins with the identification of the decision variables, the constraints that one faces in addressing the problem, and the objectives of solving the problem. These are represented in the form of linear equations which ultimately comprise the mathematical formulation of the problem to be studied. We shall look at an example to understand how formulation of the problem is done.

EXAMPLE 15A

A manufacturer of engineering components would like to decide on the daily production plan. The following information is available with respect to the production activity that the manufacturer proposes to undertake:

Two major types of components are being manufactured. These are machined castings (Product A) and cylinders (Product B). The machines required for manufacturing include CNC lathes (Machine 1), grinding machines (Machine 2), and milling machines (Machine 3). As per the process plan, the number of hours required in each of these machines per unit of manufacturing is known. Furthermore, the contribution per unit of selling these products is also known. At the moment, the manufacturer has a certain number of machines. The shop operates in a single shift of eight hours. There is sufficient demand in the market to sell whatever the manufacturer may choose to produce. The relevant details are given in Table 15A.

Formulate the problem to decide on the daily production schedule for the manufacturer.

Solution

Decision Variables for the Problem

Let us begin by identifying the decision variables for this problem. Since the problem is one of determining the daily production schedule, the decision variables are the number of units of Product A and Product B to be produced daily. Let us denote this with two decision variables as shown below:

Let X_1 denote the number of units of Product A to be produced daily

Let X_2 denote the number of units of Product B to be produced daily

Objective Function for the Problem

The next aspect of the mathematical formulation of the problem is with respect to identifying the objective function for the problem. Since the contribution per unit of each of the products is available, we shall assume that the objective is to maximize the daily contribution for the manufacturer. Using this we shall state the objective function for the problem.

The contribution is computed as $Z = 115 \times X_1 + 136 \times X_2$

Therefore the objective function is **Maximize (*Z*)**.

Constraints for the Problem

Next, we need to identify the constraints for the problem. As we see from the description of the problem, the constraint pertains to the availability of machining capacity with the manufacturer. We shall develop the corresponding constraint equations.

TABLE 15A Data for Example 15A

	Machine 1	Machine 2	Machine 3	Contribution
Product A	14 minutes	15 minutes	18 minutes	₹115
Product B	17 minutes	22 minutes	20 minutes	₹136
No. of machines available	4	5	5	

The manufacturer works on a single-shift basis of eight hours. Therefore, each machine is available for 480 minutes per day. Since four units of Machine A are available with the manufacturer, the daily capacity available with respect to Machine A is 1920 minutes (4 × 480). On the other hand, one unit of Product A requires 20 minutes in Machine 1. Similarly, one unit of Product B requires 17 minutes in Machine 1. Using this information, one can develop the constraint equation with respect to machine A as follows:

$14X_1 + 17X_2 \leq 1920$ (Machine 1 capacity constraint)

The constraints with respect to the other machines are written in a similar fashion.

$15X_1 + 22X_2 \leq 2400$ (Machine 2 capacity constraint)

$18X_1 + 20X_2 \leq 2400$ (Machine 3 capacity constraint)

We notice that in the above set of equations all relationships are linear. Therefore, in addition to the above, we need to only ensure the non-negativity constraint for the decision variables. We shall now write the complete mathematical formulation for the above problem.

Mathematical Formulation of the Problem

Maximize (Z) = $115 \times X_1 + 136 \times X_2$

Subject to:

$14X_1 + 17X_2 \leq 1920$

$15X_1 + 22X_2 \leq 2400$

$18X_1 + 20X_2 \leq 2400$

$X_1, X_2 \geq 0$

Solving an LP Problem Using Excel Solver

Microsoft Excel provides an add-in facility known as Solver which could be used for modelling an LP problem and obtaining the solution. It also helps the modeller to analyse the problem in terms of sensitivity analysis of the constraints and the decision variables. In order to make use of this the users need to ensure that solver is installed as an “add-in” in Excel.

We shall use Microsoft Excel and solve the problem that we have formulated in the previous example. The following steps are used to obtain a solution for an LP problem using Microsoft Excel Solver:

1. Open the Microsoft Excel worksheet and set up the required information in the worksheet. The information to be entered includes the parameters of the problem and their values, decision variables, the relationships between the decision variables, and resources that manifest in terms of constraints. For the above problem, Figure 15A shows how the various elements of the problem to be formulated are laid out in the spreadsheet. In the top portion, some of the parameters such as the number of shifts, the number of working hours per shift, the products manufactured, and their contribution per unit are entered. Below that, details regarding the processing requirements are specified. Finally, at the bottom, the decision variables and the objective function are entered.
2. On the **Data** tab, in the **Analysis** group, click **Solver** to input the required data for solving the LP problem.
3. Once the Solver utility is invoked a screen appears (see Figure 15B for our sample problem). Using the Solver screen, the mathematical formulation needs to be entered.

    a. The target cell is the value of the objective function to be optimized.
    b. The optimization could be to maximize or minimize and it needs to be selected
    c. Constraint sets are to be added using the **Add** tab.

In our example the relevant cells are as given below:

Decision variables: Cells C15 and C16

Objective function: Cell C17

Constraints equations:

Machine 1: Cell H10 must be less than or equal to cell F10

Machine 2: Cell H11 must be less than or equal to cell F11

Machine 3: Cell H12 must be less than or equal to cell F12

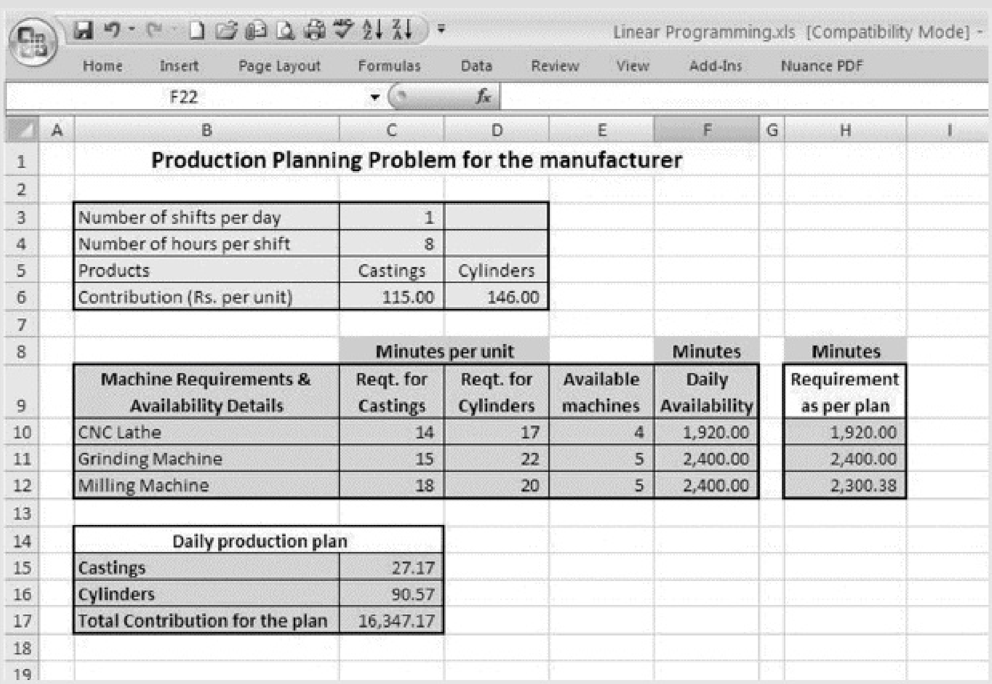
Non-negativity constraint: Cell C15 and C16 must be greater than or equal to 0.

The completed formulation is shown in Figure 15B. Once the formulation is complete, the **Solve** tab can be used to obtain the solution. A new screen appears (see Figure 15C) which can be used to view the output and perform sensitivity analysis. For our problem, the results are displayed in Figure 15D.

This is an LP problem with only the non-negativity constraint. Therefore, we get a solution in decimals. In reality, it may not be possible to invest in fractional machine capacity as indicated by the optimal solution. In order to sort out this confusion, we need to introduce additional integrality constraints for the machines. This is done by formulating the problem as an *integer programming problem* as opposed to a *linear programming problem*. However, in reality, integer programming problems are often difficult to solve optimally.

Solver allows us to add additional constraints that are integers. For example, we could add three more constraints, one each for the machines, stating they need to be integers.

FIGURE 15A Entering relevant data into Microsoft Excel for solving a LP problem using Solver



Production Planning Problem for the manufacturer

Number of shifts per day	1	
Number of hours per shift	8	
Products	Castings	Cylinders
Contribution (Rs. per unit)	115.00	146.00

	Minutes per unit			Minutes	Minutes
Machine Requirements & Availability Details	Reqt. for Castings	Reqt. for Cylinders	Available machines	Daily Availability	Requirement as per plan
CNC Lathe	14	17	4	1,920.00	1,920.00
Grinding Machine	15	22	5	2,400.00	2,400.00
Milling Machine	18	20	5	2,400.00	2,300.38

Daily production plan	
Castings	27.17
Cylinders	90.57
Total Contribution for the plan	16,347.17

FIGURE 15B Entering the mathematical formulation in the Solver screen

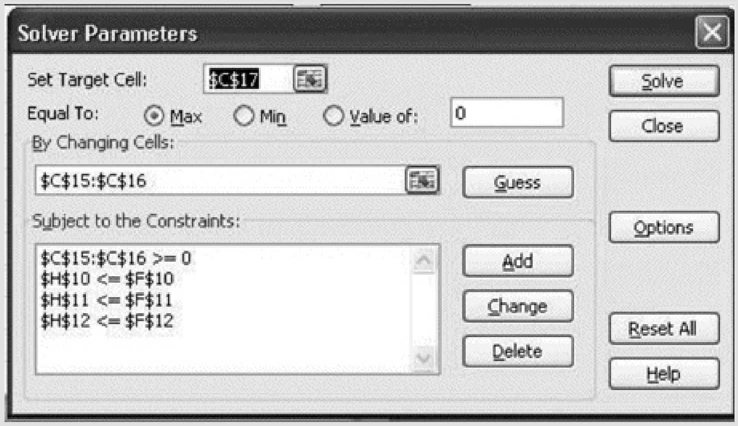


FIGURE 15C Screen for Solver results

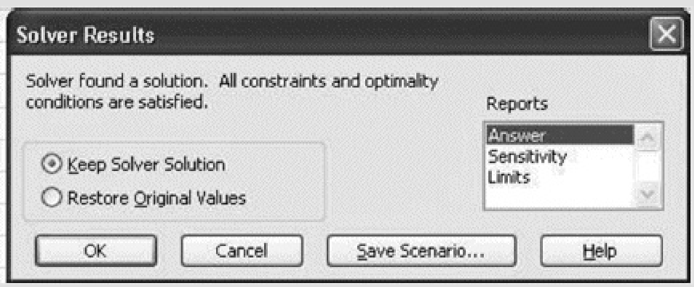


FIGURE 15D The Report Showing the Results of the Lp Solution

Microsoft Excel 12.0 Answer Report
Worksheet: [Linear Programming.xls]Sheet1
Report Created: 10/1/2009 11:22:31 AM

Target Cell (Max)

Cell	Name	Original Value	Final Value
$C$17	Total Contribution for the plan Reqt. for Castings	16,347.17	16,347.17

Adjustable Cells

Cell	Name	Original Value	Final Value
$C$15	Castings Reqt. for Castings	27.17	27.17
$C$16	Cylinders Reqt. for Castings	90.57	90.57

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$H$12	Milling Machine Requirement as per plan	2,300.38	$H$12<=$F$12	Not Binding	99.62264151
$H$10	CNC Lathe Requirement as per plan	1,920.00	$H$10<=$F$10	Binding	0
$H$11	Grinding Machine Requirement as per plan	2,400.00	$H$11<=$F$11	Binding	0
$C$15	Castings Reqt. for Castings	27.17	$C$15>=0	Not Binding	27.17
$C$16	Cylinders Reqt. for Castings	90.57	$C$16>=0	Not Binding	90.57

Introducing this constraint and solving the problem results in the following solution:

The optimal solution for the integer programming problem is as follows:
Number of Machine 1 to be procured: 3
Number of Machine 3 to be procured: 1
Total investment cost: ₹6.55 million
Consequently, the daily packaging capacities are:
Product A: 1320 units
Product B: 1896 units
Product C: 952 units

Applications of LP

Linear programming (as we have seen above) is a generic solution methodology. Therefore a wide range of applications is possible using LP. This includes addressing several operations management problems, advertising and media selection, inventory control, capital budgeting, and a host of other situations. Specifically, in operations management, LP is used often for the following problems:

- *Production planning*: One of the frequent applications of LP is in the area of production planning. Typically, aggregate production plans and monthly/weekly production planning could be done using LP. While the production plan is done several constraints need to be taken into consideration including the minimum demand to be met, the availability of machine capacity, and the availability of raw materials. This can be modelled using LP.

EXAMPLE 15B

A consumer-goods manufacturing company producing three final products needs to decide on the capacity investment with respect to a new automated packaging/assembly line that it is designing. There are three types of packaging machines available and each one of them can pack the three products, albeit in varying capacities per hour. The shop works for 8 hours a day. While certain minimum demand requirements are to be met, the exact amount of packaging capacity to be invested needs to be finalized. Any additional production could be sold in the market as there is adequate demand for the products. The relevant details for the problem are summarized in Table 15B:

Formulate the problem and obtain an optimal investment plan.

Solution

Mathematical formulation of the problem

Let X_1 be the number of machines of type 1 to be procured

Let X_2 be the number of machines of type 2 to be procured

Let X_3 be the number of machines of type 3 to be procured

Since this is an investment decision, our objective will be to minimize the investment subject to meeting the minimum daily demand of the products. The packaging capacity of the machines given in the table is per hour. We need to multiply them by 8 to get the daily packaging capacity. Based on these assumptions, the complete mathematical formulation of the problem is as follows:

Total investment cost $Z = 1.65 \times X_1 + 2.12 \times X_2 + 1.60 \times X_3$

Min (Z)

Subject to:

$360X_1 + 480X_2 + 240X_3 \geq 1100$ (Demand constraint for Product A)

$560X_1 + 416X_2 + 216X_3 \geq 1700$ (Demand constraint for Product B)

$208X_1 + 224X_2 + 328X_3 \geq 900$ (Demand constraint for Product C)

$X_1, X_2, X_3 \geq 0$ (Non-negativity constraint)

One can use Microsoft Excel to solve this problem as explained in the previous example. Figures 15E, 15F, and 15G show the relevant Solver details and the final solution.

The optimal solution is as follows:

Number of Machine 1 to be procured: 2.62

Number of Machine 3 to be procured: 1.08

Total investment cost: ₹6.05 million

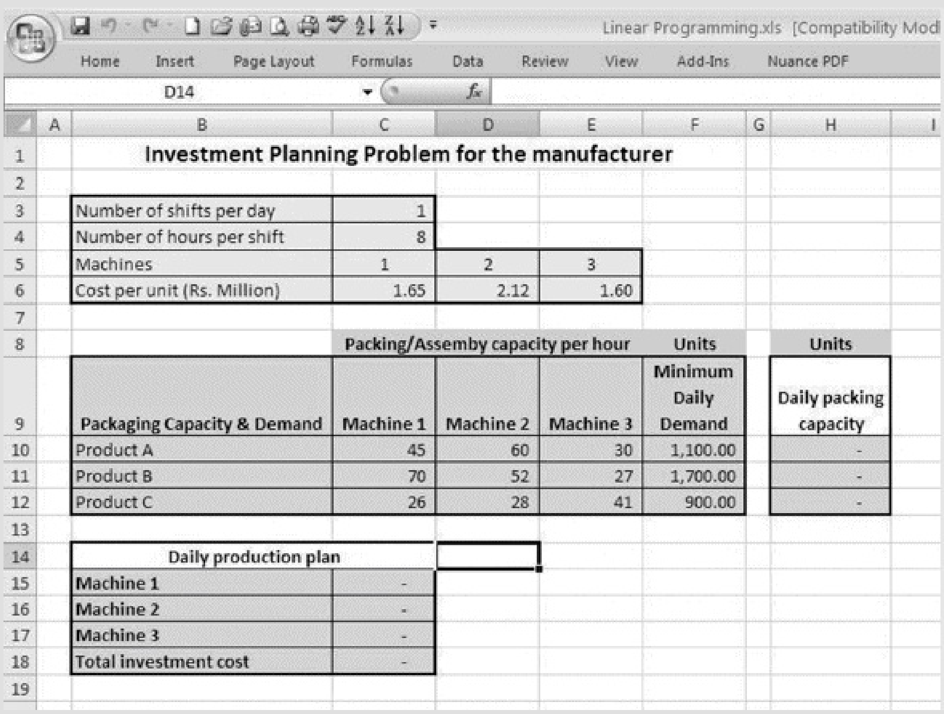
Consequently the daily packaging capacities are:

Product A: 1202.49 units
Product B: 1700 units
Product C: 900 units

TABLE 15B Data for Example 15B

	Packaging Capacity Per Hour			Minimum Daily Demand to be Met
	Machine 1	Machine 2	Machine 3	
Product A	45	60	30	1100
Product B	70	52	27	1700
Product C	26	28	41	900
Cost of the machine (in ₹millions)	1.65	2.12	1.60	

FIGURE 15E The Input Data for the Problem



	A	B	C	D	E	F	G	H
1		Investment Planning Problem for the manufacturer						
2								
3		Number of shifts per day	1					
4		Number of hours per shift	8					
5		Machines	1	2	3			
6		Cost per unit (Rs. Million)	1.65	2.12	1.60			
7								
8			Packing/Assemby capacity per hour			Units		Units
9		Packaging Capacity & Demand	Machine 1	Machine 2	Machine 3	Minimum Daily Demand		Daily packing capacity
10		Product A	45	60	30	1,100.00		-
11		Product B	70	52	27	1,700.00		-
12		Product C	26	28	41	900.00		-
13								
14		Daily production plan						
15		Machine 1	-					
16		Machine 2	-					
17		Machine 3	-					
18		Total investment cost	-					
19								

FIGURE 15F LP Formulation Details in Solver

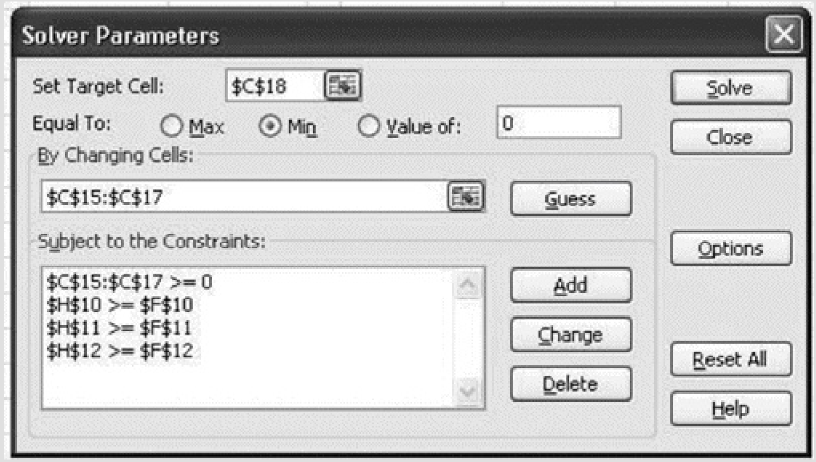
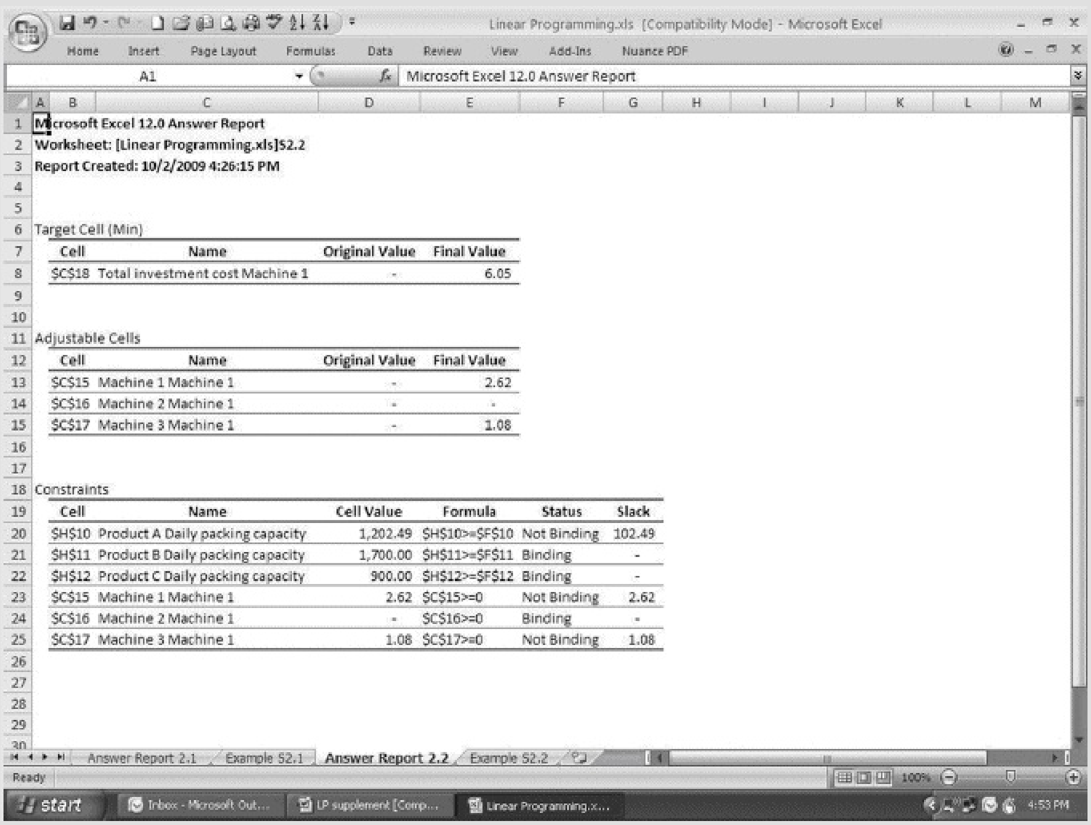


FIGURE 15G Optimal Solution to the Problem



Microsoft Excel 12.0 Answer Report
Worksheet: [Linear Programming.xls]S2.2
Report Created: 10/2/2009 4:26:15 PM

Target Cell (Min)

Cell	Name	Original Value	Final Value
$C$18	Total investment cost Machine 1	-	6.05

Adjustable Cells

Cell	Name	Original Value	Final Value
$C$15	Machine 1 Machine 1	-	2.62
$C$16	Machine 2 Machine 1	-	-
$C$17	Machine 3 Machine 1	-	1.08

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$H$10	Product A Daily packing capacity	1,202.49	$H$10>=$F$10	Not Binding	102.49
$H$11	Product B Daily packing capacity	1,700.00	$H$11>=$F$11	Binding	-
$H$12	Product C Daily packing capacity	900.00	$H$12>=$F$12	Binding	-
$C$15	Machine 1 Machine 1	2.62	$C$15>=0	Not Binding	2.62
$C$16	Machine 2 Machine 1	-	$C$16>=0	Binding	-
$C$17	Machine 3 Machine 1	1.08	$C$17>=0	Not Binding	1.08

- *Capacity planning*: As we have seen in one of the numerical examples above LP could be used to address the issue of investment decisions pertaining to capacity additions. Further, based on certain capacity constraints, several operational planning decisions could be modelled using LP.
- *Supply Chain Management*: Logistics and distribution problems, inventory planning, and materials management problems are amenable for LP modelling. Typically, transportation and assignment models are used to study logistics and distribution problems. Cutting-stock algorithms are frequently used to optimally make use of materials in several industries such as textiles, steel, and paper. In addition, lot sizing problems, economic order quantities

and a host of other inventory planning problems could be studied using and LP.

Use of Software for LP Modelling

Because of its wide applicability, a number of computer-based applications have been developed to solve LP problems. We have used the Excel Solver to demonstrate the usefulness of LP modelling. However, some of the other popular applications include MATLAB, LINDO, LINGO and GAMS. Software applications provide much useful information and relieve the user from the tyranny of going through matrix inversion operations, which is the standard practice in solving any LP problem. Furthermore, software applications also enable the user to analyse problems using integer and non-linear programming techniques so that alternate modelling mechanisms can be tried out without much effort.

Therefore, developing the ability to formulate a problem accurately can go a long way in obtaining sensible and feasible solutions using the software available for LP modelling. Furthermore, developing good conceptual understanding of some of the post-analysis aspects such as sensitivity analysis, dual prices, and Lagrangian multipliers will be very valuable in effectively using the available software for mathematical programming, including LP modelling.

SUMMARY

- Typically, in any business situation, managers face constraints with respect to several resources.
- Understanding how to make the best use of the available resources while meeting certain objectives such as maximizing production is very important. Linear programming is a methodology which helps an operations manager to address the problems that he/she faces in planning the operations in the system.
- *Linear programming* (*LP*), as the name implies, is a methodology in which linear relationships between various elements in the system can be modelled to study the behaviour of the system and to identify the best set of decisions that one should make in order to optimize the performance of the system while taking into consideration the constraints that one faces in the system.
- Before formulating the problem, it is important to understand the decisions to be made (decision variables), the constraints, and the performance measures for which the decision is being made (objective function).
- Using LP as a modelling tool also implies the linearity of all relationships between various elements that are being studied, as well as the non-negativity of the decision variables used in the modelling exercise.
- A number of computer packages are available today to solve a well-formulated LP problem. Therefore, developing adeptness in formulating the problem will be more valuable than developing the skills used in actually solving the problem using a known solution methodology.
- Linear programming could be used to model several operations: management problems, advertising and media selection, inventory control, capital budgeting, and a host of other situations.

REVIEW QUESTIONS

1. What are the conditions under which one can model a problem using LP?
2. Suppose there are “n” decision variables to be studied and there are “m” constraint equations. Can you write a generic mathematical formulation for such a problem using some standard notations?
3. Identify three advantages of using the Microsoft Excel solver for solving LP problems.
4. Suppose you successfully solved a problem using the Microsoft Excel server. How will you use the output obtained from the solver?

PROBLEMS

1. A large manufacture of petrochemicals in the country wants to address the issue of emission of pollutants into the atmosphere. The company is planning to install anti-pollution devices. The company makes two products HC1 and HC2; in each of these products, the manufacturing process yields excessive amounts of irritant gases. Table 15C shows the daily emission of each pollutant for every 1000 litres of product manufactured. The company is prohibited from using W1, W2 and W3 kg of sulphur dioxide (SD), carbon monoxide (CM) and nitric oxide (NO). The profit for each 1000 litres of Products 1 and 2 manufactured is P1 and P2.

   TABLE 15C Data for Problem 1

Kg emitted per 1000 litres of		
Type of gas	**HC1**	**HC2**
SD	24	36
CM	8	12
NO	100	50

   The production manager has approved the installation of two anti-pollution devices. The first removes 75% of the gas CM, 50% of the gas SD, and 90% of the gas NO, regardless of the product manufactured. The second device removes 33% of the gas CM, 10% of the gas SD and the 60% of Gas NO for Product 2. The variable cost of the first device per 1000 litres manufactured is C1 regardless of the product; similarly the variable cost of the second device is C2. Sales commitments dictate that at least Q1 thousand litres of HC1 and Q2 thousand litres of HC2 be manufactured.

   Formulate an appropriate LP model.

2. A Logistics service provider needs to augment its fleet and has a budgetary allocation of ₹40 million. It is contemplating three types of vehicles. Vehicle A has a 10-ton pay load and is expected to average 25 kmph. It costs ₹1.6 million. Vehicle B has a 20-ton pay load and is expected to average 15 kmph. It costs ₹2.6 million. Vehicle C is a modified version of Vehicle B; it carries sleeping quarters for one driver, and this reduces the capacity to 18 tons and raises the cost to ₹3.0 million. Vehicle A requires a crew of one man, and if driven on three shifts per day, could be run for an average of 18 hrs. Vehicles B and C require a crew of two men each, but whereas B would be driven 18 hrs per day with three shifts, C could average 21 hrs per day. The Company has 150 drivers available per day and would find it difficult to obtain further crews. Maintenance facilities are such that the total number of vehicles must not exceed 30. Formulate this problem in order to find out the number of vehicles to be purchased to maximize the capacity in ton-km per day.
3. Formulate the following problem as an LP and solve using Solver.

   A firm produces an alloy that is made from steel and scrap metal. The cost per ton of steel is ₹1050 and that of scrap is ₹820. The technological requirements for the alloy are: (i) a minimum of one ton of steel is required for every two tons of scrap, (ii) one hour of processing time is required for each ton of steel and four hours of processing time for each ton of scrap, and (iii) the steel and scrap combine linearly to make the alloy. The process loss from steel is 10% and the loss from scrap is 20%. Although production may exceed demand, a minimum of 40 tons of the alloy must be manufactured. To maintain efficient plant operation, a minimum of 80 hours of processing time must be used. The supply of both scrap and steel is adequate for the production of the alloy. The objective is to produce the alloy at a minimum cost.

4. A certain farming organization operates three farms of comparable productivity. The output of each farm is limited by the usable area and by the amount of water available for irrigation. The data for the upcoming seasons are given in Table 15D.

TABLE 15D Data for Problem 4

	Usable Area (Acres)	Water Available Farm (Kilolitres)
1	400	1,500
2	600	2,500
3	300	900

The organization is considering three crops for planting which differ primarily in their expected profit per hectare and in their consumption of water. Furthermore, the total area that can be devoted to each of the crops is limited by the amount of appropriate harvesting equipment available. Their acreage, water consumption, and expected profit are given in Table 15E.

TABLE 15E Data on Crop Yields for Problem 4

Crop	Maximum Area (Acres)	Water Consumption Per Acre (Kilometres)	Expected Profit Per Acre (in ₹)
A	700	5	4000
B	800	4	3000
C	300	3	1000

It is the policy of the organization that the percentage of useable area planted must be the same at each farm. However, any combination of the crops may be grown at any of the farms. The organization wishes to know how much of each crop should be planted at the respective farms in order to maximize the expected profit.

What is the optimal cropping pattern to be adopted by the organization?

SUGGESTED READINGS

- A. Ravindran, D. T. Philips, and S. Solberg, *Operations Research: Principles & Practice,*, 2nd edition (n.p.: Wiley India Pvt. Ltd., 2007).
- G. Srinivasan, *Operations Research: Principles & Applications* (New Delhi: Prentice Hall of India Pvt. Ltd, 2007).
- H.A. Taha, *Operations Research: An Introduction*, 8th edition (New Delhi: Prentice Hall Inc, 2008).

CHAPTER 16

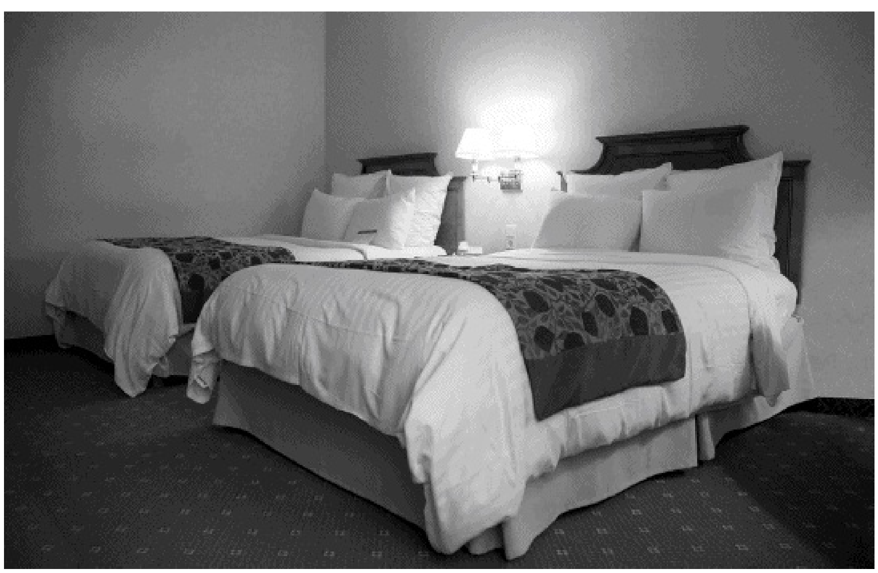
Resources Planning

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- Why is it important to adopt a different planning methodology for inventory control of dependent demand items?
- What are the basic building blocks of the materials planning methodology?
- What are the steps involved in the materials requirement planning (MRP) methodology?
- How is capacity planning done in organizations and what is its relationship with MRP?
- What is the relationship between MRP and modern-day enterprise resources planning (ERP) systems?

Two types of inventories exist in an operating system—operating inventory and distribution inventory. Operating inventory includes all the resources that are available for the operating system to consume in the production process. Distribution inventories are meant for market consumption. The number of hotel rooms to be made available is an example of distribution inventories.



Source: stock.xchng

ideas at Work 16.1

ERP Implementation at HPCL

Hindustan Petroleum Corporation Limited (HPCL) is a Fortune 500 company with an annual turnover of over ₹914.48 million for the financial year ended March 2007. The company has successfully implemented JD Edwards EnterpriseOne ERP spanning about 400 locations and 4,000 employees across the nation.

The ERP implementation programme was started in 2000. The availability of sound technical infrastructure was necessary for implementing such a large initiative. This meant building a centralized data centre where the servers and applications could be hosted as well as having efficient connectivity for all locations spread across India’s geography. Around 400 locations were completed over a period of two and a half years. As each location was selected for inclusion, the related infrastructure (like WAN, lease lines, VPN and VSATs) was built simultaneously depending on the availability.

As HPCL enjoys a national presence, it was important to determine the path for the ERP roll-out. Several business processes were analysed for determining the points affecting the process look. The project was kicked off by a 25-member in-house team comprising representatives from all functional areas. After the completion of the first phase of the project, which included system configuration, more employees were inducted into the team and its size expanded to 100 people. In addition to this, a team of 100 consultants was also working on it.

The locations due for the “Go-Live” stage in a particular month were given top priority and a “work backwards” system was followed to arrive at separate tasks and their deadlines for those locations. These tasks included the procurement of hardware, applications for communication links, and testing and liaisoning with local people at the location.

Post-implementation, the company noticed substantial improvement in efficiency. For example, before the implementation, the annual financial accounts closure would take approximately a month while the monthly closing would take 15 to 20 days. In 2007-08, the monthly and quarterly closing was completed in about five days while the annual closing took a mere 10 to 12 days.

The second major benefit of the centralized ERP implementation was that it compelled the company to look at various other services that could be offered to customers with the help of IT. It was also realized that they could improve transparency by making more information available to their customers, vendors, and transporters on a real-time basis. With the help of the Web, they can log in and check the status of loads, orders, and payments.

The implementation gave the company an opportunity to relook at all its business processes from the beginning. Several processes in manufacturing, planning, procurement, and employee benefits that were earlier done manually were automated. The ERP enabled the generation of various day-end MIS reports on a regular basis. This helped to revamp the way in which reporting was done to the top management.

HPCL's ERP implementation can potentially provide several clues to other large organizations wishing to derive benefits from ERP/IT adoption.

Source: Based on Abhishek Raval, "HPCL Refines Business Process with ERP Implementation," accessed at http://biztech2.in.com/india/casestudies/enterprise-solutions/hpcl-refines-business-processes-with-erp-implementation/28091/0.

Material requirements planning (MRP) is a computerized planning system developed during the 1960s to address the vexing problem of high inventories in manufacturing organizations. Before the introduction of MRP systems, organizations were using the same methodology for controlling all types of inventories. However, MRP systems drew the attention of managers to the fact that the planning of requirements for production, such as raw material and work in progress, require a different approach from that used for managing finished goods. MRP systems exploit certain unique characteristics of the production items. They utilize information on lead time, inventory status, and master production schedule to ensure production items are available at the time of requirement. In this chapter, we will try to understand the logic behind MRP systems. We will also see how the idea applied to controlling materials could be extended to other resources required in any operations system. The culmination of this interesting extension of the MRP logic are the modern-day enterprise resources planning (ERP) systems that serve as the backbone of the IT-enabled strategic planning and control in any operations system. Therefore, these planning methodologies can be broadly defined as resources planning.

Material requirements planning (MRP) is a computerized information system that aids the planning of materials in manufacturing organizations.

Before we discuss the issues in resources planning, it will be useful for us to understand the key differences between the two types of inventories that exist in an operations system. The first is called **operating inventory**. This includes all the resources (broadly of material and capacity) that are available for the operating system to consume in the production process. Consider an automobile manufacturer such as Hyundai. The inventory of tyres available in the stores is meant for satisfying the production requirements. If Hyundai has 4,000 tyres suitable for its Santro model at the beginning of the shift, it can assemble 1,000 Santros during the shift (we do not count the extra tyre provided as standby in this computation). Similarly, if it takes 1.5 hours to paint an assembled car at the paint shop, the capacity of paint shop required for 1,000 Santros is 1,500 hours. There is no statistical estimation involved in arriving at the number of Santros that Hyundai can assemble on that day or the capacity required at the paint shop.

Operating inventory includes all the resources (broadly of material and capacity) that are available for the operating system to consume in the production process.

On the other hand, operations systems carry another type of inventory known as *distribution inventory*. Distribution inventories are meant for market consumption. In our example, finished Santros waiting for dispatch belong to the distribution inventory. If the distribution inventory of Santros is 1,000, we cannot come to the conclusion that 1,000 Santros will indeed be sold. It depends on the demand in the open market and may be subject to statistical fluctuations. Unlike the operating inventory, it requires alternative estimation techniques to approximately guess the number of Santros likely to be demanded on that day.

One can give similar examples in the service system as well. Consider a hotel in the Andheri area of Mumbai. The number of rooms to be made available and the number of people to be served lunch and dinner are examples of distribution inventories. On the other hand, the amount of raw materials made available for use in the kitchen and the number of waiters and housekeeping staff deployed in the hotel on that day are examples of operating inventories.

Look at the converse of the problem we just discussed. How do we decide how much inventory to carry? In the case of operating inventories, it is a matter of using arithmetic to arrive at this decision, whereas in the case of distribution inventories, the decision is a little more complex. In other words, while it is difficult to decide how many Santros to assemble on a particular day, it is very easy to compute the exact number of tyres required on that day once we have decided on the assembly schedule. In this chapter, we focus our attention on operating inventories and developing a methodology to help managers plan for these inventories. Planning for intermediate components and raw material/bought-out items using this methodology is known as materials requirement planning. However, one can extend this idea of planning to capacity and other resources in an operating system. Therefore, we broadly define this methodology as resources planning. We will discuss the planning issues pertaining to distribution inventories in the next chapter.

16.1 DEPENDENT DEMAND ATTRIBUTES

Why should a manager address planning issues associated with operating inventories differently from those associated with distribution inventories? In order to answer this question, we need to know more about the demand attributes of these inventories. As we have already discussed, operating inventories have dependent demand. Distribution inventories, on the other hand, have independent demand. All other differences stem from this attribute of demand.

The foremost difference stems from the nature of the demand. There is no uncertainty in a dependent demand item. Moreover, the demand is lumpy, manifesting at specific points in time in response to a requirement in the system. Consider the domestic fan manufacturer, Crompton Greaves Limited. If Crompton Greaves decides to produce 20,000 fans in May 2014, the number of blades that it requires is 60,000 (since each assembled fan is fitted with three blades). Going one step further, if each blade consumes two hours of machine time, 350 g of a grade of steel, and 50 ml of paint, then it requires 120,000 machine-hours, 21,000 kg of steel, and 3,000 litres of paint if it were to manufacture the 60,000 blades during the month. In this example, we notice that a parent–child relationship between inventories causes the dependency. The same cannot be said in the case of independent demand items.

Due to certainty, the goal for a planning manager is to make the dependent demand items available to exactly match the requirement. It is feasible to attain a 100 per cent service level in this case. On the other hand, due to uncertainty, independent demand items cannot be made available at a 100 per cent service level. The extra inventory required increases substantially as we approach 100 per cent service level in this case. Therefore, managers plan for a certain targeted service level in the case of independent demand items.

Since dependent demand items exhibit some structure and have a causal relationship with other items in the system, it is possible to estimate the demand by appropriate planning methodologies. Moreover, as our example demonstrated, it is possible to accurately estimate how much to order. These issues are far more complex in the case of independent demand items. However, in the case of dependent demand items, the timing of the order is very crucial. This is because the dependency relationship among the items requires that items arrive exactly at the required time. Otherwise, shortage and schedule slippages could cascade through the system and create severe schedule disruptions. Table 16.1 lists the key differences between dependent demand and independent demand items.

> Since dependent demand items exhibit some structure and have a causal relationship with other items in the system, it is possible to estimate the demand through simple planning methodologies.

TABLE 16.1 Key Differences Between Dependent Demand and Independent Demand Items

Attribute	Dependent Demand	Independent Demand
Nature of demand	No uncertainty; dependent; parent–child relationships cause dependency	Considerable uncertainty, independent
Goal	Make resources availability meet requirements exactly	Make availability meet estimated demand for a targeted service level
Service level	100% service level a necessity, feasible to achieve	100% service level not feasible
Demand occurrence	Often lumpy	Often continuous
Estimation of demand	By production planning	By forecasting
How much to order?	Known with certainty	Estimate based on past consumption
When to order?	Very critical, can be estimated	Cannot be answered directly

16.2 PLANNING A FRAMEWORK: THE BASIC BUILDING BLOCKS

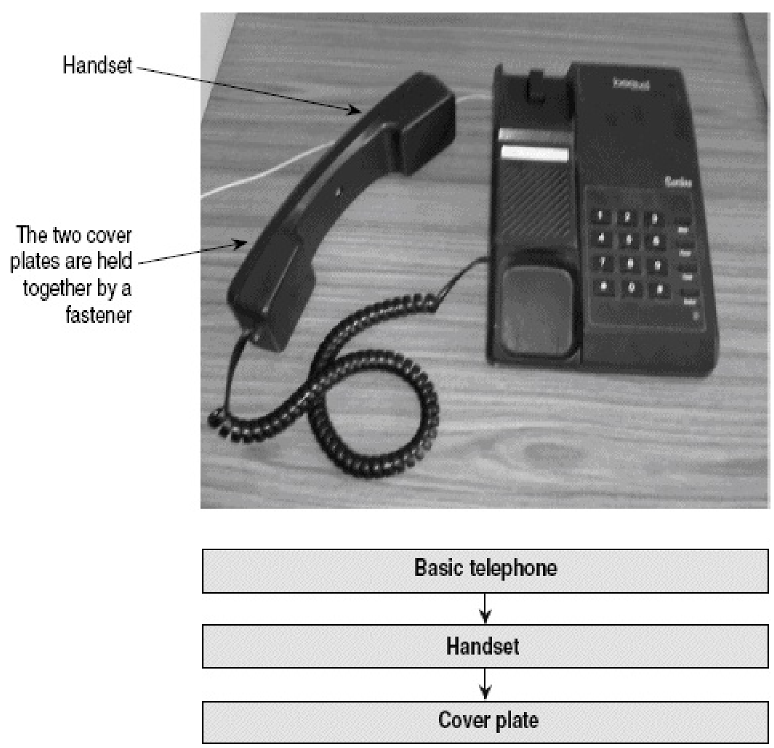
Before we unfold the planning methodology for dependent demand items, let us look at the following aspects of the planning framework: (a) multiple levels of dependency, (b) the product structure–the bill of materials (BOM), (c) time-phasing the requirement, (d) determining the lot size, (e) incorporating lead-time information, and (f) establishing the planning premises.

Multiple Levels in Products

Clearly, a parent–child relationship in dependent demand items causes dependency. In reality, multiple levels of relationships exist in a product. While computing the requirement for an item, it is important that we proceed level by level. Otherwise, the amount of inventory that we make available will be different from what is required. Let us study the example of a basic telephone instrument to illustrate this idea. As shown in Figure 16.1, the telephone instrument consists of a base unit and a handset. The handset has a speaker and a microphone and is covered by a pair of cover plates firmly held together using a pair of screws. There is a wire that connects the handset to the base unit. In this simple example, let us consider the parent–child relationship.

Let us assume that we have in stock an inventory of 30 telephones, 27 handsets and 16 cover plates. Suppose that we want to plan for the production of 100 telephones during the next week. How much inventory do we need in each of these components? One method is to merely subtract the on-hand inventory from the requirement at each level to arrive at this number (see Method A in Figure 16.2). Another method is to proceed level by level in the computation. In this method, after computing the requirement at one level, we use the parent–child relationship to compute the requirement at the next level (see Method B in the Figure 16.2).

FIGURE 16.1 A telephone instrument



This iterative process of computing all requirements at a particular level and then moving down one level is known as an **explosion** in resources planning literature.

As we see in Figure 16.2, both the methods result in different numbers. However, the second calculation truly depicts the requirement. Let us understand this using another kind of logic. Every item in an operating inventory exists on its own and as part of its parent. For instance, in addition to 16 units of on-hand inventory of cover plates, 54 more exist in the assembly of 27 handsets and another 60 in the assembly of 30 basic telephones. Therefore, the total inventory already on hand is 130 (60 + 54 + 16 = 130). Since 100 telephones are required, only 70 more cover plates are needed.

FIGURE 16.2 Methods for calculating inventory requirement

Method A	
Basic Telephone	
Required	100
On-hand inventory	30
Planned quantity	70
Handset	
Required	100
On-hand inventory	27
Planned quantity	73
Cover Plate	
Required	200
(Each handset requires two cover plates)	
On-hand inventory	16
Planned quantity Manufacturing	184

Method B		
Basic Telephone		
Required	CMR	100
On-hand inventory		30
Planned quantity		70
Handset		
Required		70
On-hand inventory		27
Planned quantity		43
Cover Plate		
Required		86
(Each handset requires two cover plates)		
On-hand inventory		16
Planned quantity		70

Therefore, it is clear that while planning for operating inventories, we need to proceed on a level-by-level basis. This iterative process of computing all requirements at a particular level and then moving down one level is known as an **explosion** in resources planning literature.

Product Structure

As it is important to compute the requirement level by level, an unambiguous definition of the levels is crucial. For this, knowledge of the product structure is important. In any product, the final assembly stage puts several major assemblies together. In order to understand this, let us look at a typical fountain pen. Figure 16.3 shows an exploded view of a fountain pen. The various components that go into one fountain pen, their exact specifications, and the quantity required for assembling every fountain pen can be arrived at from Figure 16.3.

Let us return to our example of the basic telephone instrument. If we disassemble the telephone instrument progressively, we will be able to understand the product structure. In our example, two assemblies and two components make up the final product: the base unit assembly, the handset assembly, a connecting cable, and a pair of jacks to connect the ends of the cable with the base unit and the handset.

At the next level, we can identify the sub-assemblies that make up each assembly. The base unit assembly consists of the operating unit (consisting of the basic circuitry and processor), the panel board (consisting of the buttons to dial the numbers), the control panel (consisting of controls for volume, pulse/tone settings etc.), a pair of cover plates, four lugs (to support the instrument on any surface), and four screws to cover the entire unit using the base plates form the next level. One can similarly identify all the components and proceed downwards until we reach the basic raw material/bought-out components. The resulting graphical structure is the product structure. Figure 16.4 shows the product structure for the basic telephone unit. When common items appear in more than one level, they must be represented at the lowest level of their appearance. This is known as low level coding. In our example, the item “screw” appears at Level 2 and Level 4, but we have represented them at Level 4. Low level coding does not alter the logic behind planning for the requirement but merely serves to improve the efficiency of processing.

> The product structure graphically depicts the dependency relationships among various items that make up the final product.

The product structure graphically depicts the dependency relationships among various items that make up the final product. Every level in the product structure has a parent relationship with those below it. In Figure 16.4, the numbers in parentheses show the number of items at a particular level needed to assemble one unit of its parent. Thus, 12 buttons and 12 screws are required to make one button assembly. Similarly, one speaker, one microphone, two cover plates, and two screws make up one handset.

FIGURE 16.3 The product structure of a typical fountain pen

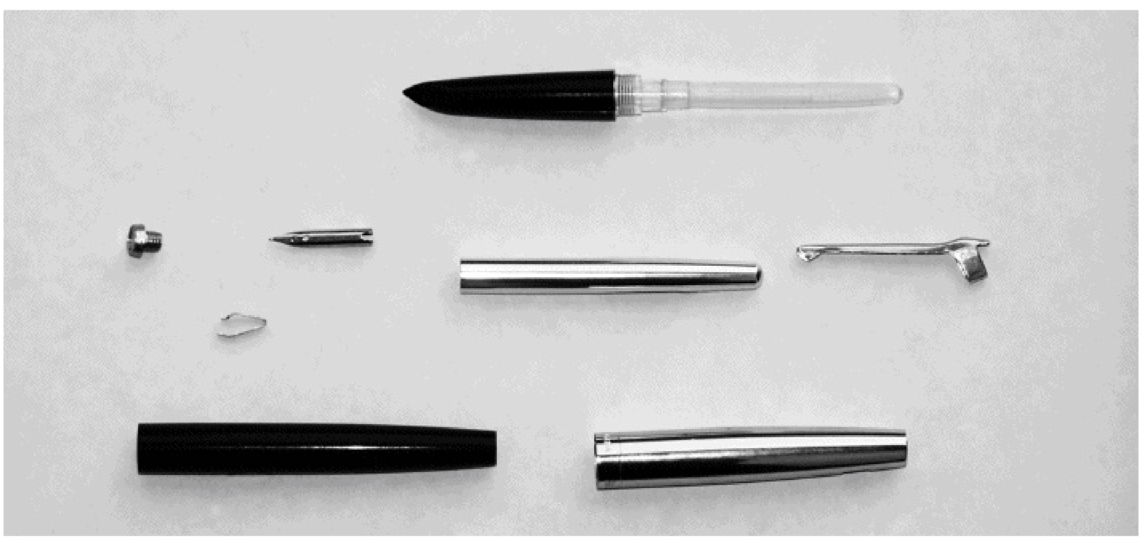
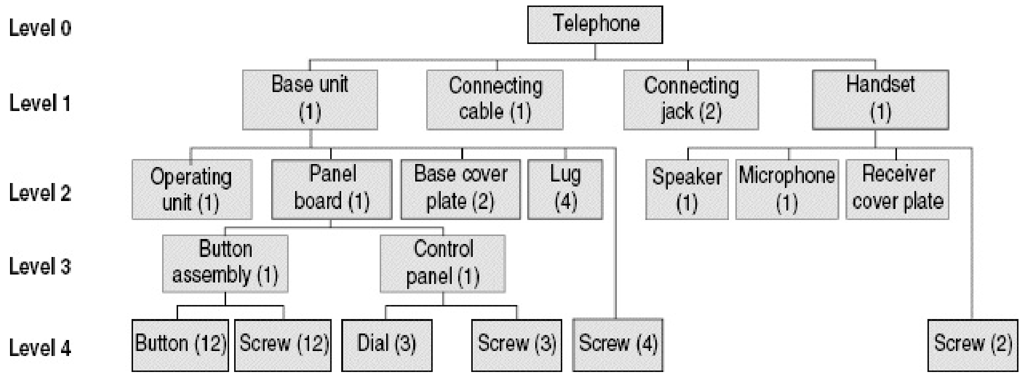


FIGURE 16.4 The product structure of a telephone



EXAMPLE 16.1

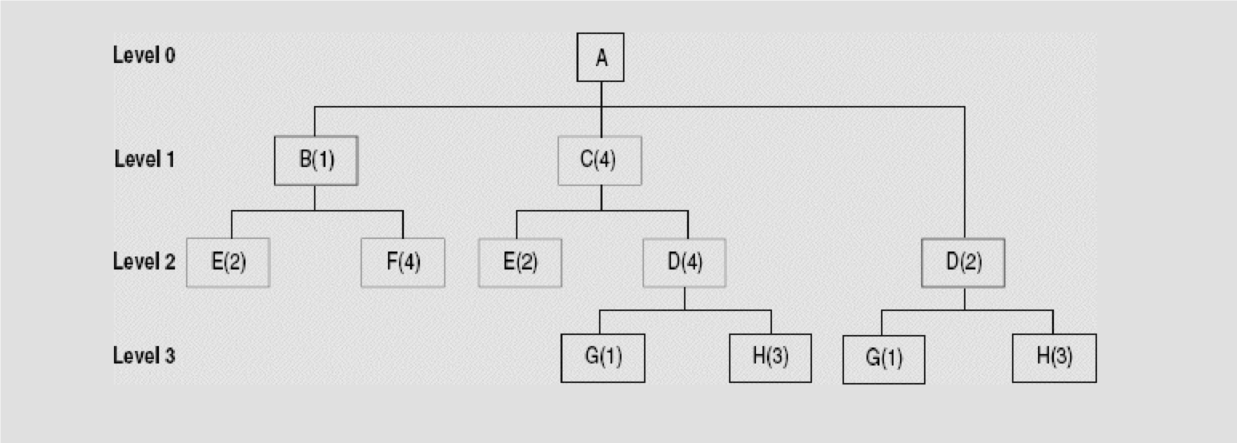
Consider a product, code-named A, manufactured by a company. Product A is made of three Sub-assemblies B, C, and D. One unit of B, four units of C, and two units of D are required for assembling one unit of Product A. Sub-assembly B is made of two units of E and four units of F. Sub-assembly C is made of two units of E and four units of D, whereas Sub-assembly D is made of one unit of G and three units of H.

a. Develop a product structure for Product A.
b. How many units of D are required to manufacture 10 units of A?
c. Will the answers change if there is already an inventory of 10 units each of C and D?

Solution

a. From a description of the product and its sub-assemblies, we note that Item D occurs at two different levels. Therefore, we employ low-level coding for Item D. The product structure is shown in Figure 16.5. The product has three levels.
b. If we assume that no inventory of sub-assemblies or the end product exists in the system, then the number of D's required is computed as follows:
   Number of C's required for assembling 10 units of A: 40
   Number of D's required for assembling 40 units of C: 160
   Number of D's required for assembling 10 units of A: 20
   Therefore, the total number of D's required for manufacturing A = 180
c. Since an inventory of the intermediate sub-assemblies exists, it is important to compute the number of D's required using a level-by-level approach.
   Number of C's required for assembling 10 units of A: 40
   Number of C's already available: 10
   Net requirement of C's: 30
   Number of D's required for assembling 30 units of C: 120
   Number of D's required for assembling 10 units of A: 20
   Total requirements of D's: 140
   Number of D's already available: 10
   Net requirement of D's for assembling 10 units of A: 130

FIGURE 16.5 The product structure



Since knowledge of the dependency is fundamental to planning operating inventories, the product structure is very important. However, in several real-life examples, it is not possible to represent the dependency information in the form of a product structure. This is because the number of components that make up a final product could be numerous and the number of levels involved could also be many. Instead, one can represent this information using a standard data structure. Such a structure is known as the *bill of materials (BOM)*.

The Bill of Materials (BOM)

A **bill of materials** is a list of all the parts, ingredients, or materials required to assemble or put together one unit of a product. A BOM essentially consists of the complete list of each part in the product structure, the components that are directly used in the part, and the quantity of each component needed to make one unit of that particular part. The data set also includes a short description and the unit of measure for each part. Clearly, a BOM is an alternative representation of a product structure. It provides an efficient methodology to represent complex product structures having multiple levels and numerous items. Codes are used to denote the level at which the item occurs in the product structure, and the number the parent requires to assemble one unit.

> The **bill of materials** is a list of all the parts, ingredients, or materials required to assemble or put together one unit of a product.

A variety of formats are available for BOMs. The simplest format is the *single-level BOM*. It consists of a list of all components that are directly used in a parent item. An *indented BOM* is a form of multi-level BOM. It exhibits the final product as Level 0 and all its components as Level 1. The level numbers increase as you proceed down the tree structure. If an item is used in more than one parent within a given product structure, it appears more than once, under every sub-assembly in which it is used. A third variation is the *modular BOM*. Modular BOMs are very useful to represent product structures with several varieties.

In the telephone example, let us assume that four different colours (grey, blue, black, and beige) are available. Further, let us assume that three different control panels (simple, deluxe, and elegant) and four different memory settings (20-call memory, 50-call memory, 100-call memory and 250-call memory) are available. This means that we can make 48 (4 × 3 × 4) unique offerings to the customer. Therefore, we need 48 different BOMs to represent each variant. One way to solve this problem is to have a modular BOM. By picking up one variation for each of the three attributes, it is possible to construct one unique BOM for the purpose of planning. In several other cases such as automobiles and IT hardware, the number of unique offerings could be as high as 250,000 considering the numerous options available for each variation. In such situations, it is prudent to use a modular BOM. Table 16.2(a), (b), and (c) illustrate the alternative BOMs for our telephone example.

TABLE 16.2(a) A Single-Level BOM for a Telephone Instrument

Item Code	Item Description	UOM	Quantity per Product
1000	Basic telephone	Each	1
1010	Base unit assembly	Each	1
1020	Handset assembly	Each	1
1030	Connecting cable	Metre	1
1040	Connecting jack	Each	2
1050	Speaker	Each	1
1060	Microphone	Each	1
1070	Receiver cover plate	Each	2
1080	Panel board assembly	Each	1
1090	Operating unit	Each	1
1100	Lug	Each	4
1110	Base cover plate	Each	2
1120	Button assembly	Each	1
1130	Control panel assembly	Each	1
1140	Buttons	Each	12
1150	Control dials	Each	3
1160	Screw	Each	21

TABLE 16.2(b) An Indented BOM for a Telephone Instrument

Level	Item Code	Item Description	UOM	Quantity per Product
0 - - - -	1000	Basic telephone	Each	1
- 1 - - -	1010	Base unit assembly	Each	1
- - 2 - -	1080	Panel board assembly	Each	1
- - - 3 -	1120	Button assembly	Each	1
- - - - 4	1140	Buttons	Each	12
- - - - 4	1160	Screw	Each	12
- - - 3 -	1130	Control panel assembly	Each	1
- - - - 4	1150	Control dials	Each	3
- - - - 4	1160	Screw	Each	3
- - 2 - -	1090	Operating unit	Each	1
- - 2 - -	1100	Lug	Each	4
- - 2 - -	1110	Base cover plate	Each	2
- - 2 - -	1160	Screw	Each	4
- 1 - - -	1020	Handset assembly	Each	1
- - 2 - -	1050	Speaker	Each	1
- - 2 - -	1060	Microphone	Each	1
- - 2 - -	1070	Receiver cover plate	Each	2
- - 2 - -	1160	Screw	Each	2
- 1 - - -	1030	Connecting cable	Metre	1
- 1 - - -	1040	Connecting jack	Each	2

TABLE 16.2(c) A Modular BOM for a Telephone Instrument

Item Code	Item Description	UOM	Quantity per Product
1000	Basic telephone	Each	1
1010	Base unit assembly	Each	1
1020	Handset assembly	Each	1
1030	Connecting cable	Metre	1
1040	Connecting jack	Each	2
1050	Speaker	Each	1
1060	Microphone	Each	1
107X	**Receiver cover plate**		
1071	Receiver cover plate: Grey	Each	2
1072	Receiver cover plate: Blue	Each	2
1073	Receiver cover plate: Black	Each	2
1074	Receiver cover plate: Beige	Each	2
1080	Panel board assembly	Each	1
109X	**Operating unit**		
1091	Operating unit: 20 calls		
1092	Operating unit: 50 calls		
1093	Operating unit: 100 calls		
1094	Operating unit: 200 calls		
1100	Lug	Each	4
111X	**Base cover plate**		
1111	Base cover plate: Grey	Each	2
1112	Base cover plate: Blue	Each	2
1113	Base cover plate: Black	Each	2
1114	Base cover plate: Beige	Each	2
1120	Button Assembly	Each	1
113X	**Control panel assembly**		
1131	Control panel assembly: Simple	Each	1
1132	Control panel assembly: Deluxe	Each	1
1133	Control panel assembly: Elegant	Each	1
1140	Buttons	Each	12
1150	Control dials	Each	3
1160	Screw	Each	21

Time Phasing the Requirement

The computing of the requirement of items is based on simple arithmetic. Let us consider a two-month period as the planning horizon. Let us use the following notations:

Gross requirement for an item during the period: *A*

Inventory of the item available for the period: *B*

Net requirement of an item during the period: *C*

We know that $C = A - B$. If C is positive, we need to schedule an order for the item so that it arrives at the beginning of the period. The “how much” question is answered but not “when”. To understand this, let us return to the telephone example and look at the issue more closely. Dependent demand items exhibit another important property—the lumpy nature of demand. In our telephone example, let us consider the requirement of base cover plates. Based on the planning cycle of the parent, the demand for base cover plates may suddenly crop up during a particular week. For instance, if it was decided to produce 100 units of base unit assembly during Week 3, 60 units during week 5 and 75 units during Week 8, then the gross requirements of base cover plates are 200, 120, and 150, respectively. In between these periods, there is no need for base cover plates. Let us also suppose that the on-hand inventory during the period is 350, computed on the basis of what is physically available and what is likely to be supplied during the two-month period for which we do the planning.

Using these equations, we find that:

B: On hand = 350

A: Gross requirement = 470 (200 + 120 + 150)

C: Net requirement = 120

Therefore, we may conclude that we need to place an order for 120 base cover plates to meet the planned requirements. While this computation is correct, it may not reveal “when” to place the order and if there are any problems that the organization may face by planning in this manner. Let us look at the same data in a different fashion in Table 16.3:

TABLE 16.3 Time Phased Estimation of Net Requirement

	Period (Week)								
	0	**1**	**2**	**3**	**4***	**5**	**6**	**7**	**8**
On Hand**	50				300				
Gross Requirements				200		120			150
Net Requirement				150					120

Notes: *Increase in on-hand inventory by 300 at the end of Week 4 (beginning of Week 5) is due to an order placed earlier; **On-hand data pertains to the inventory at the end of the period.

Table 16.3 reveals important information to the planner arising out of the lumpy nature of demand that is characteristic of dependent demand items. First, we find that the on-hand inventory, due to arrive at the beginning of Week 4 (on account of an earlier order) is “out of phase” with the requirement. Although the order can cover the requirement for the first five weeks, it is wrongly scheduled. Second, it is also clear from the computation that our order of 120 needs to arrive at the manufacturing system only at the beginning of Week 8. There is no need to order much in advance and keep the base cover plates idle in the stores.

This illustration highlights another important principle associated with resources planning. “Time phasing” of the information is a critical step in the process. In this case, we used a time bucket of “weeks”. The planner needs to choose an appropriate time bucket for the system for which planning is done and analyse the inventory-related information. Time bucketing has significant implications for the computational efficiency and the accuracy of information. In the example being discussed, by aggregating all the data to a two-month bucket, we first obtained gross information by using just four data points (on hand, on order, gross requirement, and net requirement). Later, we obtained better information by using a weekly bucket involving 25 data points (one data point for on-hand inventory at the end of time 0 and 24 data points for the eight weeks, as can be seen in Table 16.3). This is a managerial trade-off and needs to be resolved before using the system for planning purposes.

It is also important to realize that the accuracy and integrity of the inventory data is crucial for obtaining good schedules for the components. Organizations incorporate periodic checking routines (called cycle counting) to ensure that the integrity of the data is established. Physical inventory is verified with the inventory data and corrective measures are taken if there are any discrepancies.

It is evident that computing the net requirements and appropriately time phasing the requirement is the first step in the planning process for dependent demand items. A sample illustration for the operating unit of the telephone example is given in Table 16.4.

TABLE 16.4 A Sample Illustration for the Operating Unit

Item: Operating Unit		**Period (Week)**							
Computing the net requirements	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements				200		120		130	160
On hand*	50	50	50						
Net requirement				150		120		130	160

Note: *On-hand data pertains to the inventory at the end of the period

Determining the Lot Size

Lot sizing is the process of determining the size of the order quantities for each component in a product. The lot-sizing decision also affects the lead time required for the manufacture/purchase of components. While deciding on an appropriate lot size, the planner must keep in mind the influence of two sets of costs. Large lot sizes will require fewer set-ups (and associated set-up costs) but may result in carrying a huge inventory for a longer time. On the other hand, smaller lot sizes require several set-ups, thereby increasing the set-up costs. Balancing these two costs is central to the lot-sizing decision. Let us look at three lot-sizing rules commonly considered by planners.

> **Lot sizing** is the process of determining the size of the order quantities for each component in a product.

Lot-for-lot (LFL)

Lot-for-lot is perhaps the simplest of the lot-sizing rules. Under this rule, the lot size is equal to the net requirement during every period in the planning horizon. If, for a component, the net requirements for the next 4 weeks are computed to be 120, 0, 200, and 50, then the order sizes scheduled to arrive during these four weeks are 120, 0, 200, and 50, respectively. Table 16.5 shows a sample illustration of the rule for the operating unit of the phone.

The LFL rule is appropriate under the following conditions:

a. The cost of carrying inventory from one period to the next is very high compared to the cost of set-up.
b. The demand for the item is sparse and highly discontinuous (several data points in the planning horizon have zero demand).

One may find that in situations with complex product configurations and several varieties in the end product, these assumptions hold as we approach the final assembly stage.

Fixed order quantity (FOQ)

The other alternative is to use a fixed order quantity. In this rule, irrespective of the nature of the demand, orders are always placed for a fixed order quantity. After computing the net requirements for the planning period, orders are scheduled such that they arrive at the first point of demand. The next order is scheduled to arrive at the time when the first order is insufficient to meet the net requirements for the period. The procedure continues in this fashion until the requirements for the entire period are covered by the orders. Table 16.6 presents a sample illustration for the FOQ lot-sizing rule for the operating unit of the telephone. In this case, the first point of demand for operating units occurs during Week 3. Therefore, an order quantity of 300 is scheduled to arrive at the beginning of the week. The quantity that arrives during Week 3 satisfies the net requirements until Week 6. Therefore, the next order of 300 is scheduled to arrive at the beginning of Week 7.

TABLE 16.5 The LFL Rule for the Operating Unit of a Telephone

Item: Operating Unit		**Period (Week)**							
Lot size rule: Lot for lot	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements				200		120		130	160
On hand*	50	50	50						
Net requirement				150		120		130	160
Lot size (planned receipt)				150		120		130	160

Note: *On-hand data pertains to the inventory at the end of the period.

TABLE 16.6 The FOQ Rule for the Operating Unit of a Telephone

Item: Operating Unit	Period (Week)								
Lot size rule: Fixed order quantity	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements				200		120		130	160
On hand*	50	50	50						
Net requirement				150		120		130	160
Lot size (planned receipt)				300				300	

Note: *On-hand data pertains to the inventory at the end of the period

Alternative methods could be used for computing the fixed order quantity. One method is to estimate the economic order quantity for the item on the basis of set-up/ordering costs and carrying cost.[1] In the case of components manufactured “in-house”, there are preferred run lengths or economic run lengths. Similarly, for items bought from outside, minimum order quantity restrictions imposed by the suppliers, other considerations such as truck load capacity, and the prevailing quantity discounts structure will influence the choice of order quantity.

FOQ provides an alternative perspective to the “carrying cost–ordering cost” trade-off. When the unit value of the item is low and there is a continuous and more or less stable demand for the item, it is appropriate to use this rule. Items that are at the lower ends of a product structure share a greater degree of commonality among numerous end-product variations. Therefore, the demand is likely to be continuous, justifying the choice of FOQ rule. Moreover, they tend to have a low unit cost. Hence, the cost of carrying any leftover inventory from one period to the next is likely to be very low. In reality, depending on the net requirements, the order placed will be in integral numbers of FOQ (i.e., $k \times FOQ$, where k is an integer).

Periodic order quantity (POQ)

In the periodic order quantity method, an order is placed such that it covers the requirements of P periods. It does not mean that we need to place an order during every P period. It merely suggests that if we plan an order at a particular time, the quantity should cover the net requirements of P successive periods. The choice of P could be made in alternative ways. One way is to use the review cycle. If an organization reviews decisions every two or three weeks, it could be an appropriate time to also plan the orders. The other method is to use the economic order quantity (Q^*) and the average demand during the period to arrive at P. The expression is given by:

$$\text{Number of periods } (P) = \frac{\text{Economic order quantity } (Q^*)}{\text{Average demand during the planning period}} \qquad (16.1)$$

Let us return to the example of operating units. The total net requirement for the 8-week period is 560 (150 + 120 + 130 + 160 = 560). Let us suppose that the economic order quantity is 210. Therefore, using Eq. 16.1, we obtain P to be 3 periods. Table 16.7 shows the implementation of the POQ rule for operating units with P = 3. An order is scheduled to arrive at the beginning of Week 3 and the quantity ordered is sufficient to cover the net requirements during Weeks 3 to 5. Similarly, another order is scheduled to arrive at the beginning of Week 7.

TABLE 16.7 Implementation of the POQ Rule for Operating Units with P = 3

Item: Operating Unit		**Period (Week)**							
Lot size rule: Periodic order quantity	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements				200		120		130	160
On hand*	50	50	50						
Net requirements				150		120		130	160
Lot size (planned receipt)				270				290	

Note: *On-hand data pertains to the inventory at the end of the period

Incorporating Lead-time Information

We observed earlier that timing of the orders in dependent demand items is very crucial. Errors in scheduling will have a cascading effect right through the product structure. One important aspect of timing is to incorporate lead-time information in the planning exercise. In our telephone example, let us consider the following situation:

During Week 8, we want to assemble 200 sets of telephones. A look at the product structure indicates that in order to accomplish this task, we need 200 base unit assemblies, 200 handset assemblies, 400 connecting jacks and 200 metres of connecting cable. Let us suppose that it takes one week to assemble 200 base units and we have no inventory in stock. This implies that we should launch a work order to the assembly shop at the beginning of Week 7 to assemble the required number of base units. Since assembling base units take one week, by beginning the assembly in Week 7 itself, they will be able to deliver 200 base units exactly at the beginning of Week 8.

At the next level, let us assume that the operating units are not available in stock and it takes two weeks to manufacture the operating units. Therefore, in order to make 200 operating units available at the assembly shop at the beginning of Week 7, we need to send a work order to the production shop at the beginning of Week 5 to begin the manufacturing process. The process is graphically portrayed in Figure 16.6.

This illustration (Figure 16.6) shows that lead-time information is required to correctly schedule the launch of work order for the components. At every level of planning, the component schedule gets offset to the extent of lead time. For a planned receipt of items during a period, we merely offset the time to the extent of lead time to arrive at the planned order release. If:

Planned receipt for the component during period t is PR_t,

Lead time for the component is L, and

Planned order release for the component during $t-L$ is POR_{t-L}, then

$$POR_{t-L} = PR_t \qquad (16.2)$$

Accurate computation of component lead times is therefore important in obtaining realistic schedules for the components. Lead time consists of set-up time, processing time, waiting time, and the move time between work stations involved in the manufacture of the component. While estimating the process time and the set-up time is relatively easy, estimating the waiting time is difficult. It calls for detailed data collection and analysis. Alternatively, if the item is bought from outside, ordering, supplier lead time for delivery, inspection and issue determine the lead time for the component.

Let us return to our example of planning the requirements for the operating unit. If we assume that the lot-sizing rule used is LFL and the lead time for the manufacture of operating units is two weeks, we can then arrive at the planned receipt and the planned order release using this additional information. Figure 16.7 shows the calculations.

FIGURE 16.6 The impact of lead time in resources planning

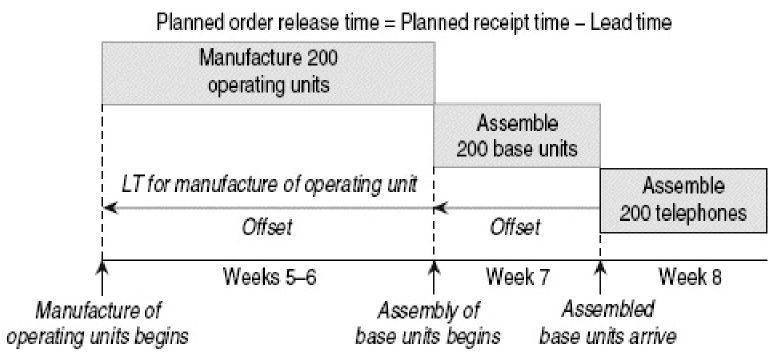


FIGURE 16.7 Computation for planned receipt and planned order release

Item: Operating unit; LT = 2 weeks	Period (week)								
Lot size rule: Lot for lot	0	1	2	3	4	5	6	7	8
Gross requirements				200		120		130	160
On hand*	50	50	50						
Net requirements				150		120		130	160
Planned receipts				150		120		130	160
Planned order releases		150		120		130	160		

Note: *On-hand data pertains to the inventory at the end of the period

Establishing the Planning Premises

In the examples discussed earlier, we have not addressed the key issue, that is, the basis on which the component level planning needs to be done. We address that issue now. Planning for dependent demand items begins with a simple goal, that is, make availability meet the requirements. Therefore, the first step in the planning process is to know exactly what the requirement is. In organizations, a master production schedule (MPS) is drawn for this purpose. A master production schedule disaggregates the information contained in an aggregate plan, links it to specific varieties of the product being manufactured, and specifies the exact timing of the requirement.[2]

Let us assume that our telephone manufacturer makes four varieties of phones. At the time of planning, we need to know the exact number of telephones of each variety that should be produced in each time period and the associated BOM. An MPS serves this purpose and “fixes” the requirements of each end product. An illustrative example is shown in Table 16.8.

In this example, the aggregate plan of 1,200 instruments for the first month and 1,400 in the second month is split into the specific varieties of phones to be manufactured during each week. Eighty units of the basic telephone is the gross requirement for the first week, 190 units for the second week, and so on. Using this information and the on-hand inventory, the net requirements for the basic telephones can be computed for all the weeks. Further, using the lot-sizing rule appropriate, lots are identified for the planned order receipt and using the lead-time data, the orders can be offset to schedule planned order releases.

Once the planned order release of the end product is arrived at in this fashion, it is possible to use the dependency information available in a product structure or BOM to estimate the gross requirements of the lower level items. However, some lower level items may have “independent” demand as well, since they are consumed directly in the market as spares. The MPS also identifies the spares requirement of lower level components. Therefore, for the lower level items, gross requirements may arise in two ways; one as a dependent demand of its parent and the other as spares. These are to be added up while planning for the item.

TABLE 16.8 MPS for a Telephone Manufacturer

Master Production Schedule	**Period (Week)**							
Item	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Aggregate production plan								
Total Production				1,200				1,400
Phone-basic	80	190	110		100	100	100	100
Phone-deluxe	0	50	0	50	0	50	0	50
Phone-home office	75	120	40	20	70	60	0	0
Phone-enterprise	90	125	125	125	125	245	200	200

Let us assume that based on the on-hand inventory of basic telephones, base unit assemblies and operating units as well as the scheduled receipts of these during the planning period, the planned order releases for base unit assemblies are computed to be 140 for Week 3, 80 for Week 5, 130 for Week 7, and 120 for Week 8. Let us further assume that the MPS has projected the demand for operating units as spares to be 60 units in Week 3, 40 units in Week 5, and 40 units in Week 8. In general, we can compute the gross requirements of components for a period t at any level using the following notations:

The planned order release of the parent = POR_t

The quantity required to assemble one unit of the parent = $BOMQ_t$

Independent demand of the component as spares = ID_t

Gross requirements of a component = GR_t

$$GR_t = (POR_t \times BOMQ_t) + ID_t \tag{16.3}$$

In our telephone example, each base unit assembly requires one operating unit. Therefore one can use the given information and Equation 16.3 to compute the gross requirements of operating unit for the planning period. Figure 16.8 explains the computation of gross requirements in the case of the operating unit of the phone.

FIGURE 16.8 Computation of gross requirements

MPS for telephone manufacturer	Period (week)							
	1	2	3	4	5	6	7	8
Operating unit			60		40			40

Item: Base unit assembly	Period (week)							
	1	2	3	4	5	6	7	8
Planned order releases			140		80		130	120

Item: operating unit	Period (week)							
	1	2	3	4	5	6	7	8
Gross requirements			200		120		130	160

16.3 MRP LOGIC

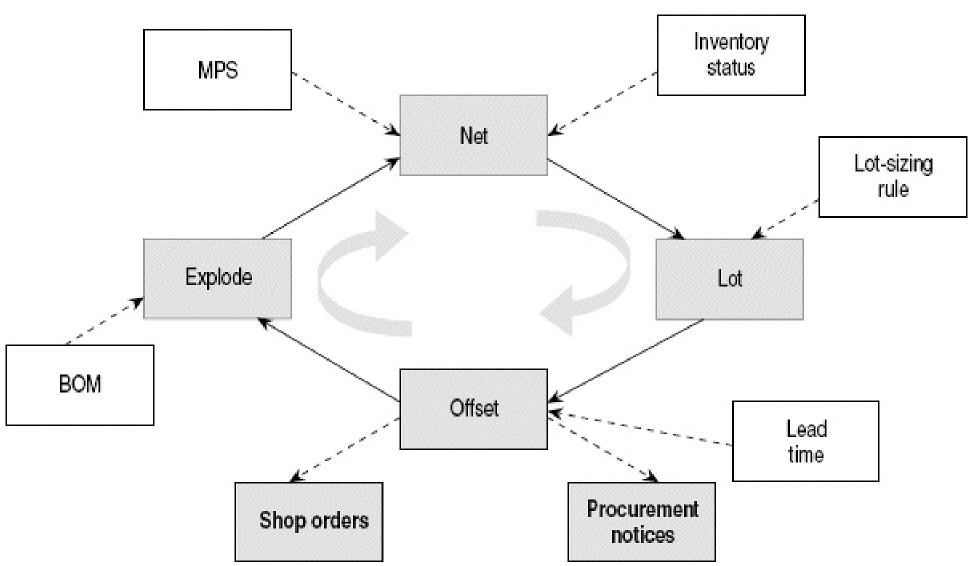
Material requirements planning is a structured approach that develops schedules for launching orders for materials in any manufacturing system and ensures the availability of these at the right time and at the right place. It uses the basic building blocks of resources planning that we described in the previous section to develop these schedules. Figure 16.9 shows the core logic of the MRP process, its input, and output.

As shown in the figure, four key processes drive the MRP procedure. These processes occur in a cyclic fashion. The first process is the “net” process. The MPS for the end product provides information on the gross requirements for the end product. By utilizing the information available in the inventory records, the “net” process computes the net requirements for the end product. The second process is the “lot” process. Once the net requirements are computed, the lot-sizing rule is used to schedule planned receipts of the product. The third process is the “offset” process. Once the planned receipts are identified, lead-time information is used to offset and obtain the planned order releases for the product. The planned order releases are either work orders for a manufacturing shop to assemble as many components as per the schedule or a purchase order to obtain sub-assemblies from outside.

Once these three processes are completed, the requirements for the end products are estimated and orders are scheduled. Then the next step is to cascade the process down the product structure and repeat the procedure with all the components at the next level in the product structure. This process is the last in the cycle denoted as “explode”. In order to perform the explosion process, BOM data is required. The planned order releases of a parent creates dependent demand for the offspring as specified in the BOM. This becomes the gross requirements for the offspring. The procedure continues iteratively, level by level, until the lowest level is reached and all component schedules are determined.

Therefore, the key inputs for the MRP processes are MPS, BOM, inventory status, lead-time data, and lot-sizing rule. We have already discussed in detail in the earlier sections the role each one of them plays in accurately determining the quantity and timing of the material requirements. As we proceed through the lower level components, two types of outputs are generated from the MRP system. The first output is a work order. Work orders are generated for items that are manufactured in-house. In our telephone example, we would have generated work orders for base set and handset assemblies as they are likely to be done in-house. The second output is a procurement notice. Procurement notices are generated for items that are bought from outside and directly used in the assembly. It triggers the purchase ordering process in an organization. In our telephone example, it is possible that the manufacturer might directly source connecting cables and jacks instead of producing them in-house. In such a situation, the outcome of the MRP process will be a procurement notice.

FIGURE 16.9 Material requirements planning core logic



EXAMPLE 16.2

A manufacturing organization needs to plan the materials required for the next six weeks for the manufacture of its end-product (Product A), as per a master production schedule. In addition to the end product, there is an independent requirement of Component C, as it is sold as a spare in the market. The master production schedule for both the end product and the spares are given in Table 16.9. In order to assemble one unit of Product A, Components B to G are required. Figure 16.10 shows the product structure. In the figure, the number alongside each component denotes the number of each component required to assemble its immediate parent. An extract of the inventory status (Table 16.10) reveals the inventory on hand. There are no pending orders for delivery. Different lot-sizing rules are used for the components of Product A. Moreover, the components have different lead times. All this information is available in Table 16.10. Perform an MRP exercise to estimate the quantity and timing of the components required for the manufacture of Product A as per the MPS.

Solution

We perform the MRP exercise by using the four-step process given in Figure 16.8. We begin with Product A. Figure 16.11 shows the calculation of the net requirements. Since the lot-sizing rule is lot-for-lot, the net requirements and the planned receipts are the same. We offset the planned receipt by lead time to obtain the planned order releases. Figure 16.11 shows the calculations.

Now, we continue the process by exploding the product structure and moving to the next level. There are two components at this level: Components B and C. In our example, if an order needs to be released for assembling 100 units of Product A in Week 1, then we need 300 units of Component B and 100 units of Component C at the beginning of the week so that we can launch the work order. Therefore, the planned order releases of a parent determine the gross requirements for the offspring. We repeat the process once for B and then for C before we explode to the next level. The two tables in Figure 16.12 show the calculations for Components B and C.

While computing the gross requirements for C, we take into consideration both the dependent demand of C (as indicated in the product structure) as well as the independent demand (as indicated in the MPS in Table 16.9). Consider Period 2. The planned order releases for Product A during this period is 200. Therefore, there is a gross requirement of 200 units of C. There is also an independent demand of 50 units of C during Period 2. Therefore, the gross requirement for Component C is 250 (200 + 50 = 250). Similar computations have been made for all other periods also.

FIGURE 16.10 The product structure

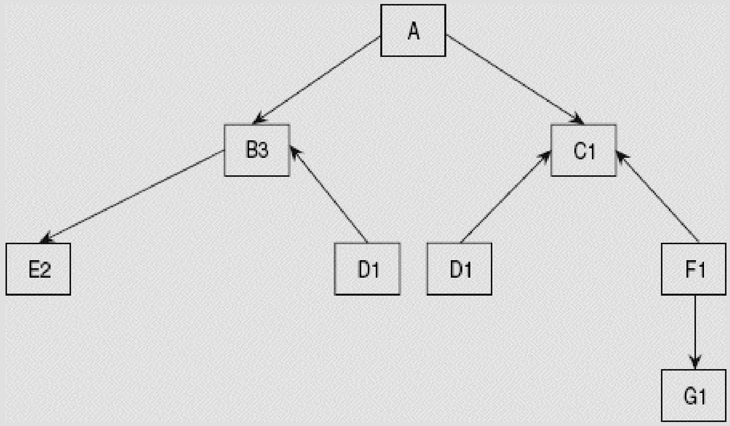


TABLE 16.9 MPS for the Next Six Periods

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Product A	100	150	200	100	0	200
Component C		50	60			70

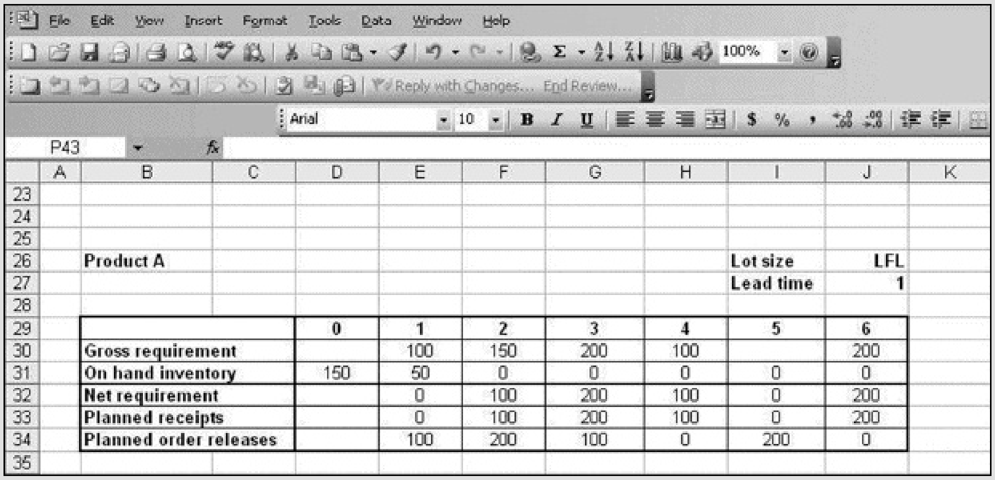
TABLE 16.10 Inventory Status, Lead Time, and Lot-sizing rule

Component	On hand	Lead time	Lot size
A	150	1	LFL
B	1,000	2	LFL
C	300	1	LFL
D	750	2	3 periods
E	700	6	3 periods
F	200	1	400
G	500	3	500

Component D is used by both B and C. Therefore, while arriving at the gross requirements of D, we take into consideration the planned order releases of both the parents. For example, during Period 1, the planned order releases of Components B and C are 200 and 50, respectively. Since they both require one component of D, the gross requirement for D during Period 1 is 250. Since the first instance of planned receipt is Week 3, we add up the requirements of three weeks (Weeks 3 to 5) in order to implement the POQ policy and schedule a planned order release during the beginning of Week 1.

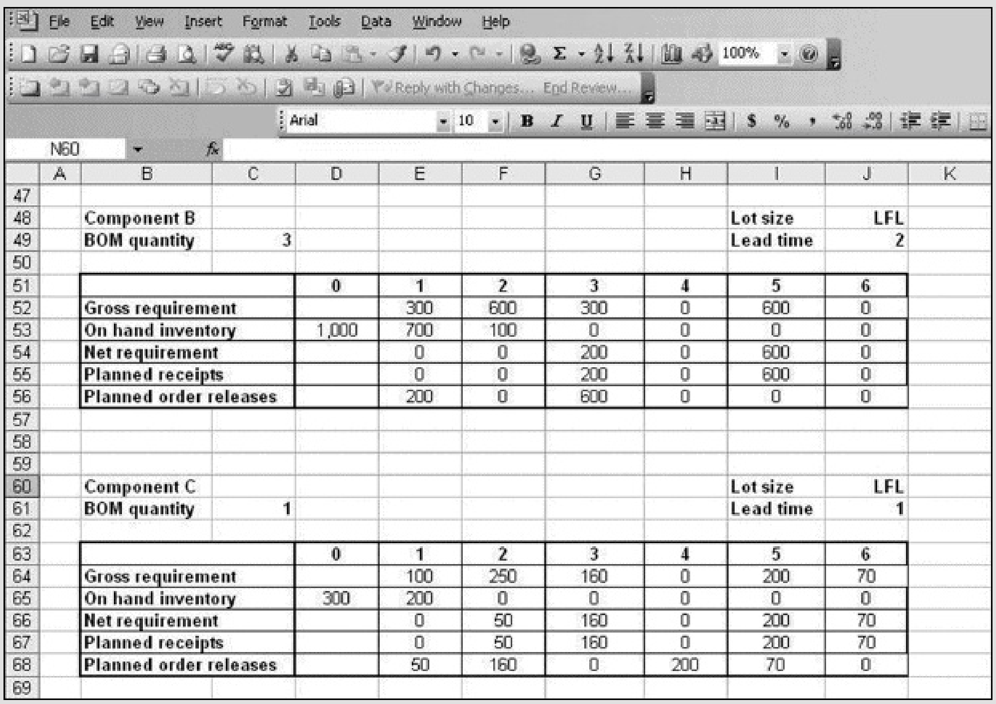
We perform similar computations for the remaining items in the product structure. Figure 16.13 presents the detailed calculations for Components D and E, while Figure 16.14 has the calculations for Components F and G.

FIGURE 16.11 Calculations for Product A



	A	B	C	D	E	F	G	H	I	J	K
23											
24											
25											
26		**Product A**							**Lot size**	**LFL**	
27									**Lead time**	**1**	
28											
29				**0**	**1**	**2**	**3**	**4**	**5**	**6**	
30		**Gross requirement**			100	150	200	100		200	
31		**On hand inventory**		150	50	0	0	0	0	0	
32		**Net requirement**			0	100	200	100	0	200	
33		**Planned receipts**			0	100	200	100	0	200	
34		**Planned order releases**			100	200	100	0	200	0	
35											

FIGURE 16.12 Calculations for components B and C



	A	B	C	D	E	F	G	H	I	J	K
47											
48		**Component B**							**Lot size**	**LFL**	
49		**BOM quantity**	**3**						**Lead time**	**2**	
50											
51				**0**	**1**	**2**	**3**	**4**	**5**	**6**	
52		**Gross requirement**			300	600	300	0	600	0	
53		**On hand inventory**		1,000	700	100	0	0	0	0	
54		**Net requirement**			0	0	200	0	600	0	
55		**Planned receipts**			0	0	200	0	600	0	
56		**Planned order releases**			200	0	600	0	0	0	
57											
58											
59											
60		**Component C**							**Lot size**	**LFL**	
61		**BOM quantity**	**1**						**Lead time**	**1**	
62											
63				**0**	**1**	**2**	**3**	**4**	**5**	**6**	
64		**Gross requirement**			100	250	160	0	200	70	
65		**On hand inventory**		300	200	0	0	0	0	0	
66		**Net requirement**			0	50	160	0	200	70	
67		**Planned receipts**			0	50	160	0	200	70	
68		**Planned order releases**			50	160	0	200	70	0	
69											

FIGURE 16.13 Detailed calculations for components D and E

D90 | 1700

Component D							**Lot size**	**POQ-3**
BOM quantity	1	for B					**Lead time**	2
	1	for C						
		0	**1**	**2**	**3**	**4**	**5**	**6**
Gross requirement			250	160	600	200	70	0
On-hand inventory		750	500	340	0	0	0	0
Net requirement			0	0	260	200	70	0
Planned receipts					530			
Planned Order releases			530		0	0	0	0

Component E							**Lot size**	**POQ-3**
BOM quantity	2	for B					**Lead time**	6
		0	**1**	**2**	**3**	**4**	**5**	**6**
Gross requirement			400	0	1,200	0	0	0
On-hand inventory		1,700	1,300	1,300	100	100	100	100
Net requirement			0	0	0	0	0	0
Planned receipts			0	0	0	0	0	0
Planned order releases			0	0	0	0	0	0

FIGURE 16.14 Calculations for components F and G

P120

Component F							**Lot size**	**400**
BOM quantity	1	for C					**Lead time**	**1**
		0	**1**	**2**	**3**	**4**	**5**	**6**
Gross requirement			50	160	0	200	70	0
On hand inventory		200	150	0	0	0	0	0
Net requirement			0	10	0	200	70	0
Planned receipts			0	400	0	0	0	0
Planned order releases			400	0	0	0	0	0

Component G							**Lot size**	**500**
BOM quantity	1	for F					**Lead time**	**1**
		0	**1**	**2**	**3**	**4**	**5**	**6**
Gross requirement			400	0	0	0	0	0
On hand inventory		500	100	100	100	100	100	100
Net requirement			0	0	0	0	0	0
Planned receipts			0	0	0	0	0	0
Planned order releases			0	0	0	0	0	0

16.4 USING THE MRP SYSTEM

Perhaps the most significant impact that a well-designed MRP system could provide to an organization is the reduction in inventory. MRP systems were first developed in the early 1960s and organizations that started using them reported dramatic reductions in their inventory. The reasons are obviously related to the logic of exploiting the peculiar characteristics of dependent demand items. Using traditional EOQ-based inventory control systems will often result in having inventory when not required. The other advantage of the MRP system is the increased visibility of items and their dependencies through a BOM representation of products being manufactured. Further, it could potentially inculcate a certain discipline in the planning process.

> Despite their simplicity and their initial success, MRP installations faced several problems after implementation.

Despite the simplicity and initial success, MRP installations faced several problems after implementation. In several cases, MRP systems suffer from three major problems:

- The data integrity is low. The quality of the solution is only as good as the data used for the computation. If the lead-time data is wrong, organizations may either have too much inventory or frequent shortages. Similarly, if the inventory status is wrong it could jeopardize the entire computation.
- Users did not have the discipline of updating the required databases as and when changes were taking place elsewhere in the organization. If the R&D department creates new designs and revisions in existing product design, this data needs to be incorporated in the BOM file. Failure to do so will mean introducing errors in the process, resulting in inappropriate planning.
- There are uncertainties associated with several issues that lie outside the control of the people and the system (for instance, bad supply management resulting in many uncertainties in lead time and quantity delivered, and so on).

The net result of these problems is that the predictions made by MRP systems may often turn out to be less accurate and the system may have to be rerun often. This could also result in several production schedule changes and consequent delays in the downstream supply chain.

Moreover, there are other limitations in using the MRP system. The amount of computation involved in generating component-wise schedules for the planning horizon is large. Real-life examples require thousands of iterations that consume time. In some cases, it is not uncommon to have a single run of an MRP extending for about 12–16 hours. Although speed and availability of computing power keep increasing continuously, this issue still merits some attention and puts realistic limits to the frequency of generation of MRP schedules.

Therefore, an organization needs to incorporate certain aspects into the MRP planning framework to minimize problems arising out of these issues. Alternative methods are available to re-run an MRP system and they have implications on the accuracy, cost, and time pertaining to the exercise. However, there are methods available to handle some of the uncertainties in the system and thereby reduce the risk of shortage, but such alternatives have cost implications as well. We shall look at some of these alternatives in the following sections.

Updating MRP Schedules

In real-life situations, plans become obsolete over time due to several changes in the environment. For example, a customer might have cancelled an order or amended the order quantity and delivery schedule. A supplier could have defaulted in the supply schedule. Similarly, there could have been some unexpected disruptions in the manufacturing and assembly schedules within the manufacturing system. In each of these cases, the MRP and the schedules for order releases and purchase become inaccurate and call for a certain amount of re-planning. Several such instances happen on a daily basis in any manufacturing system. Therefore, the critical issue that a manager needs to resolve while using the MRP system is the frequency with which the MRP schedules are re-run. Before addressing this issue let us first understand the methods available for updating schedules in MRP.

Regeneration is one method to update MRP schedules. In this method, the MRP system is run from scratch. Based on the changed information, one can start from Level 0 and run the MRP logic right up to the bottom level. The implication of this in real-life situations is that large computational efforts are required. It also amounts to 100 per cent replacement of the existing MRP information. The second method of updating the MRP schedule is known as *net change*. In this method, instead of running the entire MRP system, schedules of components pertaining to portions where changes have happened are updated. Let us consider a product structure with three levels. Suppose one of the components in Level 2 is likely to be made available two periods later, one can analyse this information and process only the relevant records to arrive at an alternative MRP schedule. Clearly, the net change method of updating MRP schedule modifies only a subset of data as opposed to regeneration. Therefore, it is likely to be computationally more efficient than the regeneration method. Moreover, it may be possible to run it in frequent intervals.

> **Regeneration** is a method to update the MRP schedules where the MRP system is run from scratch.

The decision to use net change or regeneration depends on the magnitude of changes that occur in an organization. If the number of changes to be incorporated in the system tends to be large, then organizations are better off using the regenerative method for updating MRP schedules. One sees a similar kind of logic being applied to bringing out the next edition of the telephone directory in a large metropolitan city such as Mumbai. Every year, they may come up with a new telephone directory (equivalent to regenerative method). However, between two editions of the telephone directory, they bring out a small supplement announcing the changes (equivalent to net change). The cost of running an MRP system and the number of changes happening in the planning horizon influence the type of updating procedure employed and the frequency of updation.

Safety Stock and Safety Lead Time

Uncertainties in the system that are outside the control of an MRP system is a reality that organizations need to face and plan for. Generally, two types of uncertainties are prevalent: the quantity of components received, and the timing of receipt. First is the uncertainty with respect to supply quantity. Poor quality input material could result in quantity loss on account of rejections. Alternatively, the reliability of suppliers may also result in uncertainty in quantity. In the case of components manufactured in-house, there could be uncertainty in supply quantity due to changes in the batch quantity of upstream stages. Therefore, it may be desirable to plan for a safety stock to absorb these uncertainties. The inclusion of safety stock in MRP computation is fairly straightforward. At the time of “netting” the requirements, an order is scheduled to arrive when the on-hand quantity falls below zero. Instead, the order needs to be scheduled when the on-hand inventory falls below the safety stock. Figure 16.15 shows the MRP schedules for a component both without any safety stock and with a safety stock of 50.

In this figure, the first table shows the MRP schedule where no safety stocks are assumed. We see that the inventory on hand could satisfy the requirements up to Period 4 (since the total requirement up to this period is only 190). In order to satisfy the requirements for Periods 5 and 6 quantities are scheduled after taking the lead time into consideration. On the other hand, the second table shows that although sufficient inventory is available to meet the requirements of Period 4, the on-hand inventory falls below the safety stock of 50. Therefore, 40 units are scheduled to arrive during the beginning of Period 4. It is clear from this example that inclusion of safety stock will result in carrying more inventory throughout the period. Moreover, it may significantly alter the ordering pattern. Therefore, managers need to exercise careful thought before fixing safety stock levels for the components in an MRP system.

Safety lead time while planning for the components is quite similar to safety stock. Safety lead time is incorporated in MRP systems by offsetting the planned receipts to the extent of the safety lead time. Let us assume that the planned receipt for a component during Period 5 is 1,200 units. If the safety lead time is one week, then by offsetting the planned receipts by one week and scheduling the receipt to Period 4, one can ensure that the uncertainties related to timing of delivery are largely addressed. Figure 16.16 illustrates the use of safety lead time in MRP. Compared to the first table in the figure, which has no safety lead time, the planned receipts and the planned order releases in the second table are further offset to the extent of the safety lead time of one week. Therefore, one can infer that incorporating safety lead time does not inflate the lead time—it merely shifts the planned order release schedule.

FIGURE 16.15 MRP schedules for a component without any safety stock and with a safety stock of 50

Component XX			**Safety stock**		**Nil**		**Lot size**	**LFL**
BOM quantity	3						**Lead time**	2

	0	1	2	3	4	5	6
Gross requirement		75	75	0	40	90	60
On hand inventory	200	125	50	50	10	0	0
Net requirement		0	0	0	0	80	60
Planned receipts		0	0	0	0	80	60
Planned order releases		0	0	80	60	0	0

Component XX			**Safety stock**		**50**		**Lot size**	**LFL**
BOM quantity	3						**Lead time**	2

	0	1	2	3	4	5	6
Gross requirement		75	75	0	40	90	60
On hand inventory	200	125	50	50	10	0	0
On hand inventory (net of safety stock)	150	75	0	0	0	0	0
Net requirement		0	0	0	40	90	60
Planned receipts		0	0	0	40	90	60
Planned order releases		0	40	90	60	0	0

FIGURE 16.16 The use of safety lead time in MRP

Component XX			**Safety lead time**		**Nil**		**Lot size**	**LFL**
BOM quantity	3						**Lead time**	2

	0	1	2	3	4	5	6
Gross requirement		75	75	0	40	90	60
On hand inventory	200	125	50	50	10	0	0
Net requirement		0	0	0	0	80	60
Planned receipts		0	0	0	0	80	60
Planned order releases		0	0	80	60	0	0

Component XX			**Safety lead time**		**1 week**		**Lot size**	**LFL**
BOM quantity	3						**Lead time**	2

	0	1	2	3	4	5	6
Gross requirement		75	75	0	40	90	60
On hand inventory	200	125	50	50	10	0	0
Net requirement		0	0	0	0	80	60
Planned receipts (before incorporating safety LT)		0	0	0		80	60
Planned receipts (after incorporating safety LT)					80	60	
Planned order releases		0	80	60	0	0	0

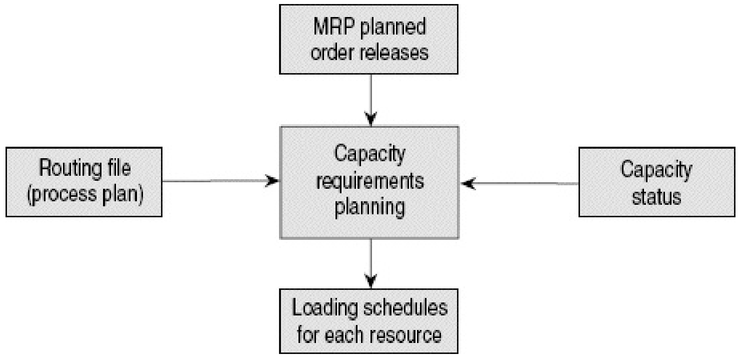
Consider a hypothetical plan of Maruti Udyog Limited (MUL) to produce 20,000 Omni vans, 15,000 Altos, and 9,000 Zens during a month. Using MRP logic, MUL can schedule the arrival of materials, sub-assemblies, and components at various shops in the factory. MRP thus addresses the material aspect of the planning problem. However, in addition to material, we need capacity in the form of resources such as machines and skilled labour. What is the guarantee that there is sufficient capacity available in the factory to complete the tasks as per the MRP schedule? Clearly, MRP merely addresses “what needs to be produced” during each time period in a planning horizon.

However, MUL should also take into consideration “what can be produced” during each time period in a planning horizon and do the required planning to match these two. Therefore, capacity requirement planning (CRP) is necessary to ensure that what needs to be produced during a period can in fact be produced. **CRP** is a technique that applies logic similar to MRP to address the capacity issues in an organization. Similar to MRP, CRP develops schedules for planned releases of capacities to specific work orders as identified in an MRP schedule. The output of an MRP process becomes the basis for the CRP exercise.

> **Capacity requirement planning (CRP)** is a technique that applies the MRP logic to address the capacity issues in an organization.

The notion of dependency applies very well to capacities also. Every manufacturing process generates a dependent demand for the resources involved in the conversion process. In the MUL example, if it takes three hours to complete the painting of one Alto and 20 minutes to complete the final inspection process using a specialised photo-sensitive gadget, then 45,000 hours of paint-shop capacity and 5,000 hours of the testing facility are required during the month. Just as the BOM provides information on materials required to complete one unit of the parent, a routing file or a process plan will provide information on the resources that are required to complete the processing of one unit of the parent. The basis for the MRP is an MPS. Similarly, CRP systems employ the detailed schedule generated by an MRP system as the basis for capacity planning. Just as MRP systems perform netting of the requirements using on-hand inventory data at the beginning of a planning horizon, a CRP system uses the capacity status as the starting point for the “netting” process. Figure 16.17 illustrates the underlying logic of CRP.

FIGURE 16.17 The underlying logic of CRP



There are striking similarities between MRP and CRP and therefore organizations use logic similar to that of MRP for performing CRP (see Table 16.11 for a comparative picture of both). However, there are certain important issues that one needs to understand about MRP–CRP–MPS interfaces. In a simple hierarchical mode, MPS will drive MRP and MRP in turn will drive CRP. If both the schedules are feasible, then the plan is finalized. On the other hand, if there are mismatches between capacity and material schedules due to non-availability of capacity to meet the MRP schedule, then it calls for a few iterations of the process. The MRP schedules are first modified to obtain feasible MRP and CRP schedules. However, if this is not possible, then the MPS is modified until feasible schedules are obtained for both material and capacity. The process is presented in Figure 16.18.

16.6 DISTRIBUTION REQUIREMENT PLANNING (DRP)

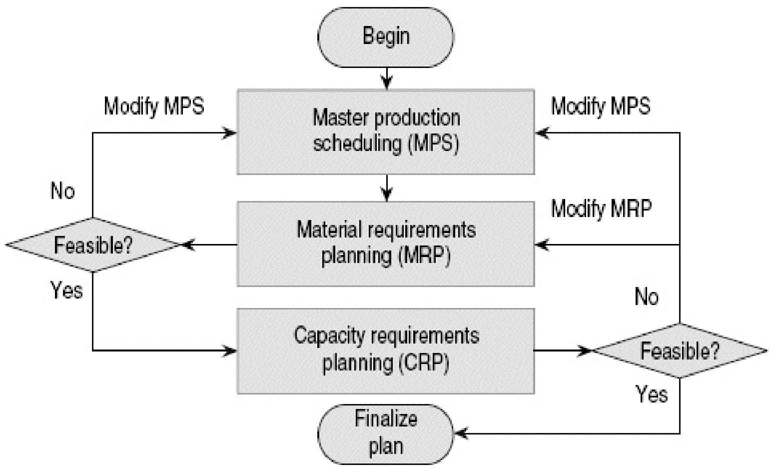
The logic of MRP is sufficiently general to apply to several other areas of business. One extension of MRP is to plan distribution inventories in the downstream supply chain, consisting of depots and stocking points at the dealer level. Consider a downstream supply chain consisting of a factory warehouse, four distribution centres, and 20 dealers geographically spread out in the country. The demand at the dealers' level aggregates up in the chain and eventually reaches the factory warehouse. Transporting the products through the supply chain involves a certain lead time. Further, the products are transported in some preferred lot sizes. In general, ordering decisions happen based on a periodic review of stock and the emerging demand. This causes the demand at the next level in the supply chain to be lumpy. Therefore, it calls for time phasing of the planning process.

TABLE 16.11 MRP and CRP: A Comparative Picture

Criteria for Comparison	Material Requirements Planning (MRP)	Capacity Requirements Planning (CRP)
Input	Bill of material (product structure)	Routing information (process plan)
	MPS	MRP schedules
	Lead-time data	Lead-time data
	Inventory status	Capacity status
	Lot-sizing rules	
Output	Purchase orders	Capacity loading schedules

	Work orders	Capacity usage profiles

FIGURE 16.18 MPS–MRP–CRP: Iterative process of planning



It is easy to notice that the logic of MRP could be readily applied to planning distribution requirements. Using a time phased data, organizations could schedule the planned receipt of products at various points in the supply chain and offset these by the required lead time to arrive at planned order releases for dispatch of material to the demand points. A dealer may review the inventory on hand and the likely demand during the planning period and arrive at the net quantity to order. Based on his lot-sizing considerations, he may lot the orders and determine the planned receipts. Further, by offsetting the order to the extent of the lead time required for receiving the order (due to transportation time and administrative processes) he may arrive at planned order releases for each order. This becomes the gross requirement for the distribution centres. The entire process could be repeated at the distribution centres and the planned order releases of the four distribution centres eventually influence the MPS at the factory.

A distribution requirement planning (DRP) exercise will help organizations and their supply chain partners to jointly plan and reduce investment in inventory in the supply chain. They will be in a position to respond to changes in the demand, such as sudden surges and drops, and have a cost-effective operation. They will also be able to offer a high level of service to their customers. However, unlike the MRP exercise, a DRP exercise relies on key information pertaining to planned order releases outside the domain of an organization. Retailers should be willing to share with dealer the planned order releases and their estimates of upcoming demand, for better planning. Similarly, dealers need to share similar information with the manufacturer. If the information exchange is not proper and if there is no data integrity, then the value of the entire exercise will be severely undermined. It will eventually result in inventory build-up or shortages, poor service, and increased costs of the operation in the supply chain.

16.7 MANUFACTURING RESOURCES PLANNING (MRP II)

The previous sections show the applicability of MRP logic to other domains of the business. Furthermore, the availability of computing power and software for storage and the manipulation of large chunks of data has increased ever since organizations began to use MRP systems. Therefore, it was logical that newer systems were developed to expand the application of MRP into other domains of business where dependency relationships exist. In the 1980s, organizations began to incorporate several modules in the MRP systems. This extended version is known as **manufacturing resources planning (MRP II)**.[3]

> **Manufacturing resources planning (MRP II)** is an extended version of MRP.

A typical MRP II system will consist of the following modules:

- Business planning
- Purchasing
- Forecasting/demand management
- Inventory control
- Order entry and management
- Shop-floor control
- Master production scheduling (MPS)
- Distribution requirements planning (DRP)
- Material requirements planning (MRP)
- Service requirements planning (SRP)
- Capacity requirements planning (CRP)
- Accounting

As we see from this list, MRP II covers all activities, from business planning to servicing the customer. In reality, the business planning exercise triggers dependency relationships for all resources in an organization. The forecasting/demand management module and the order entry system essentially interface with the outside world and bring recent information into the planning system. Based on these, production planning, MPS, and other requirements planning can be done. Since the outcome of these exercises is to procure items and services from outside and perform in-house activities as per plan, the relevant modules have also been included to close the gap. Essentially, the focus is on planning for all the resources that an operations system requires.

The advantage of MRP II lies in its ability to provide numerous feedback loops between different modules and minimize re-planning on a piece-meal basis. We saw in an earlier section that with the inclusion of CRP it was possible to close the gap between material and capacity. Similarly, adding DRP could address distribution-related issues. As more and more gaps are closed, it promotes a centralised approach to planning and promises to bring additional benefits arising out of integration.

ideas at Work 16.2

Open Source ERP Solution for Venkateswara Hatcheries

Venkateswara Hatcheries (VH) was established in 1971. By 2013, it was a ₹60 billion conglomerate and is arguably the largest fully-integrated poultry group in Asia. Uttara Foods and Feeds Limited (UFFL), a division of VH group is a leading manufacturer of quality poultry feed. Venky's Feed, and Venky's Chicken are among the forerunners in their respective markets. UFFL has production plants spread across eight locations in India.

Until 2012, UFFL was using an in-house IT solution for managing its operations. With the gradual expansion and resultant globalization of business, the existing IT solution was not enough. The limitations of the standalone IT solution became apparent when UFFL began seriously exploring the proposals for poultry seed farming in Bangladesh and Vietnam. Poor infrastructure in these countries prevented the company from laying its own corporate lease lines, and privacy concerns ruled out cloud or public domain as an option. Also, language and local tax conditions posed challenges as well.

The IT team at UFFL chose OpenBravo, an Open Source ERP vendor. The Open Source solution gave UFFL the opportunity to experiment with new ideas and build new capabilities. In collaboration with solution architects from OpenBravo, UFFL's IT team developed the new ERP solution. OpenBravo provided a localization feature, which allows it to operate in 64 different languages. UFFL could make use of this for their proposed operations in Bangladesh and Vietnam. UFFL went live with the new ERP in early 2011. UFFL has more than 250 users on the Open-Bravo system.

OpenBravo's web service addressed UFFL's twin needs of protecting data and enabling mobility. The company has also developed a mobile application which its sales force can use to place purchase and transaction orders. The system has enabled UFFL to discover new capabilities. For instance, they have developed a new desktop application that allows employees working from remote areas with poor internet connectivity access an offline module to continue work uninterrupted. The web service functions can auto-synchronize any incremental work as soon as connectivity is established. The biggest benefit, however, has been the increase in transparency.

ERP implementation often calls for a good deal of change management as users will be required to modify their behaviours on many counts. One example in the case of UFFL was the reporting system. With the new solution, UFFL standardized its reporting structure. However, as users were very used to seeing reports in a certain format, the company launched a massive awareness and training exercise to educate users about the merits of the new system and turned their reluctance into approval.

Source: Adopted from http://www.cio.in/case-study/venky-s-develops-erp-poultry-business-open-source; Last accessed on 14 June 2014.

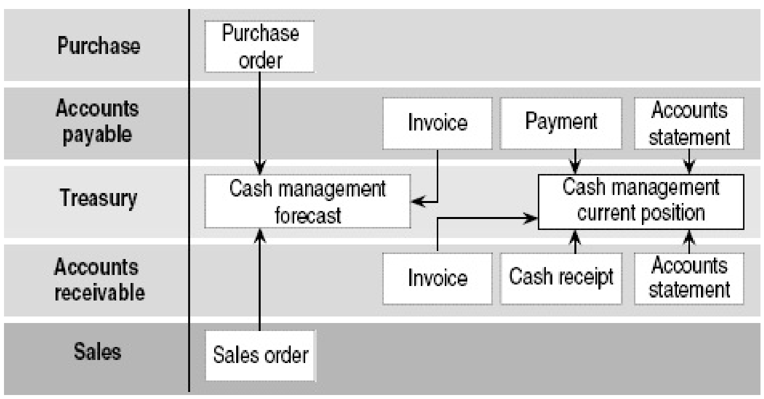
16.8 ENTERPRISE RESOURCE PLANNING (ERP)

Enterprise resource planning is an organization-wide planning system that utilizes some common software and an integrated database for planning and control purposes. An ERP embeds all the organization processes into the software and creates a workfl ow mechanism such that different organizational players engaged in planning and control of a variety of activities can make use of the system. Viewed alternatively, an **ERP** system is a mammoth transaction engine that runs on some common software.

> **Enterprise resource planning** is an organization-wide planning system that utilizes some common software and an integrated database for planning and control purposes.

Since activities in an organization typically have hundreds of processes comprising of thousands of activities, the software is split into modules representing different functional domains. Each module has a set of inputs, processes, and outputs. Moreover, each module is closely interconnected with several other modules (see Figure 16.19 for an illustration of this). Experts say that the power of ERP software lies in its ability to manage these interfaces well, thereby providing tighter integration. The following are the typical modules in ERP software:

FIGURE 16.19 The role of ERP in interfacing functional areas of business



- Sales and distribution
- Production planning
- Logistics
- Accounts payable/receivable, treasury
- Operational (shop floor) control
- Purchasing
- Finance and cost control
- Human resources

In addition, other tools are also available for generating Web interfaces, coding and programme generation for specialised requirements, report generation routines, data import/export, and a library of best practices from which an organization could choose processes for implementation. A wide number of software options are available for ERP today. The most popular among them include SAP, Oracle, Ramco Systems, PeopleSoft, and JD Edwards. Ramco Systems provide ERP software using a cloud based architecture focusing on small and medium enterprises. Initially, ERP software were proprietary standards that were expensive and inflexible. However, all of them are now available as cloud based and customizable. They are also relatively less expensive and amenable to a greater degree of customization.

The heart of ERP is the organization-wide integration of several activities. This ranges from the integration of functions to markets, divisions, plants, products, and customers across the globe. The greatest benefit organizations get from implementing ERP is its ability to link various functional areas of business tightly through the software. Figure 16.19 is an illustration of the idea. Let us consider the issue of cash management activity pertaining to treasury. Purchase and sales order information directly affects the cash forecasting exercise. Similarly, the accounts payable and accounts receivable functions affect the actual cash management position. The ERP software will ensure that with the input new information in each of these modules, the treasury module will get automatically updated with this information.

Prior to the implementation of ERP, an organization re-engineers its processes. It also identifies the level of customization it needs on various functionalities in the software. Usually, a consulting firm assists the whole process and the software is implemented in a project mode.

Through the efficient use of a host of IT-enabled mechanisms, ERP promises to cut down cycle time, transaction costs, layers of decision making, and thereby improve responsiveness and flexibility. The other benefits include a greater sense of empowerment, better visibility of information, and improved customer service. Moreover, an ERP system could be the backbone of IT infrastructure for an organization with which several outward-facing IT applications can be built in the future. All these will eventually lead to improving the competitiveness of the organization at the marketplace.

16.9 RESOURCES PLANNING IN SERVICES

Consider a typical eye hospital, such as the Aravind Eye Hospital in Madurai, which conducts a large number of eye surgeries. A typical eye surgery requires certain resources. Let us look at four key resources: eye surgeon, operation theatre (OT) and medical equipment, pre-operative care, and post-operative care. Let us assume that a typical eye surgery requires 1 hour each of the eye surgeon and the OT, 8 hours of pre-operative care, and 20 hours of post-operative care. If we need to plan to perform 1,000 operations in a 6-day week, one can compute the amount required of each of these resources. For example, the hospital requires 1,000 hours each of the eye surgeon and OT, the 8,000 hours of pre-operative care, and 20,000 hours of post-operative care. Furthermore, we also know that an item in this list could in turn depend on a host of other resources. Pre-operative care may mean the requirement of certain skills of medical professionals, diagnostic and curative equipment, medical consumables, medicines, support staff, and so on.

There are striking parallels between the eye hospital example and that of the telephone set, which was used to develop the logic of MRP. The end product in this case is a treated and discharged patient (similar to the telephone instrument in the manufacturing example). In the telephone examples, four sub-assemblies were required to complete the product. In this case, the product structure in the previous level will have post-operative care as a single item.

Therefore, as in the manufacturing situation, one can develop a bill of resources (BOR) in the case of service organizations and employ a similar planning exercise to schedule service deliveries and the associated resources and materials.

ideas at Work 16.3

Ser vices Resources Planning(SRP): An ERP Solution from Ramco

Professional services industry is globally becoming more competitive forcing companies to move up the value chain, incorporate best business methods, predict and analyze near-term requirements, optimize costs, and identify new and stable revenue generation opportunities. Services industry faces multiple challenges ranging from the use of multiple standalone applications for the daily functioning of internal departments. This results in lack of control over project expenses and cash outflow.

FIGURE 16.20 Product guide for Ramco services resources planning

Ramco SRP provides an end-to-end solution for customers of service industry by tightly integrating key functions such as HR and Finance with Project Management. Its core functionality is project based billing where projects can be Fixed Bid/Milestone or Time and Material (T and M) in nature. SRP is also equipped with built-in adaptors to integrate with project management tools such as Microsoft Projects and Primavera. It further provides comprehensive project tracking with revenue recognition. Figure 16.20 provides the product guide for Ramco's SRP.

Ramco's SRP provides industry specific applications for the services sector. ITes/BPO industry is project-centric, making project management very essential for its success. SRP supports milestone-based, T and M based as well as capped T and M based projects. In addition, it also helps in comprehensive project tracking by integrating with MS Project and Primavera. SRP provides an integrated platform for process-centric consulting companies where timesheet entry, invoice generation, and billing are all inter-linked to one another. This reduces data redundancy and manual data entry into excel spreadsheets. Being a resource-centric industry, workforce management plays a key role in staffing companies. SRP application for staffing company includes processes and the flexibility and variations required for recruitment and selection, onboarding and resource deployment, and a transparent client billing process from Time/Attendance approval through payroll till invoicing.

SRP provides seamless real-time flow of information between multiple departments within the company such as HR, Finance, Project Control Office, and Resource Management Group.

Employees, who form the core of services industry, can be managed very efficiently by optimizing their skills and effort across multiple projects or assignments simultaneously. On the whole, SRP reduces the time and effort spent in manual activities through process automation and also makes day-to-day transactions of the organization paperless by providing a single electronic source of information as a global data repository.

Source: Adopted from http://www.ramco.com/hcm/why-ramcohcm/services-resources-planning/; Last accessed on 15 June 2014.

SUMMARY

- Dependent demand items exhibit certain characteristics such as lumpy demand and parent-offspring relationships that can be exploited while planning for materials in organizations.
- Bill of materials (BOM) and product structures depict the dependency relationships among various components in a manufacturing set-up.
- Various lot-sizing rules can be utilized to batch requirements and schedule orders. The lot-sizing rules strike an appropriate trade-off between carrying cost and ordering cost.
- MRP logic involves a four-step logical process: net–lot–offset–explode. Through an iterative process, the material requirements of all components in an organization during a planning horizon are arrived.
- Regeneration and net change are the two methods used for updating the MRP schedules.
- Capacity requirements planning (CRP) uses logic similar to that of MRP.
- Furthermore, the logic of MRP can be extended to several other spheres of an operations system. MRP II systems provide this functionality. Modern-day ERP systems are further extensions of MRP logic to other areas of business such as marketing, finance, and personnel.

REVIEW QUESTIONS

1. What do you mean by dependent demand and independent demand? Is knowledge of this useful to an organization? If so, in what way is this information useful?
2. Consider each of the following operating systems and identify three examples of dependent and independent demand items.

   a. A hospital providing coronary health care services
   b. A university offering post-graduate level courses
   c. A manufacturer of ceiling fans
   d. A transportation service provider for industrial products
   e. The corporation office of the city of Bangalore
   f. A computer facilities maintenance provider
   g. A BPO offering call centre services to clients

3. What are the key attributes of a dependent demand item? Explain with one example each from manufacturing and service organizations.
4. Why should an organization plan the requirements for a dependent demand item differently from that of an item with independent demand?

5. Suppose that an organization uses normal inventory control methods to plan for its dependent demand items. What will the impact of this be on material planning? Under what conditions will the planning result in satisfactory results?
6. What is meant by a bill of materials (BOM)? Why do organizations need BOMs?
7. Are BOMs and product structures the same? Explain with an example.
8. An organization engaged in the manufacture of electrical appliances is not clear if they need to use a modular or a single-level BOM. Prepare an advisory note clearly specifying the conditions under which each of these alternatives is appropriate.
9. Suppose that an organization prepared an MRP on the basis of incorrect data on lead time of the components. What will the impact of this be on the actual operations?
10. What is meant by the “explosion” of a BOM? Explain with a simple example
11. Identify the appropriate lot-sizing rule for each of the following components. Justify your choice of the rule.

    a. Steel plates for manufacturing automobile doors
    b. Eye surgeon time (in hours) in an eye hospital
    c. Bed linen for a five-star hotel
    d. Packing cartons for a computer manufacturer
    e. Sliced vegetables for use in 12 vegetarian dishes in a fast food joint
    f. Aircraft engines for Hindustan Aeronautics Limited’s advanced light helicopter

12. What is a time bucket? Why do you need it in an MRP exercise?
13. A firm performing an MRP exercise has been using a time bucket of “months” so far. Beginning next month they have chosen to change the time bucket to “weeks”. What are the implications of this change to the organization?
14. What do you mean by safety stock and safety lead time in MRP? When should organizations use these in MRP?
15. What are the key implications to a manager in using the regenerative and net change updation of MRP schedules?
16. An organization was performing the MRP re-run schedule every week. It decided to change the time between two such re-runs to 10 days. What are the implications of this change for the organization?
17. Data integrity is a major issue for many organizations while using an MRP system. Comment on this statement.
18. How is MRP II different from MRP? What are the additional advantages that an organization will obtain by using an MRP II system?
19. “Organizations can obtain realistic plans by properly integrating MPS, MRP, and CRP through an iterative process.” Comment on this statement.

PROBLEMS

1. Omega, a manufacturer of office supplies, produces a desktop calendar unit using a simple process and the following components. The desktop calendar unit is basically assembled using a base plate, a sliding unit and a calendar assembly. The sliding unit is made up of a plastic tray and a set of 30 cards to store telephone and address information. The sliding unit is fixed to the base plate using a pair of 3 mm screws. The calendar assembly is made up of two U-shaped hooks and a calendar (consisting of about 400 pages containing the daily calendar details). The calendar assembly is fixed to the base plate by clamping the U-shaped hooks using a pair of 3 mm screws each.

   Each base plate is made of plastic sheets and requires 150 square inches of plastic sheet. Similarly, the sliding unit is also made of the same plastic sheet and requires 30 square inches of the plastic sheet. Each U-shaped hook is made from 7 inches of 4mm steel rod. The calendar is bought directly from a supplier. Finally, the product is packed in a specially made carton box and sealed using 12 inches of tape. There are also four bar-coded labels stuck to each carton box after it is sealed. This makes it a packaged calendar ready for shipping.

    a. Develop a product structure for the desk calendar unit.
    b. Using the given information, prepare a bill of material for the desktop calendar unit.

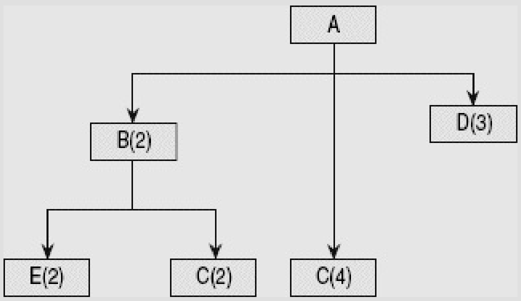
2. In Problem 1, assume that Omega offers the following alternatives:

    - Two different varieties [one is the basic version and the other has provision for keeping pens/pencils (these affect only the base plate)]

- Five different colour choices in the desktop calendar unit (these affect the base plate and the sliding unit)
- Three different configurations of the calendar itself (one page per day, half a page per day, and month planner sheet at the beginning of every month in addition to one page per day)
    a. How many different varieties of desktop calendar units can the organization offer to the customer?
    b. Develop a BOM for the product range offered by Omega.

3. A gearbox manufacturer has 20 gearboxes in stock. Each gearbox has four gears. There are 200 gears already in stock. The gears are made from gear blanks. The stock of gear blanks in the stores is 100. Each gear blank requires 30 kilograms of alloy steel. The stores have 7,000 kilograms. of alloy steel. Compute the requirement of components for manufacturing 570 gearboxes in the next month.
4. Consider the product structure given in Figure 16.21 pertaining to a product manufactured by Oriental Housings & Seals. The numbers in parentheses in the figure indicates the number of units of the item required to assemble one unit of its parent. Use the information available in the product structure to answer the following questions:

FIGURE 16.21 Product structure for Oriental Housings & Seals product



a. How many units of C are required to manufacture one unit of Product A? Did you make any assumption in computing this value?
b. How much inventory of each component is required for satisfying a demand of 100 units of the final product if: (i) there is no stock of finished goods (ii) there is a stock of 30 units of the final product?
c. Consider Problem (a). Will the computations change if there is some stock of Item B? Why and by how much? (Hint: Assume that you have x units of Item B to proceed with the analysis)

5. In Problem 4, the lead times for manufacture/assembly of the components are as follows:

Product A	2 weeks
Component B	1 week
Component C	2 weeks
Component D	2 weeks
Component E	1 week

a. How early can Oriental deliver an order of 100 units of the product to the customer if (i) there is no stock of Item B (ii) there is a stock of 220 units of Item B?
b. Will the results change if there is a stock of Product A?

6. Given in Table 16.12 is a partially completed MRP working for Component X. Using the information provided, complete the table.

TABLE 16.12 Incomplete Table for Problem 6

Component X	Lot Size: 2 Periods						
BOM Quantity: 1	Lead Time: 1						
	0	**1**	**2**	**3**	**4**	**5**	**6**
Gross requirement		200	150	100	200	120	200
On-hand inventory	300						
Net requirement							
Planned receipts							
Planned order releases							

7. Consider Component XX, for which the MRP exercise needs to be done. The relevant information pertaining to the component has been extracted from the company records and reproduced in Table 16.13. Currently, no decision has been made about the lot-sizing rule. Company estimates suggest that the cost of carrying inventory is ₹10 per unit per period and the cost of scheduling an order is ₹500 per order. The economic order quantity is 150 units.

TABLE 16.13 Data about Component XX (Problem 7)

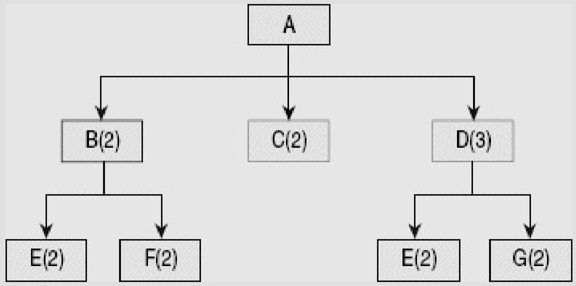
Component XX	Lot Size: ?						
BOM Quantity: 1	Lead Time: 1						
	0	**1**	**2**	**3**	**4**	**5**	**6**
Gross requirement		200	350	400	200	450	200
On-hand inventory	600						
Net requirement							
Planned receipts							
Planned order releases							

Use this information to analyse the following five lot-size rules and suggest an appropriate lot-sizing rule for the component.

a. Lot for lot
b. POQ = 3 periods
c. POQ based on the economic order quantity
d. FOQ = 500
e. FOQ = 1,000

8. Consider the product structure of a manufacturing firm, as shown in Figure 16.22. The company is interested in performing an MRP exercise for the next eight weeks to cover the requirements indicated in the MPS. The MPS requirements for the next eight weeks are 20, 80, 100, 200, 100, 0, 120, and 150.

FIGURE 16.22 Product structure for Problem 8



The relevant information on lead time, inventory status and lot sizing are available in Table 16.14. Develop the MRP schedule for the final product as well as for all the components and answer the following questions:

TABLE 16.14 Lead Time, Inventory Status, and Lot-sizing Rules for Problem 8

Item	Lead Time (Weeks)	Inventory Status	Lot-sizing Rule
A	1	100	Lot for lot
B	2	200	Lot for lot
C	1	400	2 periods
D	2	1,000	3 periods
E	2	2,000	2 periods
F	2	1,200	500
G	1	2,000	1,000

a. Do we need to schedule order releases for Component B? If so, when and how much?
b. How long will the on-hand inventory of Item D satisfy the requirement?
c. How many orders need to be placed for Component F?
d. If the cost of scheduling an order is ₹2,000, what is the total cost of ordering for the MRP plan?

9. Figure 16.23 shows the product structure for a manufacturing firm. In addition to the final product (Product A), Component B is sold as a spare in the market. The MPS for Product A and Component B and other relevant information for the problem are given in Tables 16.15 and 16.16.
Perform an MRP exercise to cover the requirements of the MPS and answer the following questions:

a. What is the gross requirement for Component B during the six periods?

FIGURE 16.23 Product structure for Problem 9

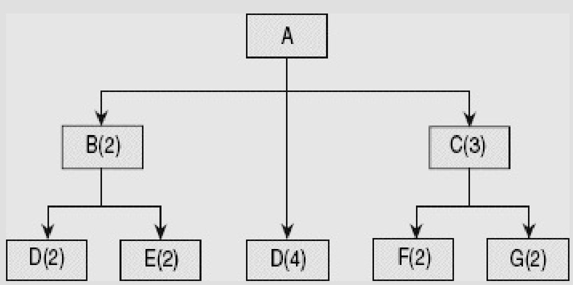


TABLE 16.15 MPS for the Next Six Periods

Period	1	2	3	4	5	6
Product A	100	80	220	140	70	160
Component B	40	30	70		60	50

TABLE 16.16 Lead Time, Inventory Status, and Lot-sizing Rule for Problem 9

Item	Lead time (Weeks)	Inventory Status	Lot-sizing Rule
A	2	200	Lot for lot
B	2	900	Lot for lot
C	1	750	Lot for lot
D	2	2,500	2 periods
E	1	300	3 periods
F	2	1,000	500
G	1	600	1,000

TABLE 16.17 MRP for Component C

Component C BOM Quantity: 1	Lot Size: LFL Lead Time: 1						
	0	1	2	3	4	5	6
Gross requirement		100	250	160	0	200	70
On-hand inventory	400	300	50	0	0	0	0
Net requirement		0		110	0	200	70
Planned receipts		0		110	0	200	70
Planned order releases			110	0	200	70	0

b. How many orders do we have to place for Component C and in what quantities?
c. Suppose the lead time for Component G is two weeks instead of one week, what will its impact be on the planning process?
d. Suppose that the economic order quantity for Component C is 320 units. What will the appropriate POQ lot-sizing rule be for Component C?

10. Consider the following MRP (Table 16.17) for Component C, which is used in a product manufactured by an organization.

Of late, the organization has been experiencing frequent shortages of this component. It has been estimated that on an average, the company loses ₹5,000 by way of lost business and goodwill due to these shortages in a six-week period. Therefore, it has been decided to include a safety stock of 100 units. Rework the planning details for this component by incorporating the safety stock requirement.

11. In Problem 10, assume that the organization decided to implement a safety lead time of one week instead of safety stock.

a. Rework the planning details for this component by incorporating the safety lead time requirement.
b. Compare the two results and list two significant observations that you have made.

NET-WISE EXERCISES

1. Visit the Web sites of the major ERP vendors (SAP, PeopleSoft, Oracle, Ramco, J.D. Edwards). Study the product offerings of all these vendors and prepare a detailed report to answer the following questions:

    a. What are the key components of the ERP system offered by the major vendors?
    b. How do these vendors differentiate differ their offerings?
    c. If an organization wishes to choose one of the four vendors, what factors will you suggest to the organization to enable appropriate selection?
    d. Are there industry-specific offerings of ERP by these vendors? If so, which sectors of the industry are covered and how well?

MINI PROJECTS

1. Take a simple household gadget or appliance such as a dining table set or a sofa set with a centre table. Carefully analyse the assembly of the appliance and identify the parts that make up the appliance. Identify the major assemblies and sub-assemblies of the appliance.

    a. Using this information prepare a complete BOM and a product structure for the appliance
    b. What are the various ways by which you think product varieties can be created for this appliance? Identify them and prepare an indented BOM for the entire set of product offerings.
    c. Assume an MPS and other relevant data for the components that you have identified for the appliance. Can you set up a standard table for performing the MRP exercise for the appliance?

2. Set up the table created in Problem 1 in a Microsoft Excel worksheet (assume a planning horizon of 6 periods). Use the worksheet to accomplish the following tasks:

    a. Perform the MRP exercise for the appliance that you have chosen.
    b. Assume that the MPS is wrong. Quantities have been underestimated to the extent of 10 per cent during Periods 4 and 5 and overestimated to the extent of 5 per cent during Period 6. What is the likely impact of this on customer commitment?

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CHAPTER 17

Inventory Planning and Control

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What are the various types of inventory found in an organization?
- What are the costs and decisions related to inventory management?
- How is economic order quantity computed?
- How can one model demand uncertainty and compute appropriate levels of investment to be made in inventory?
- What are the alternative inventory management systems in use in organizations?
- What are the alternative approaches available for selective control of inventories?
- How is inventory planning done in the case of a single-period demand?

Organizations need to spend a considerable amount of money to carry inventory. The cost of stores and warehousing and the administrative costs related to maintaining inventory and accounting for it form a significant part of this cost.

Source: MTR Foods Pvt. Ltd.

ideas at Work 17.1

Inventory Management in a Consumer Products Company

A consumer products company dealing in cosmetics and other personal-care products was exploring ways to reduce inventory levels across their outbound supply chain and improve inventory record accuracy at their storage points. The company had a supply chain network of three factories with bonded stock rooms (BSRs) attached for dispatch to the depots and 35 depots for servicing distributors. Goods moved from the factory to the BSRs. The BSRs dispatched stocks to one centralized depot. Other depots received stocks from this depot and sold them to distributors.

These depots were holding high levels of inventory of old/withdrawn stocks and damaged stocks for a long time (over three months). The total average inventory holding at the BSRs was 8.2 weeks of sales and at the depots was 6.5 weeks of sales. There were several reasons for high levels of inventory. Some of them are discussed here.

Sales and dispatch forecasts were not in line with actual sales. Furthermore, there was no process to periodically review and refine the annual forecasts utilizing market feedback. Stocking across all points in the distribution chain was driven by a push-oriented system that did not have any provision for factoring in market requirements. Actual safety stocks maintained at depots were significantly higher than the target safety stocks agreed on at the beginning of the operating year. No system was in place to monitor and correct this practice. There was also a high level of old/damaged/slow-moving stocks. Dead stock was allowed to accumulate in the system mainly because there was an absence of visibility into inventory details across stocking points. The process to monitor and act on dead stock was not adhered to and records of slow-moving/old/damaged stocks were not maintained methodically at the stocking points.

A study was conducted focusing on the inventory-related issues at the BSRs and depots. This included inventory holding as a proportion of sales, practices employed for tracking goods in the warehouse, and the proportion of fast- and slow-moving stocks to the total inventory. The study also looked at the inventory planning process pertaining to forecast accuracy, the process of reviewing and revising forecasts, the level of safety stock at each location, combined with the process to review and reset the same

An IT solution was implemented for computing the forecast using consolidated orders, with factoring for promotions and seasonality. The IT solution also enabled the organization to calculate safety stock levels based on the number of weeks of sales target. Demand planning and forecasting were made a periodic activity using the IT solution to align forecasting with market orders and actual sales. The process of setting safety stocks at depots was made periodic and dynamic, based on updated sales data. Furthermore, norms were set to act on damaged/old and other dead stocks. Clear steps were laid down regarding the liquidation or destruction of these stocks. An accountability chain was set up in the organization to monitor and authorize activities in this regard, based on the visibility provided by the IT solution.

The overall benefit of the exercise was that the organization was able to ensure availability of fresh stocks in the market. This was achieved mainly by reducing inventory levels across the chain and also through better stock management at the depots. The company achieved a stock-level reduction from 8.2 weeks to 5.5 weeks at the BSRs and from 6.5 weeks to 4 weeks at the depots. Transparency of saleable and damaged stocks quantities across the supply chain resulted in more accurate demand planning, stock allocation, and production.

Source: K. Ravichandran and Debjyoti Paul, "Best Practices in Inventory Management," http://forumcentral.sify.com/athena/login/casestudyinventory.pdf. Last accessed on 15 December 2008.

The term **inventory** refers to any idle resource that can be put to some future use. Manufacturing and several service organizations have significantly invested in inventory. Often, investment in inventory has a direct bearing on the profitability of a firm. Experiences in the last twenty years suggest that the world-class performance of a firm hinges on the firm's ability to cut investment in inventory to very low levels. Automobile assembly plants and component manufacturers are known to carry very little inventory and yet provide good quality finished goods at the right time. In addition to cutting down cost, reduced inventory levels help an organization improve quality, planning systems, and supply chain coordination. They also reduce wastage and obsolescence. Hence, inventory planning and control continues to derive considerable attention of the management in organizations.

The term **inventory** denotes any idle resource that could be put to some future use.

17.1 INVENTORY PLANNING FOR INDEPENDENT DEMAND ITEMS

In manufacturing organizations, finished goods and spare parts typically belong to the category of independent demand items. While planning for a dependent demand item is done to meet manufacturing requirements, in the case of independent demand items, it is done to meet customer requirements. Two attributes characterize and distinguish independent demand items: They are in continuous demand, and there is an element of considerable uncertainty in the demand for such items.

In manufacturing organizations, finished goods and spare parts typically belong to the category of independent demand items.

Continuous Demand

Independent demand items are in continuous demand. Consider the sale of consumer appliances of manufacturers such as Videocon or LG. The demand for 32” LCD colour television panels in a particular city will be continuous. When there is a continuous demand for an item, constant availability of items and periodic replenishment of stock are important elements of the planning process. Non-availability of items translates into lost sales, poor customer goodwill, and additional costs in servicing the promised deliveries.

Uncertainty of Demand

There is an element of considerable uncertainty of demand in the case of independent demand items. On the other hand, in the case of dependent demand items, the demand is always derived and hence known with certainty. For example, the number of tyres required per month for new vehicles is known accurately once the monthly production is finalized. However, the number of spark plugs required for sale as spare parts needs to be estimated on some basis. Therefore, inventory planning for independent demand items should include some cushion for handling uncertainties whenever they are significant.

Given these requirements, inventory planning of independent demand items must address the following two key questions:

a. *How much?* Good inventory planning must devise means by which the planner can continuously replenish the stock as it depletes over time. The replenishment could be of a fixed quantity or variable. It could be based on the costs associated with inventory. It could also satisfy certain practical considerations such as truck capacity, quantity discounts, and minimum order quantity restrictions posed by the supplier.
b. *When?* The other issue is the timing of replenishment. Since demand is continuous and uncertain, the timing of replenishment is equally crucial. There are numerous ways of addressing the timing. It could be based on consumption patterns, the value of the item, managerial preferences for review, and other practical considerations.

> Inventory planning of independent demand items must address the two key questions: *how much, and when?*

17.2 TYPES OF INVENTORY

Before planning for inventory, it is important to know why organizations carry inventory and what factors influence the level of investment. Five types of inventory are normally found in most organizations.

Seasonal Inventory

Organizations carry inventory to meet fluctuations in demand arising out of seasonality. During festival periods, the demand for consumer durables may be high due to an increase in disposable income in the hands of consumers. In order to meet this surge in demand, there is inventory build-up during non-peak periods. Similarly, in a fast-food restaurant, a certain amount of inventory build-up happens during non-peak hours to handle the increase in demand during peak hours. In both these cases, inventory plays the crucial role of addressing short-term capacity issues in an organization.[1]

Five types of inventory are normally found in organizations: *seasonal inventory*, *decoupling inventory*, *cyclic inventory*, *pipeline inventory*, and *safety stock*.

Decoupling Inventory

Manufacturing systems typically involve a series of production and assembly workstations. Raw material passes through these stages before it is converted into finished goods. Each stage behaves idiosyncratically on account of varying process times, downtimes, and resource availability. Therefore, the planning and control of such multi-stage production processes becomes very complex. One way to simplify the production planning and control problem is to decouple successive stages using inventory at some intermediate points. Each stage will have an input buffer and an output buffer. The output buffer of the preceding stage becomes the input buffer of the succeeding stage. Inventory decisions in this case require analysis of workstation capacities, resource availability, and bottlenecks.

Figure 17.1 illustrates the use of decoupling inventory. In the first case, there is no decoupling inventory. In this case, all the ten stations of production are to be closely monitored and flow balance is to be ensured on a continuous basis. If there is a problem in one of the stations, it will affect all upstream and downstream stations. Further, the vagaries of demand uncertainty will directly affect the system's performance. Planning and control is challenging, especially when the number of stations is very large. On the other hand, the second case in Figure 17.1 has decomposed the production into three major stages. Each stage is linked to the other using decoupling inventory. This enables each stage to work with reasonable levels of independence. Further, the adverse impact of one stage will not immediately affect the others. Therefore, a certain amount of decentralized planning and control is possible.

FIGURE 17.1 An illustration of the use of decoupling inventory

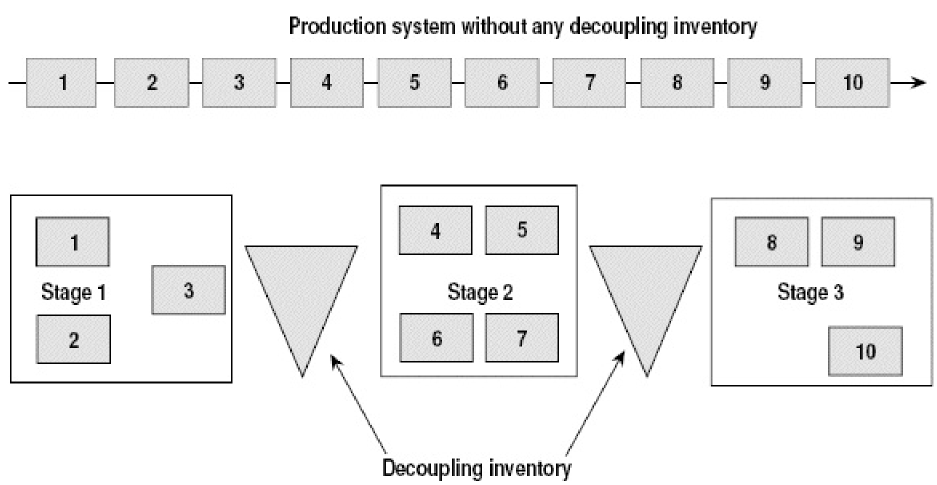
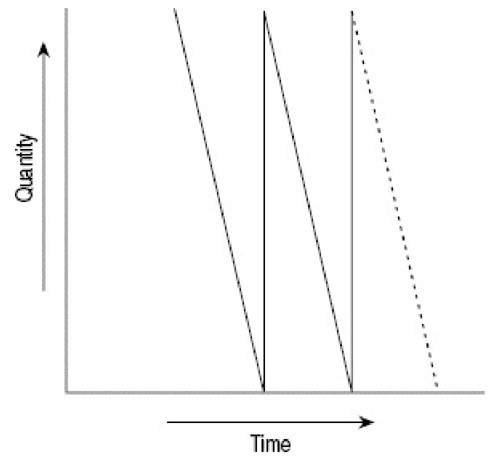


FIGURE 17.2 Cyclic inventory



Cyclic Inventory

It is customary for organizations to order inventory in repeated cycles and consume them over time. For example, a hospital may order disposable syringes in quantities of 10,000. If the average consumption rate is 500 per day, then it takes 20 days to deplete one order. On the twenty-first day, another order of 10,000 will arrive and it will be consumed over the next 20 days, and so on. Cyclic inventory goes through a saw-toothed pattern as shown in Figure 17.2. Each cycle begins with replenishment and ends with complete depletion of the inventory.

If Q is the order quantity per cycle,

$$\text{The average cyclic inventory} = \frac{Q+0}{2} = \frac{Q}{2} \qquad (17.1)$$

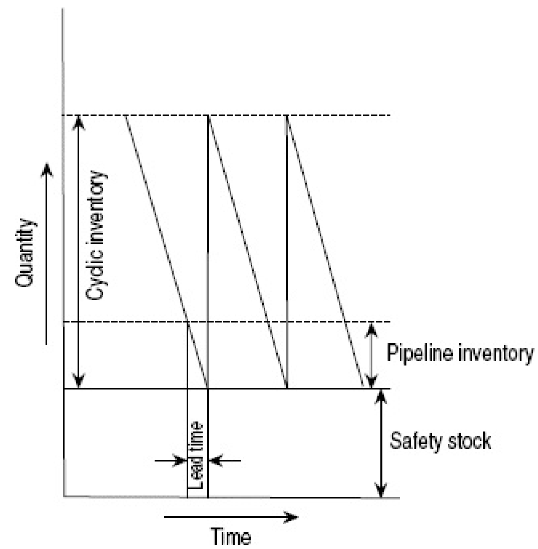
Pipeline Inventory

Pipeline inventory pertains to the level of inventory that organizations carry in the long run due to non-zero lead time for order, transport, and receipt of material from the suppliers. Because of the geographical distances between the buyers and the suppliers and the host of business processes involved in ordering and receiving material, there is a time delay between order placement and order receipt. The inventory carried to take care of these delays is known as pipeline inventory.

Consider the example of the hospital. Suppose it takes three days to supply disposable syringes. Then the hospital should place an order at the end of Day 17 in order to replenish the stock to 10,000. This means that an order will be placed when the inventory level reaches 1,500 (3 days at the rate of 500 syringes per day).[2] In general, if the lead time for supply is L, and the mean demand per unit time is μ, then the pipeline inventory is $L \times \mu$.

In the long run, the system will always have this inventory in order to take care of lead time for supply. The only way organizations can reduce this inventory is to cut down lead time for procurement, production, and distribution. Locating suppliers nearby, re-engineering the business processes related to procurement and distribution of materials, and using efficient alternatives for logistics are some of the ways in which an organization can reduce lead time and pipeline inventory.

FIGURE 17.3 Cyclic inventory, pipeline inventory, and safety stock



Safety Stock

Organizations also have additional investment in inventory to buffer against uncertainties in demand and supply of raw material and components. We know from the elementary theory of probability distributions that when demand is stochastic, carrying average inventory will ensure that the demand is met only 50 per cent of the time (in the long run). However, in order to improve the availability to meet uncertain demand, an additional quantity known as safety stock is kept. Greater investment in safety stock leads to a lower probability of inventory going out of stock. Similarly, the higher the uncertainty, the greater is the need for safety stock. Safety stock only serves to prevent shortages in the short run. However, in the long run, the demand will tend toward an average value and the safety stock will not be consumed. Figure 17.3 represents an inventory system with safety stock and other types of inventory.

EXAMPLE 17.1

A manufacturer of transformers requires copper (both in plate and wire form) as a key ingredient. The average weekly requirement of copper is 200 tonnes. The lead time for the supply of copper is two weeks. If the manufacturer places monthly orders of copper, analyse the various types of inventory in the system.

Solution
Order quantity Q = 1 month requirement = 800 tonnes.

Cyclic inventory in the system $= \frac{Q}{2} = \frac{800}{2} = 400$ tonnes.

Lead time L = 2 weeks
Average weekly demand μ = 200 tonnes
Pipeline inventory = $L \times \mu = 200 \times 2 = 400$ tonnes.

Reducing safety stock calls for reducing uncertainty in the system. Investment in superior planning and forecasting systems and good supplier development practices will help organizations reduce uncertainty in the system. In the case of components manufactured in-house, better production planning and improved maintenance of resources will help reduce uncertainty in the system.

Reducing safety stock calls for reducing uncertainty in the system.

Cyclic inventory, pipeline inventory, and safety stock are critically linked to both the "how much" and "when" questions in inventory planning. Lead time influences the "when" decision directly and determines the level of pipeline inventory in the system. Similarly, cyclic inventory is the outcome of the "how much" decision that an inventory planner makes. Safety stock influences both "how much" and "when" in an indirect sense. However, in order to understand how these decisions are made, one needs to understand various costs associated with inventory planning and control.

Cyclic inventory, pipeline inventory, and safety stock are critically linked to the "how much" and "when" questions in inventory planning.

17.3 INVENTORY COSTS

There are several costs associated with inventory planning and control. These costs could be classified under three broad categories:

- The cost of carrying inventory. All costs related to maintaining inventory in organizations will be classified under this.
- The cost associated with ordering material and replenishing it in cyclic intervals.
- The cost arising out of shortages.

Inventory control models should take these into consideration and aim at minimizing the sum of all these costs. Sometimes, the unit cost of the item for which inventory planning is done is also a relevant cost for decision making. This is because when large quantities are ordered, there could be some discount in the unit cost of the item.

Inventory-carrying Cost

Organizations need to spend a considerable amount of money to carry inventory. The most significant component is the interest for the short-term borrowals for the working capital required for inventory investment. The second significant cost relates to the cost of stores and warehousing and the administrative costs related to maintaining inventory and accounting for it. The elements of storing and warehousing costs include the following:

- Investment in store space and storage and retrieval systems
- Software for maintaining the inventory status
- Managerial and other administrative manpower to discharge various activities related to stores
- Insurance costs
- Cost of obsolescence, pilferage, damages, and wastage

TABLE 17.1 Computation of Carrying Cost: An Illustration

Sl. No.	Item of Expenditure (Annual)	Amount (₹)
1	Stationary	75,000.00
2	Insurance premium	375,000.00
3	Establishment expenses and overheads	275,000.00
4	Salary of stores personnel	1,100,000.00
	Total expenditure	**1,750,000.00**
	Average value of the inventory in stores	**35,000,000.00**
	Warehousing cost (in % inventory value)	**5.00%**
a	Cost of warehousing	5.00%
b	Cost of capital (assumed)	15.00%
c	Obsolescence (estimated historically)	2.00%
d	Damages, spoilage, etc. (estimated historically)	1.00%
	Carrying cost (%)	**23.00%**

In the case of high-tech electronics and short-shelf-life items, such as active chemical compounds, food items, and pharmaceutical formulations, obsolescence costs could be significant. Table 17.1 shows a sample computation of carrying cost for a company. The components of inventory-carrying costs exert considerable pressure on an organization to keep inventory levels low. However, the ability of an organization to reduce inventory depends on the nature of business processes in place, the lead time for procurement, and the quality of planning, as pointed out in the earlier section.

Note that all the costs related to carrying inventory are directly related to the level of inventory. Graphically, it can be shown as a simple linear relationship (Figure 17.4). Let C_c denote the inventory-carrying cost per unit per unit time. Since the interest component is the predominant part of C_c, the usual practice is to represent C_c as a percentage of the unit cost of the item. Thus, if C_u is the unit cost of the item, then $C_c = iC_u$, where i is in percentage. For example, if the unit cost of an item is ₹5,000, the annual interest charges are 12 per cent, and the other annual costs related to carrying inventory are 3 per cent, then the inventory-carrying cost is 15 per cent of the unit cost, that is, ₹750 per unit per year.

For an order quantity of Q, the average inventory carried by an organization is $Q/2$. Therefore, Cost associated with carrying inventory

$$= \left(\frac{Q}{2} \times C_c \right) \quad (17.2)$$

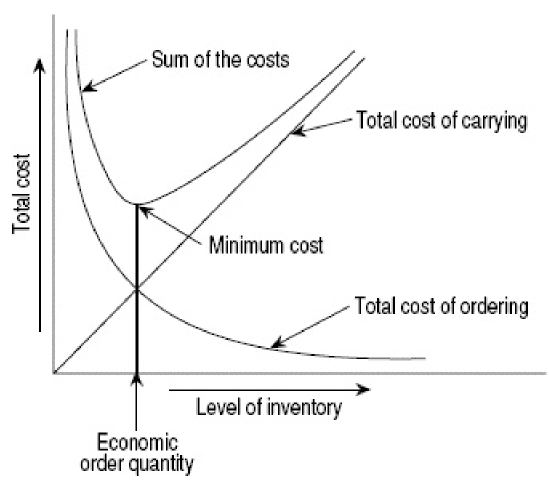
Cost of Ordering

Replenishment of cyclic inventory is achieved by ordering material with the suppliers. Organizations perform a series of tasks related to ordering material. These include search and identification of appropriate sources of supply, price negotiation, contracting and purchase-order generation, follow-up and receipt of material, and eventual stocking in the stores after necessary accounting and verification. In Chapter 7, we have discussed several aspects pertaining to this in some detail. All these tasks involve manpower, resources, and time that can be classified under cost of ordering. Since several of these costs are fixed in nature, ordering a larger quantity could reduce the total costs of ordering. A larger order quantity Q will require fewer orders to meet a known demand D, and vice versa. The relationship between Q and the total cost of ordering is graphically shown in Figure 17.4. Table 17.2 shows a sample computation of ordering cost for a company.

The number of orders to be placed to satisfy a demand of $D = D/Q$. If C_0 denotes the cost of ordering per order, then:

$$\text{Total ordering cost} = \left(\frac{D}{Q} \times C_0 \right) \quad (12.3)$$

FIGURE 17.4 Behaviour of ordering and carrying costs of inventory



Sometimes, components required for use in an organization are sourced from within. A division or a department of the organization may be specially manufacturing the required components for internal consumption. In such situations, the costs associated with setting up the required machinery will represent the cost of ordering. For example, let us assume that a component is produced in-house. In order to manufacture the component, two machines are to be set up and it takes 60 minutes and 120 minutes respectively in these machines. It also requires consumables and tools for the purpose of setting up the machine. Finally, direct labour time and supervisor time needs to be devoted for the activity. By estimating the cost of all these factors, we can arrive at the cost of set-up.

The cost of carrying and the cost of ordering are fundamentally two opposing cost structures in inventory planning. For instance, when the order quantity becomes smaller, the total cost of carrying inventory decreases. On the other hand, since a large number of orders are to be placed to satisfy the demand, the total ordering costs will go up. Conversely, when the order quantity is increased, while the total cost of ordering will come down owing to fewer orders being placed, the total cost of carrying inventory will increase due to an increase in the average cyclic inventory in the system. Balancing these two opposing costs will be central to inventory planning and control in any organization. Figure 17.4 gives a graphical representation of the sum of these two costs.

TABLE 17.2 Computation of Ordering Cost: An IIustration

Sl. No.	Item of Expenditure (Annual)	Amount (₹)
1	Stationary	80,000.00
2	Telephone	40,000.00
3	Other communication expenses	60,000.00
4	Salary of purchase department personnel	1,100,000.00
5	Inwards goods inspection section expenses	350,000.00
6	Other expenses and overheads	200,000.00
	Total expenditure	**1,830,000.00**
	No. of purchase orders generated	**600.00**
	Average cost of ordering	**3,050.00**

Cost of Shortages

Despite careful planning, organizations are likely to run out of stock for several reasons. There could be a sudden surge in demand. Alternatively, the suppliers might not have delivered the material as per schedule, or a lot could have been rejected because of defective components. Such events disrupt production and have a cascading effect down the supply chain. Delivery schedules are missed, leading to customer dissatisfaction and loss of goodwill. It also introduces additional costs arising out of pushing the order back and rescheduling the production system to accommodate these changes. Rush purchases, uneven utilization of available resources, and lower capacity utilization further escalate the costs in the system. All these form part of the cost of shortage.

> The cost of carrying and the cost of ordering are fundamentally two opposing cost structures in inventory planning.

The cost of shortage per unit is denoted by C_s. Since the effects of shortage are vastly intangible, it is difficult to accurately estimate C_s. In practice, managers tend to use other measures to incorporate the cost of shortage if estimation of C_s proves to be futile.

17.4 INVENTORY CONTROL FOR DETERMINISTIC DEMAND ITEMS

Let us consider a situation in which the demand for an item is continuous and is known with certainty. Since the demand is known, we exclude the possibility of having shortages. Better inventory control requires that we answer the "how much" and "when" questions by balancing the total costs of carrying inventory and ordering. For an order quantity of Q, we can compute the total cost of carrying and ordering from Eqs. 17.2 and 17.3.

Total cost of the plan = Total cost of carrying inventory + Total cost of ordering

$$TC(Q) = \left(\frac{Q}{2} \times C_c\right) + \left(\frac{D}{Q} \times C_0\right) \qquad (17.4)$$

When the total cost is minimum, we obtain the most economic order quantity (EOQ).

By taking the first derivative of Eq. 17.4 with respect to Q and equating it to zero, we can obtain the EOQ. Differentiating Eq. 17.4 with respect to Q we obtain:

$$\frac{dTC(Q)}{dQ} = \left(\frac{C_c}{2}\right) - \frac{C_0 D}{Q^2}$$

Note that the second derivative is positive and hence we obtain the minimum cost by equating the first derivative to zero. Equating the first derivative to zero and rearranging the terms, we obtain Eq. 17.5.

Denoting EOQ by Q^*, we obtain the expression of Q^* as:

$$Q^* = \sqrt{\frac{2C_0 D}{C_c}} \qquad (17.5)$$

$$\text{Optimal number of orders} = \frac{D}{Q^*} \qquad (17.6)$$

$$\text{Time between orders} = \frac{Q^*}{D} \qquad (17.7)$$

Q^* answers the “how much” question directly. Every time the inventory depletes to zero, it is economical to place an order equal to Q^*. Similarly, time between orders answers the “when” question. Since the demand is continuous, the demand rate will determine “when” to place an order. For instance, if the annual demand for an item is 2,500 units and if there are 250 working days, the daily demand is 10. If Q^* is 300, then it is implied that an order needs to be placed every 30 days.
2500

EXAMPLE 17.2

A two-wheeler component manufacturing unit uses large quantities of a component made of steel. Although these are production items, the demand is continuous and inventory planning could be done independent of the production plan. The annual demand for the component is 2,500 boxes. The company procures the item from a supplier at the rate of ₹750 per box. The company estimates the cost of carrying inventory to be 18 per cent per unit per annum and the cost of ordering as ₹1,080 per order. The company works for 250 days in a year. How should the company design an inventory control system for this item? What is the overall cost of the plan?

Solution
Annual demand for the item (D) = 2,500 boxes
Number of working days = 250

The average daily demand = $\frac{2500}{250} = 10$ boxes

Unit cost of the item (C_u) = ₹750.00 per box
Inventory-carrying cost = iC_u = 0.18 × 750.00 = ₹135.00 per unit per year
Cost of ordering (C_0) = ₹1,080.00 per order

The “how much” decision:
Economic order quantity(Q^*)

$$= \sqrt{\frac{2C_0D}{C_c}} = \sqrt{\frac{2 \times 1080 \times 2500}{135}} = 200 \text{ Boxes}$$

Number of orders to be placed

$$= \frac{D}{Q^*} = \frac{2500}{200} = 12.5 \cong 13^3$$

The “when” decision:

Time between orders

$$= \frac{Q}{D} = \frac{250}{2500} = 0.08 \quad \text{year} = 0.08 \times 250 = 20 \text{ days.}$$

Total cost of the plan

$$= TC(Q^*) = \left(\frac{Q^*}{2} \times C_c\right) + \left(\frac{D}{Q^*} C_0\right)$$

$$= \frac{200}{2} \times 135 + \frac{2500}{200} \times 1080 = ₹27{,}000$$

Hence, the manufacturer will place an order for 200 boxes of the component once in every 20 days and will incur a total cost of ₹27,000 for the plan. Any quantity above or below will increase the cost of the plan.

Problems in the EOQ model

We have made several assumptions while deriving Q^*. The salient among these include the following:

a. The demand is known with certainty and is continuous over time.
b. There is an instantaneous replenishment of items.
c. The items are sourced from an external supplier.
d. There are no restrictions on the quantity that we can order.
e. There are no preferred order quantities for the items.
f. No price discount is offered when the order size is large.

In practice, several of these assumptions do not hold. Despite this, the EOQ model can be applied with suitable modifications because it is robust. Because of the square root in the formula, changes in model parameters, such as demand and cost, have less impact on the solution. If demand is not known accurately, one can use representative figures for D and assess the impact of changes on the total cost of the plan (see Problem 4 at the end of the chapter). The assumption of instantaneous replacement can be easily taken care of by placing an order ahead. If the lead time is L, then by placing an order L periods ahead of depletion of inventory, one can ensure availability of material. Similarly, if the items are manufactured in-house, it is possible to estimate the economic run length by a simple modification to Eq. 17.5.[4]

> The EOQ model is robust and can be applied in several real-life settings with some modifications.

Assumptions (d), (e), and (f) indicate the need for examining the suitability of utilizing order quantities different from Q^*. Large order sizes result in price discounts. There are other reasons for placing a larger order than what the EOQ suggests. Sometimes, it will be economical to transport a truckload of items and save on transportation cost. In other cases, the supplier may impose a minimum order quantity. In all these cases, the relevant cost for analysis includes cost elements other than carrying and ordering. An analysis of these relevant costs will help the inventory planner make an appropriate choice in order quantity. See Example 17.3 for an illustration of this.

EXAMPLE 17.3

Consider Example 17.2. Assume that the carrying cost of the component remains ₹135 per unit per year and that the supplier is willing to offer a discount on the unit price as per the following structure:

Up to 399 boxes = No discount
400 − 799 boxes = 2 per cent discount
800 − 1,000 boxes = 3 per cent discount
What should the company do in this case?

Solution

The economic order quantity is 200 boxes and the unit price of the item is ₹750.

There are two other order quantities at which the unit price changes on account of discount.

At Q1 = 400, unit price of the item = 0.98 × 750 = ₹735.00
At Q2 = 800, unit price of the item = 0.97 × 750 = ₹727.50

Since there is a discount on the price as the order quantity is varied, the total cost comparison between alternatives can be made only after incorporating the purchase price.

Total cost for Q^*

$$= TC(Q^*) = \left(\frac{Q^*}{2} \times C_c\right) + \left(\frac{D}{Q^*} \times C_0\right) + D \times C_u$$
$$= \frac{200}{2} \times 135 + \frac{2500}{200} \times 1080 + 2500 \times 750$$
$$= ₹1,902,000$$

Total cost for $Q1$

$$= TC(Q1) = \left(\frac{Q1}{2} \times C_c\right) + \left(\frac{D}{Q1} \times C_0\right) + D \times C_u$$
$$= \frac{400}{2} \times 135 + \frac{2500}{400} \times 1080 + 2500 \times 735$$
$$= ₹1,871,250$$

Total cost for *Q*2

$$= TC(Q2) = \left(\frac{Q2}{2} \times C_c\right) + \left(\frac{D}{Q2} \times C_0\right) + D \times C_u$$
$$= \frac{800}{2} \times 135 + \frac{2500}{800} \times 1080 + 2500 \times 727.5$$
$$= ₹1,875,125$$

Since *TC*(*Q1*) is the lowest among the alternatives, the firm can make use of the discount offered and reset the order quantity to 400 boxes.

17.5 HANDLING UNCERTAINTY IN DEMAND

With some modifications, the EOQ model can accommodate several practical considerations. However, when the demand is uncertain, instances of shortages occur while operating the system with EOQ. There are two ways of handling the issue of shortages. One is to incorporate shortage cost in the model. The other is to use the concept of service level. **Service level** is the desired probability of not running out of stock between the time an order is placed with a supplier and the order is received. For example, if an organization wants to operate with a 90 per cent service level, it means that in the long run, the organization is able to meet the demand on 90 per cent of all occasions.

Service level is the desired probability of not running out of stock between the time an order is placed with a supplier and the order is received.

Consider an item with uncertain demand. When the item is available in stock, there is no risk of shortage. However, when an order is placed, the demand can be met only with the available stock until the stock is replenished by an order. Hence, if an organization is protected from the risks of shortage during the supply lead time, then inventory planning is better. The concept of service levels seeks to achieve this objective. Let us understand the concept of service level through a simple example.

Consider an item with uncertain demand that has a lead time of one week. Based on observed consumption patterns one can estimate the weekly demand. Table 17.3 has illustrative data for the item. The last two columns show the cumulative frequency of demand exceeding the lower class. For example, the weekly demand exceeded 30 units during 98.25 per cent of the observed occasions and exceeded 180 units during 18.42 per cent of the occasions. The information in the table can also be plotted as a frequency ogave (see Figure 17.5).

From the data, one can compute the average demand during lead time to be 143 units. If the organization stocks 143 units at the time of placing the order with the supplier, then in the long run, it will be able to meet the demand during lead time only on 50 per cent of the occasions. In other words, the organization has a 50 per cent service level if it operates with this inventory level. Clearly, this will be an undesirable situation and managers would want to offer better service. From the data, we can compute the number of units to be stocked to offer 90 per cent and 95 per cent service levels to be 203 and 224 units, respectively. By stocking 60 more units (203–143), the organization can improve the service level from 50 per cent to 90 per cent. Similarly, by investing an additional 21 units, it can further increase the service level to 95 per cent. This additional stock is known as “safety stock” because it provides the needed safety to an organization to handle uncertain demand during lead time.

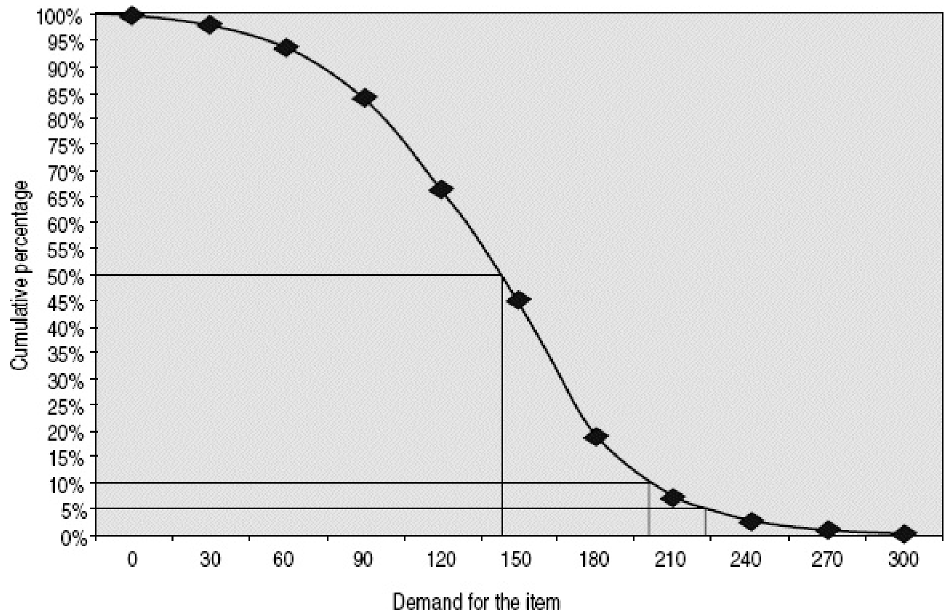
TABLE 17.3 The Service Level Concept: An Illustration

		Demand Exceeding Lower Class	
Demand During Lead Time	**Frequency of Occurrence**	**Cumulative Frequency**	**Cumulative Percentage**
0–30	2	114	100.00%
31–60	5	112	98.25%
61–90	11	107	93.86%
91–120	20	96	84.21%
121–150	25	76	66.67%
151–180	30	51	44.74%
181–210	13	21	18.42%
211–240	5	8	7.02%
241–270	2	3	2.63%
271–300	1	1	0.88%

The concept of service levels permits managers to sidestep problems related to estimating shortage cost per unit. Using this concept, it is possible for managers to relate the amount of additional investment required and the improvement in service and strike appropriate trade-offs between additional investment and service. In the example we just discussed, a 5 per cent increase in service level from 90 per cent to 95 per cent entails an additional investment of 21 units. Depending on the unit cost of the item in question, the cost of carrying and the competitive scenario, managers can strike a better trade-off in their choice towards the appropriate level of service that needs to be offered.

The concept of service level permits managers to sidestep problems related to estimating shortage cost per unit.

FIGURE 17.5 Frequency ogave of weekly demand



These computations can be generalized by using a few notations and replacing the empirical distribution for demand by a theoretical distribution such as normal distribution.

Let the demand during lead time follow a normal distribution with:

$\mu_{(L)}$, the mean demand during lead time and

$\sigma_{(L)}$, the standard deviation of demand during lead time

Let $(1 - \alpha)$ denote the desired service level, where α denotes the probability of a stockout.

Z_α is the standard normal variate corresponding to an area of $(1 - \alpha)$ covered on the left side of the normal curve.

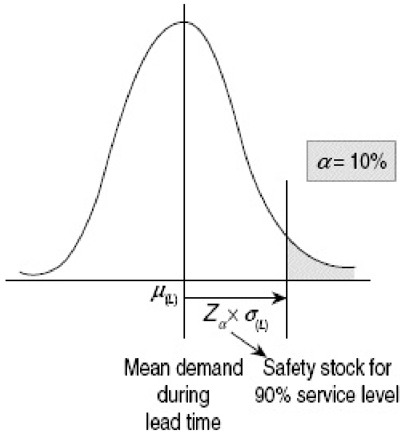
An expression for safety stock (SS) is given by SS = $Z_\alpha \times \sigma_{(L)}$. Figure 17.6 represents the principle of safety stock and service level.

Due to the introduction of safety stock, the total cost of the plan will change. The total cost for an order quantity equal to Q^* is given by:

Total cost of the plan = Cost of ordering + Cost of carrying cyclic inventory + Cost of carrying safety stock

$$TC(Q^*) = \left(\frac{D}{Q^*} \times C_0\right) + \left(\frac{Q^*}{2} \times C_c\right) + \left((Z_\alpha \times \sigma_{(L)}) \times C_c\right) \qquad (17.8)$$

FIGURE 17.6 Illustration of service level and the safety stock concept



If the organization places an order when the stock on hand is equal to the sum of mean demand during lead time and safety stock, then it will be able to provide a service level of $(1 - \alpha)$ in the long run. Therefore, an expression for reorder point (ROP) for systems with uncertain demand is given by:

$$\text{ROP} = \mu_{(L)} + Z_\alpha \times \sigma_{(L)} \tag{17.9}$$

17.6 INVENTORY CONTROL SYSTEMS

The previous sections provide organizations with the necessary building blocks to put inventory control systems in place. In practice, organizations employ some methods to manage and control inventory. Prominent among them include the use of continuous review of inventory and periodic review of inventory. Let us understand the working of these two systems, and also how various decision parameters of these systems can be estimated using the building blocks provided in previous sections.

The Continuous Review (Q) System

Organizations widely use a continuous review system called a *two-bin* system. In operation, the available inventory is stocked in two bins, first in a smaller bin and the balance in a larger bin. As the material is consumed, the larger bin is emptied first. As soon as the larger bin is empty, an order is placed with a supplier for a predetermined quantity, Q, and until the material arrives in the stores, the smaller bin is consumed. During replenishment, the smaller bin is filled in first and the cycle continues. Can you guess what will be the capacity of the smaller bin? A little thought will help you appreciate that the capacity of the smaller bin is indeed the reorder point as per the calculations that we performed in the previous section.

Figure 17.7 shows the general working of a Q system. The inventory position in the system[6] is continuously monitored to check if it has reached the reorder point. Once it reaches the reorder point, an order is placed for a fixed quantity of Q.

EXAMPLE 17.4

The daily demand for an item is stochastic and follows the normal distribution with a mean of 100 and a standard deviation of 20. The supplier of the item takes two weeks to deliver the item from the date the order is placed. What will be the appropriate reorder point for 90 per cent and 95 per cent service level? The cost of ordering is ₹1,000 per order and the carrying cost is ₹250 per unit per year. There are 250 working days in a year. If the organization places orders in fixed quantities of 500, what will be the total cost of the plan?

Solution

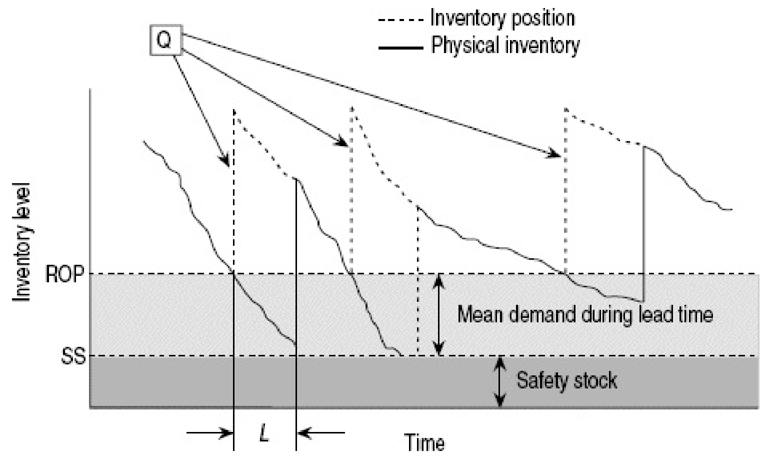
Mean daily demand = 100
Number of working days in a year = 250
Total annual demand = 25,000
Lead time for supply (L) = 2 weeks = 14 days
Therefore, mean demand during LT, $\mu_{(L)} = 14 \times 100 = 1{,}400$
Standard deviation of daily demand = 20
Variance of daily demand = 400
Variance of the demand during $LT = 14 \times 400 = 5{,}600$
Standard deviation of demand during LT[5], $\sigma_{(L)} = 74.83$
For 90 per cent service level, α = 10 per cent and $(1 - \alpha)$ = 90 per cent.
From standard normal tables $(Z_\alpha) = 1.28$
Safety stock (SS) = Za × $\sigma_{(L)} = 1.28 \times 74.83 = 95.78 \approx 96$
Therefore, ROP = $\mu_{(L)} + Z_\alpha \times \sigma_{(L)} = 1{,}400 + 96 = 1{,}496$
Total cost of the plan,

$$
\begin{aligned}
TC(Q) &= \left(\frac{D}{Q^*} \times C_0\right) + \left(\frac{Q}{2} \times C_c\right) + \left((Z_\alpha \times \sigma_{(L)}) \times C_c\right) \\
&= \frac{25{,}000}{500} \times 1000 + \frac{500}{2} \times 250 + 96 \times 250 \\
&= ₹136{,}500
\end{aligned}
$$

For 95 per cent service level, the corresponding values are:
α = 5 per cent, $(1 - \alpha)$ = 95 per cent and $Z_\alpha = 1.645$, SS = 123.09 ≈ 124 and ROP = 1,400 + 124 = 1,524.
Total cost of the plan

$$
= \frac{25{,}000}{500} \times 1000 + \frac{500}{2} \times 250 + 124 \times 250 = ₹143{,}500
$$

FIGURE 17.7 Continuous review (Q) system



Due to this design choice of ordering fixed quantities, Q systems are also known as fixed order quantity systems. After a lead time of *L*, the inventory arrives in the system and the physical inventory increases. In Figure 17.7, the continuous line indicates the on-hand inventory in the system. When there is a pending order, the physical inventory in the system is less but the total inventory in the system must take into consideration scheduled receipts in the future. This is shown by the dotted line of inventory movement. The two constant dotted lines in the bottom of the figure represent the safety stock built into the system and the average demand during lead time (LT). The summation of these two quantities is the reorder point for the system.

> The “when” decision in a Q system is answered by reorder point.

The “when” decision is answered by ROP. We can employ the computations in the previous section to arrive at ROP. The “how much” decision is answered by our choice of Q. Several alternatives are available to fix Q.

- One is to compute EOQ and fix Q at this value.
- The other is to fix Q to be the minimum order quantity that the supplier insists, if EOQ value is lesser than this.
- The third option is to have any other preferred quantity arising out of practical considerations such as full truckload requirement, quantity discounts, savings in transportation costs, economies of scale, or any other consideration.

The total cost of using a Q system can be computed using Eq. 17.8 for a chosen value of Q.

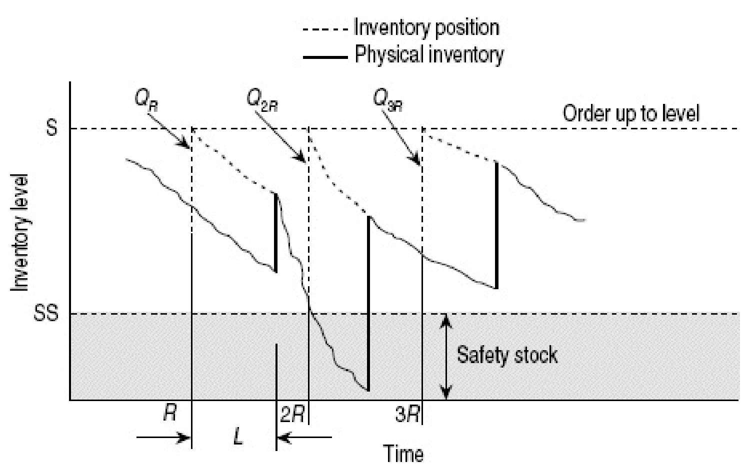
The Periodic Review (P) System

An alternative model for inventory control, known as the periodic review system, operates differently from the Q system. In a periodic review system, the inventory level in the system is reviewed at fixed intervals of time. Therefore, these systems are also known as fixed order interval systems. At the time of review, an order is placed to replenish the inventory to a predetermined level, *S*. The parameter *S*, known as the order up to level, dictates the order quantity. If at any time R, a review is made and if the inventory position in the system is I_R[7], then order quantity $Q_R = S - I_R$. Figure 17.8 illustrates the working of the P system.

The two decisions "when" and "how much" are made in a different fashion compared to the Q system. The review period R determines when to order. There are several alternatives available for determining R. One way is to use the EOQ model, derive the time between orders, and use it for R. Managers tend to review the performance of departments on a periodic basis. R can be linked to such intervals. Alternatively, the MRP system used in some organizations has some time buckets and it is possible to fix R on this basis. In a petrochemical manufacturing unit in western India, the review period is linked to the value of items under inventory control. In the case of low-value items, the review is once in 60 days, and in the case of medium-value items, there is a monthly review. In the case of high-value items, there is a fortnightly review of inventory and ordering decisions are taken.

In a periodic review system, the inventory level in the system is reviewed at fixed intervals of time.

FIGURE 17.8 Periodic review (P) system



The order up to level S determines how much to order. Hence, it is important to derive an appropriate expression for S. Let us consider an instant of time t, when a review is taken and an order is placed with the supplier. The organization gets the next opportunity to review the inventory R periods later. An order placed at that point in time will reach the organization only after L time periods, which is the lead time for supply. Hence, at every review, the organization needs to protect itself from the risks of shortages for a period of (R + L) periods. Therefore, an expression for S can be derived by modifying Eq. 17.9 as follows:

The order-up-to-level S determines how much to order in a P system.

Order up to level S = Mean demand during $(L + R)$ + Safety stock for the period $(L + R)$.

$$S = \mu_{(L+R)} + Z_{\alpha} \times \sigma_{(L+R)} \tag{17.10}$$

Where, $\mu_{(L+R)}$ = Mean demand during $(L + R)$ and $\sigma_{(L+R)}$ = Standard deviation of demand during $(L + R)$

Issues in the P and Q Systems of Inventory Control

The Q system is based on perpetual monitoring of the inventory level in the system. This calls for elaborate methods of keeping track of available inventory. To overcome this problem, organizations use the two-bin system. In recent years, several manufacturing firms have used a variety of visual control systems to manage the Q system. For instance, an automobile component manufacturer in South India stocks steel ingots in its stores with three colour-coded level indicators. When the stock level depletes from the green zone to yellow zone, an order is placed. When the stock level depletes further down to the red zone, close follow-up and monitoring of supply is done to avoid shortage. In other words, the yellow zone corresponds to the reorder point in the Q system and the red zone to the safety stock.

The Q system is less responsive to changes in demand. When there is a decline in demand, the ROPs move to the right. Moreover, the system will continue to order Q even when there is a decline in demand, leading to a situation of keeping the inventory for a longer period. Therefore, ordering high-value components using the Q system during periods of falling demand could increase the risk of excessive stocking of inventory for longer periods and resultant obsolescence. Similarly, if there is an increase in demand, the ROPs shift to the left, necessitating frequent orders and increasing both the ordering cost and the risks of shortages. One way of addressing this problem is to order variable quantities depending on the demand.

> The Q system is less responsive to changes in demand and poses greater difficulty in ordering multiple items from the same supplier.

TABLE 17.4 Comparison of the Q and P Systems of Inventory Control

Criterion	Continuous Review (Q) System	Periodic Review (P) System
How much to order	Fixed order quantity: Q	$S = \mu_{(L+R)} + Z \times \sigma_{(L+R)}$
		$Q_R = S - I_R$
When to order	$ROP = \mu_{(L)} + Z_{\alpha} \times \sigma_{(L)}$	Every R periods
Safety stock	$SS = Z_{\alpha} \times \sigma_{(L)}$	$SS = Z_{\alpha} \times \sigma_{(L+R)}$
Salient aspects	Implemented using two-bin system	More safety stock
		More responsive to demand
	Suited for medium and low value items	Ease of implementation

Another issue in using the Q system is the difficulty of ordering multiple items from the same supplier. Consider three items—A, B, and C—purchased from a supplier using the Q system of inventory control. Since demand attributes can vary between the three, the three items can reach the reorder point on different days. This will call for multiple orders being placed with the same supplier within a short span of time. In addition to increasingthe costs of ordering, the administrative mechanisms related to follow-up and receipt of material against each order is also increased. On the other hand, the organization could have benefited from placing a single order clubbing the requirements for Items A, B, and C. This would have resulted in significant reduction in ordering costs, monitoring and follow-up costs.

> The P system is responsive to demand and enables ordering multiple items from the same supplier at the same time.

However, the P system overcomes several of these limitations of the Q system and offers many advantages over the Q system. This includes more responsiveness to demand, the ability to order multiple items from the same supplier at the same time, ease of planning and control, greater chances for linkages with MRP, and other planning systems in the organization. Table 17.4 compares the salient features of P and Q systems of inventory control. The safety stock investment in the P system, however, is more than that of the Q system because it requires protection from shortage for a longer period of time.

> The safety stock investment in the P system is more than that of the Q system because it requires protection from shortage for a longer period of time.

EXAMPLE 17.5

A manufacturing organization is using a certain raw material, which is consumed in large quantities by various products. The raw material is procured from a local supplier. An extract of the relevant records from the stores indicate the following details about the component:

Mean of weekly demand: 200

Standard deviation of weekly demand: 40

Unit cost of the raw material: ₹300

Ordering cost: ₹460 per order

Carrying cost percentage: 20 per cent per annum

The purchase department has indicated that the lead time for procurement of this raw material is two weeks. Past experience with the supplier suggests that there is no uncertainty with respect to the lead time. The organization has been using EOQ for the purpose of scheduling orders. However, there is a general feeling that it is not working satisfactorily. It is not uncommon for the organization to experience stock-outs. Work out the parameters of the P and Q systems of inventory control.

Solution

EOQ Model
Weekly demand = 200
Number of weeks per year = 52
Annual demand, $D = 200 \times 52 = 10{,}400$
Ordering cost, C_0 = ₹460 per order
Unit cost of the item = ₹300
Carrying cost, C_c = ₹60 per unit per year

Economic order quantity

$$= \sqrt{\frac{2C_0D}{C_c}} = \sqrt{\frac{2 \times 460 \times 10400}{54}} = 399.33 \approx 400$$

$$\text{Time between orders} = \frac{400}{10400} = \frac{2}{52} = 2 \text{ weeks}$$

Since there is a two-week lead time, an order needs to be placed two weeks ahead of complete depletion of the inventory, that is, by the time the inventory position in the system reaches 400 units. The order quantity is 400. There is no safety stock to protect the system from shortages arising out of uncertain demand. The system can be improved either by using a Q system or a P system, as shown here.

Q System
Standard deviation of weekly demand = 40
Lead time, L = 2 weeks
Mean demand during L, $\mu_{(L)} = 2 \times 200 = 400$

Standard deviation of demand during L, $\sigma_{(L)} = \sqrt{2} \times 40 = 56.57$

For a service level of 95 per cent,
$SS = Z_\alpha \times \sigma_{(L)} = 1.645 \times 56.57 = 93.05 \approx 93$
ROP $= \mu_{(L)} + Z_\alpha \times \sigma_{(L)} = 400 + 93 = 493$

Using EOQ as the fixed order quantity, the Q system can be designed such that, as the inventory position in the system reaches 493, an order is placed for 400 units. In the long run this will ensure a service level of 95 per cent.

P System

Using the time between orders derived from the EOQ model as the basis for review period

Review period, R = 2 weeks

Mean demand during ($L + R$), $\mu_{(L+R)} = 200 \times (2 + 2) = 800$ Standard deviation of demand

during ($L + R$), $\sigma_{(L+R)} = \sqrt{(2+2)} \times 40 = 80$

For a service level of 95 per cent,

$$SS = Z_\alpha \times \sigma_{(L+R)} = 1.645 \times 80 = 131.6 \approx 132$$

Order up to position, $S = \sigma_{(L+R)} + \sigma_{(L+R)} = 800 + 132 = 932$
The P system can be designed such that the inventory position in the system is reviewed every two weeks and an order is placed to restore the inventory position back to 932 units. This will ensure a service level of 95 per cent.

17.7 SELECTIVE CONTROL OF INVENTORY

Managing inventory invariably amounts to handling a large number and variety of items. For instance, an automobile manufacturer such as Ashok Leyland may have an inventory of about 50,000 items in their stores. A vast majority of them will be consumed (albeit in varying rates) and will require a mechanism for monitoring inventory on-hand, establishing reorder points, order quantity, and the type of inventory control system that needs to be adopted. Clearly, establishing the same level of monitoring and control for all the items may not be practically feasible. Therefore, organizations devise suitable ways of categorizing the items and adopt mechanisms that have variable levels of control on the different categories of items.

Consider two items in inventory, a simple fastener that costs less than a rupee and a specialized electronic sub-assembly that costs several thousands of rupees. Managing the latter item with close monitoring and tighter control will benefit the organization more than exercising greater managerial attention and control on fasteners. If there were errors in judging the demand for the item, or if extra items were ordered, the impact of these factors will be minimal in the case of fasteners. Also, if there were shortages, the response time to procure fasteners will be very low. On the other hand, in the case of the electronics sub-assembly, the impact will be significant. It is therefore obvious that managers need alternative methods and levels of control while dealing with a multitude of items in the inventory. Selective control of inventory achieves this objective.

ABC Classification

It is clear from the arguments outlined earlier that the unit cost or total cost of items consumed could be one basis on which items could be classified. The ABC classification of inventories is based on the cost (or value) of items consumed. Very high-value items are “A-class items” and may require tighter control. Medium-value items are categorized as “B class” and low-value items as “C class”.

TABLE 17.5 Sample Data for ABC Classification

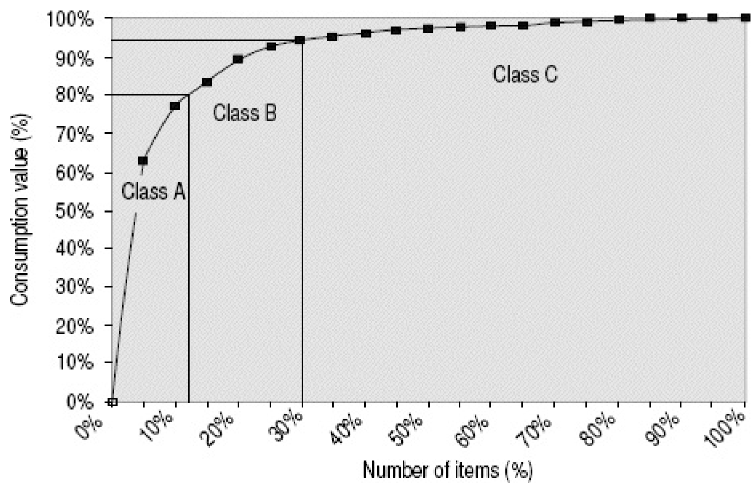
Item No.	Unit Value (₹)	Annual Consumption	Cumulative Value (₹)	Cumulative Number of Items (%)	Consumption Value (%)
1	30,000	80	2,400,000	5.00%	62.96%
2	450	1,200	540,000	10.00%	77.12%
3	590	400	236,000	15.00%	83.32%
4	25,000	9	225,000	20.00%	89.22%
5	600	200	120,000	25.00%	92.37%
6	4,500	15	67,500	30.00%	94.14%
7	400	100	40,000	35.00%	95.19%
8	30	1,000	30,000	40.00%	95.97%
9	145	200	29,000	45.00%	96.73%
10	2,300	12	27,600	50.00%	97.46%
11	9	1,500	13,500	55.00%	97.81%
12	11	1,000	11,000	60.00%	98.10%
13	2,000	5	10,000	65.00%	98.36%
14	4	4,000	16,000	70.00%	98.78%
15	120	120	14,400	75.00%	99.16%
16	20	500	10,000	80.00%	99.42%
17	10	1,000	10,000	85.00%	99.69%
18	80	100	8,000	90.00%	99.90%
19	25	100	2,500	95.00%	99.96%
20	1	1,500	1,500	100.00%	100.00%
Total			**3,812,000**		

Let us consider an example of twenty items in inventory, as shown in Table 17.5. For the twenty items, the unit value and annual consumption are available. Using this, it is possible to compute the cumulative percentage of items and cumulative value of consumption (see the last two columns of Table 17.5) and rank them in the descending order of cumulative value. Figure 17.9 shows a graphical representation of this data.

As shown in Table 17.5, 5–10 per cent of the items typically contributes to 70–80 per cent of the value and constitutes A-class items.[8] These items require greater control and close monitoring. By virtue of constituting a small percentage of the total in terms of volume, it will be practically feasible to exercise close monitoring and greater control. At the other extreme, about 60–70 per cent of items constitute about 5–10 per cent of the total value. These are the C-class items. These items require simple control mechanisms such as level-based reordering. The middle portion of about 10–25 per cent by value and about 20–30 per cent by number of items constitute B-class items. These items require a moderate level of control.

The periodic review and the continuous review systems of inventory control can be linked to the category of items. Since A-class items require closer control and better response to changes in the demand pattern, periodic review systems are more appropriate. In the case of “B” class items, continuous review systems are appropriate. “C” class items can have simple level-based rules for inventory control. C-class items are often available readily off the shelf and it is possible to obtain them by ordering over the phone. Hence, issuing blanket purchase orders for a year and following up with specific requests for supply against the purchase order is often practiced in the case of C-class items.

FIGURE 17.9 ABC classification of inventories



Other Classification Schemes for Selective Control

Using the consumption value as the basis for categorizing inventory is just one method. In practice, organizations use a wide variety of measures for selective control. Each of these has relevance in specific contexts. Let us look at a few alternative categorization schemes:

1. *On the basis of unit cost of the item (XYZ classification)*: (a) high unit cost (X-class item); (b) medium unit cost (Y-class item); (c) low unit cost (Z-class item)

   This classification is based only on the unit cost, whereas ABC classification, takes the consumption pattern also into account. A very high-value item often turns out to be specially made to order, complex, and may call for lengthy supply identification procedures. If the item is consumed in small quantities, it may be classified as a “B-class item” and may be denied adequate managerial attention.

   > *XYZ classification* is based only on the unit cost, whereas *ABC classification* takes into account the consumption pattern as well.

2. *On the basis of movement of inventory (FSN classification)*: (a) fast-moving, (b) slow-moving, (c) non-moving.

This method of classification is ex-post, as opposed to ABC classification, which is future oriented. Items that have not been moving for sometime incur carrying costs and may call for managerial attention for disposal decisions. On the other hand, fast-moving items can be controlled using available inventory control systems.

VED classification is relevant in the case of maintenance items.

3. *On the basis of criticality of items (VED classification)*: (a) vital, (b) essential, (c) desirable.
   This classification is relevant in the case of maintenance items. In several cases a vital item for maintenance may not be very expensive. For instance, a wide variety of oil seals are used in hydraulic systems. If the oil seals are not available, the entire equipment becomes inoperative and has a ripple effect on the entire system. However, by virtue of having smaller unit value or lower consumption value, these items may escape the attention of the management without this classification scheme in place.

It is often possible to combine more than one classification scheme and make use of them to further sub-categorize the inventory and devise appropriate inventory control system for each of them.

4. *On the basis of sources of supply: (a) imported, (b) indigenous (national suppliers), (c) indigenous (local supp*liers).
   Imported items are usually of high value. Moreover, they have long lead times owing to several statutory and procedural complexities involved in the buying process. Therefore, they may require tighter control. On the other hand, items procured from the local suppliers are available "off the shelf".

ideas at Work 17.2

The Inventory Control System of a Petrochemical Manufacturer

A few years ago, a well-known petrochemical manufacturer in the country devised a simple yet effective system of inventory control in one of its manufacturing locations. It adopted a two-dimensional classification scheme to classify its inventory. Based on the consumption value, the items were classified as A-, B-, or C-class items using the ABC classification. Similarly, based on the unit value, items were classified as X, Y, or Z using XYZ classification.

The management adopted a periodic review control system for the AX items. The review period was weekly, fortnightly, or monthly. The BY items were controlled using continuous review (reorder-level based) methods. The system parameters for the BY items were as follows:

Maximum inventory = Reorder level + Order quantity Reorder level = Safety stock + Lead time consumption

Safety stock = 1 month consumption for indigenous items and 2 months for imported items

The CZ items had no specific control mechanism in place. It was customary to have one blanket purchase order per year and request for 3 or 4 deliveries in a year.

Source: Based on data gathered from the author's own research.

It is often possible to combine more than one classification scheme and make use of them to further sub-categorize the inventory and devise an appropriate inventory control system for each of them. In practice, organizations have utilized a variety of these combinations to implement appropriate inventory control systems for the items.

17.8 INVENTORY PLANNING FOR SINGLE-PERIOD DEMAND

So far we have considered the problem of inventory planning in the case of recurring demand that requires continuous replenishment. However, there are a number of situations that require inventory planning for a single-period demand. In a single-period demand, the unfulfilled demand cannot be back-ordered to the next period because the demand ceases to exist after the period for which planning is done. In other cases, even though demand exists in the future, what is ordered for a period cannot be used for future periods due to the perishable nature of the item. Examples include the demand for morning newspapers, tickets for journeys, advertising space for a mega entertainment event, and expensive maintenance spares. This type of inventory models are referred to us news vendor model. Often, there is a high degree of uncertainty involved in estimating the demand for a single period.

> In a single-period demand, the unfulfilled demand cannot be back-ordered to the next period.

Planning for appropriate levels of inventory in such situations requires careful balancing of two opposing costs. The main driver of costs in this inventory planning is the fact that uncertain demand manifests only for a period. Therefore, carrying lesser inventory than demand directly results in lost opportunity to make profit. This represents the *cost of understocking*. In the same way, any excessive inventory cannot be consumed afterwards. At the most, the unused inventory may fetch some salvage value and the resulting loss on account of this could be termed as the *cost of overstocking*.

Let C_{os} = Cost of overstocking per unit
C_{us} = Cost of understocking per unit
Q = Optimal number of units to be stocked
d = Single-period demand
$P(d \leq Q)$ = The probability of the single-period demand being at most Q units

If $d > Q$, then we incur costs on account of cost of understocking. On the other hand, if $d < Q$, then we incur the cost of overstocking. At a very low value of Q, we tend to experience costs arising out of understocking and as we increase Q incrementally we will approach optimal Q. At very high values of Q, we will incur overstocking costs. By incremental analysis, we find that while taking a decision to stock Q units, we would like to ensure that:

The expected cost of overstocking ≤ The expected cost of understocking

$$P(d \le Q) \times C_{os} \le P(d > Q) \times C_{us}$$
$$P(d \le Q) \times C_{os} \le \{1 - P(d \le Q)\} \times C_{us}$$
$$P(d \le Q) \times (C_{os} + C_{us}) \le C_{us}$$
$$P(d \le Q) \le \frac{C_{us}}{C_{us} + C_{os}} \tag{17.11}$$

Therefore, we choose that largest value of Q that satisfies Eq. 17.11 as the optimal value.[9]

EXAMPLE 17.6

Navratri is a popular festival in India. In South India, beautifully painted dolls made of clay are bought by customers during this festival. After the festival, there is no demand for these dolls. A manufacturer of dolls needs to decide on the optimal stock of dolls that he needs to carry in his inventory to satisfy the demand during the festival time. The item fetches a sales value of ₹1,300 per box. The cost of production is ₹1,000 per box. After the festival is over, the items at best can be salvaged at a value of ₹800 per box. Table 17.6 presents the distribution of demand for the item during the festival time. What is the optimal quantity to stock?

TABLE 17.6 Distribution of demand for Example 17.6

Number of units demanded	Probability	Cumulative probability
0	0.05	0.05
100	0.15	0.20
200	0.20	0.40
300	0.25	0.65
400	0.20	0.85
500	0.15	1.00

Solution

Since each unfulfilled demand results in a foregone profit, the cost of understocking is the profit per box. Similarly, by salvaging each unsold box after the festival, the manufacturer loses an amount equal to the difference between the cost of manufacture and salvage value, which represents the cost of overstocking.

Selling price per box of the item: ₹1,300.00

Cost of production: ₹1,000.00

Cost of understocking, C_{us}: ₹300.00

Salvage value: ₹800.00

Cost of overstocking, C_{os}: ₹200.00

As per Eq. 17.11, the optimal quantity to stock is:

$$P(d \le Q) \le \frac{C_{us}}{C_{us}+C_{os}} = P(d \le Q) \le \frac{300}{200} \le 0.60$$

On examination of the cumulative probability values in the last column of the demand table, we notice that Q lies between 200 and 300. We round up the value of Q to 300. Therefore, the manufacturer should plan for an inventory of 300 boxes for sale during the festival.

17.9 OTHER ISSUES IN INVENTORY PLANNING AND CONTROL

In practice, inventory control systems vary from theoretical formulations in many ways. Moreover, there is a lack of understanding of certain critical issues that influence inventory management. One serious drawback of inventory control systems in practice is that they tend to stand aloof from reality. Any inventory control system should have provisions for linking key parameters such as reorder level and safety stock to actual changes in consumption pattern, measured in terms of mean and standard deviation of demand. In the absence of this linkage, the model parameters become outdated and result in either piling up of inventory or in frequent shortages.

With the installed base of ERP systems and other MIS systems for transactional data capture, it is possible to upgrade computerized inventory control systems from an ordinary MIS system generating a host of shortage reports and accurate inventory status records to one of a decision-support system. On a periodic basis, these computerized systems could analyse the consumption patterns of items, detect impending changes, and adjust the model parameters of the inventory control system.

Better management of inventory does not happen only because of good inventory planning tools. Organizations need to take several other measures to bring down inventory. A frequently encountered issue is part number proliferation. Over the years, an organization creates a vast number of part numbers and managing such a large variety of parts in inventory could be a herculean task. Efforts to reduce part numbers by variety reduction measures are an important aspect of better inventory management. Similarly, an organization having several manufacturing/service divisions must engage in inter-divisional joint planning efforts towards standardization of classification and coding systems and stock holding of expensive items such as capital spares. These efforts go a long way in better inventory control.

Opportunities for better inventory control and management often exists outside of the materials management function in organizations. For example, alternative methods of launching material onto the shop floor, such as kit launching, helps reduce inventory mismatch and non-moving inventory. In a kit launching system, items required for manufacture and assembly are always launched into the system in exact quantities of ship sets or assembly sets. This reduces the chances of ending up with excess and unwanted work in progress at the end of the planning period. Another example relates to performance measurement systems in organizations. Management control systems that emphasize on utilization-based measures for rewards and incentives tend to promote inventory build-up in the system. As shown in Chapter 13, better structures and systems also contribute positively to reducing inventory build up in the system.

> Opportunities for better inventory control and management often exist outside of the materials management function in organizations.

An inventory planning manager should take all these into consideration while actively pursuing the models suggested in this chapter. Such an approach will ensure greater chances of reducing inventory in the system.

SUMMARY

- Every organization carries five different types of inventory. This includes *cyclic stock, pipeline inventory, safety stock, decoupling inventory, and seasonal inventory*. The purpose of carrying these types and the manner to assess the level of investment required in each of these vary.
- *Inventory planning* is done in order to minimize the total cost of the plan. The costs include the unit cost of the item for which planning is done, the cost of carrying inventory, the cost of ordering, and the cost of shortages.
- The key decisions in any inventory planning scenario is to answer the "how much" and the "when" questions. These decisions are made by balancing various costs associated with inventory.
- The *EOQ model* is useful for inventory planning in the case of multi-period deterministic demand situations. The EOQ model is robust to model parameters and could be suitably modified to incorporate some real-life situations such as quantity discounts and non-zero lead time for supply.
- *Service level* is a useful concept for modelling inventory planning in the case of stochastic demand. Safety stocks can be built commensurate to the desired service level.
- A *fixed order quantity* (Q system) or continuous review system of inventory planning and control is useful for B-class and C-class items of inventory. A popular application of the continuous review system in organizations is the two-bin system.
- A *fixed order interval* or a periodic review system (P system) is useful for planning and control of high-value or A-class items. The P system is more responsive to changes in demand patterns than the Q system.
- Selective control of inventories is achieved through alternative classification methodologies. The ABC, VED, and XYZ classifications are often used by organizations.

FORMULA REVIEW

Total cost associated with carrying inventory = $\left(\frac{Q}{2} \times C_c\right)$

Total ordering cost = $\left(\frac{D}{Q} \times C_o\right)$

Total cost of inventory, $TC(Q) = \left(\frac{Q}{2} \times C_c\right) + \left(\frac{D}{Q} \times C_o\right)$

Economic Order Quantity (EOQ), $Q^* = \sqrt{\frac{2C_oD}{C_c}}$

Optimal number of orders = $\frac{D}{Q^*}$

Time between orders = $\frac{Q^*}{D}$

For the perpetual review inventory system
Re-order Point (ROP) = $\mu_{(L)} + Z_\alpha \times \sigma_{(L)}$

Total cost, $TC(Q^*) = \left(\frac{D}{Q^*} \times C_o\right) + \left(\frac{Q^*}{2} \times C_c\right) + \left((Z_\alpha \times \sigma_{(L)}) \times C_c\right)$

For the periodic review inventory system
Order up to level, $S = \mu_{(L+R)} + Z_\alpha \times \sigma_{(L+R)}$

Optimal quantity (Q) to order in a single period inventory system is given as $P(d \leq Q) \leq \frac{C_{us}}{C_{us} + C_{os}}$

REVIEW QUESTIONS

1. Which of the following constitutes independent demand items?

a. Maintenance spares for machine tools in a manufacturing firm
b. Carburettors for a petrol engine manufacturer
c. Fresh linen in a five-star hotel
d. Radiography services in a multi-specialty hospital
e. Number of tyres for an automobile manufacturer
f. Replacement clutch cables for two-wheelers
g. Halogen lamps for automotive headlights
h. Number of operations management text books in a business school
i. Number of bottles of mineral water in a restaurant
j. Number of lunches for the mid-day Chennai–Mumbai flight

2. How is inventory planning for independent demand items different from that for dependant demand items?
3. Do organizations need to carry inventory? Why?

4. What is the relationship between inventory investment and profitability in an organization?
5. Consider the inventory planning problem. Write down the relevant total cost equation in each of the following situations:

   a. The organization can fetch a discount on the purchase price if large quantities are ordered
   b. There is a benefit in transportation costs if ordered in full truckloads
   c. The supplier is willing to set up elaborate systems for easy ordering, monitoring, and follow-up of orders if the order quantity is large
   d. There is uncertainty in demand and the organization wishes to carry safety stock

6. What are the difficulties in using shortage cost measures in inventory planning models?
7. Can you identify four alternatives that organizations use as a basis for fixing the order quantity?
8. On what basis would you recommend the periodic review system of inventory control?
9. Why should organizations adopt a selective system of inventory control? If you were asked to recommend a suitable classification scheme, how would you go about the task?
10. What is the relationship between the service level and safety stock?
11. There are ***N*** locations at which an organization faces demand for an item. The demand for the item is uncertain and hence the organization needs to carry safety stock. If it were to make the choice between centralized storage of the item and localized storage of the item in each of the location, which alternative will result in lower investment in inventory? (**Hint:** Assume that all locations have the same mean and standard deviation for demand).
12. What is the effect of the cost parameters on the economic order quantity? Perform a "what if" analysis using a spreadsheet by varying these cost parameters. What did you deduce from the results?
13. When is it appropriate to use the ABC classification scheme and the FSN classification scheme?
14. Suppose you develop a classification scheme for selective control of inventories using ABC and VED classification as two dimensions. Relate the discussions pertaining to service level to this two-dimensional classification scheme.

PROBLEMS

1. Consider an item that is ordered once per month. The daily requirement is 200 and the lead time for supply is two days. There are 25 working days in a month. The cost of ordering is ₹300 per order and the cost of carrying is ₹150 per unit per year.

   a. Draw a sketch showing the cyclic and pipeline inventory in the system
   b. What is the reorder point for this item?
   c. What will the cost of this plan be?

2. An auto-component manufacturer requires a certain steel forging in large quantities. The annual requirement is 40,000 pieces, each costing ₹450. The ordering cost is ₹600 per order and the carrying cost is ₹100 per unit per year.

   a. What is the optimal order quantity?
   b. How frequently should the manufacturer place the order with the supplier?
   c. Compute the total ordering cost and total carrying cost. Do you notice anything?

3. Consider Problem 2. Perform a "what if" analysis for the following scenarios and compute the total cost of the plan for ordering an optimal order quantity:

   a. The actual demand is −12 per cent, −8 per cent, −4 per cent, 0 per cent, 4 per cent, 8 per cent, and 12 per cent of the demand mentioned in the previous problem.
   b. The actual ordering cost has a similar variation as that of the demand
   c. The actual carrying cost has a similar variation as that of the demand

   Plot the total cost in each of the three scenarios and make your observations.
4. Excel Toys, a manufacturer of plastic toys for children, requires constant supply of high-density polyethylene (HDPE) in the resin form. HDPE is available in the resin form and one tonne costs approximately ₹2,000. The manufacturer runs his

factory for 250 days a year and the daily consumption rate for HDPE is four tonnes. The suppliers normally take a week to replenish an order. The ordering cost is ₹2,000 per order and the carrying cost is 20 per cent.

a. Estimate the cyclic and pipeline inventory in the system at Excel Toys.
b. What is the total cost of the plan?
c. Suppose if the supplier insists on a minimum order quantity of 75 tonnes, what is your recommendation to Excel? Will the recommendation change if the minimum order quantity is 150 tonnes?
d. Suppose Excel launches some improvement initiatives in the company and brings down the ordering cost by 20 per cent. Recompute the economic order quantity.
e. If Excel spent a sum of ₹10,000 towards improvements in the system, when will the improvement efforts bring payback? (**Hint:** Estimate the savings in costs due to reduced ordering cost)

5. Consider Example 17.2 in this chapter. If the company continues with the same plan even when there is an increase in the demand by 10 per cent, what will the impact be? What do you infer from the result?
6. A manufacturing organization has been consuming a certain item in large quantities and is currently procuring the item from Supplier A. The price offered by the supplier is ₹400 per piece. The ordering cost is ₹2,800 per order and the carrying cost is ₹350. The annual demand for the item is 10,000. The supplier is currently not offering any discount. However, another supplier, Supplier B, is willing to offer the following discount structure:
   Up to an order size of 999 = No discount
   For an order size of 1,000–1,999 = 2 per cent discount in price
   For an order size of 2,000 and above = 5 per cent discount in price
   Switching over to this supplier means incurring an initial cost of ₹15,000. This cost is primarily to set-up new communication systems with the new supplier. What should the company do in the light of the new offer?
7. Siemens India Limited manufactures switchgears at their Kalwa plant. One of the key components, *Kombishraube* (contacts), is manufactured in-house. If the machine producing these contacts manufactures at the rate of 800 pieces per hour and the demand rate is 450 pieces per hour, what is the economic run length for this production process? How often should they set up the machine if the factory works for 250 days in a year on a single shift (of 8 hours) basis? The cost of setting up the machine is ₹3,000 per set-up and the cost of carrying the components is ₹400 per unit per year.
8. Consider an item with the following demand attributes:
   Mean daily demand = 20; Standard deviation of daily demand = 8.
   Compute the safety stock required for a continuous review system in each of the situations given in Table 17.7:
   What do you infer from these calculations?

TABLE 17.7 Situations for Problem 8

Lead Time	**Service Level**
1 week	90%, 95%, 99%
10 days	90%, 95%, 99%
2 weeks	90%, 95%, 99%
3 weeks	90%, 95%, 99%

9. For Problem 8, compute the order up to levels and safety stock for a periodic review system with a two-week review period.
10. The weekly requirement of furnace oil in a foundry has a mean of 3,000 litres and a standard deviation of 900 litres. A litre of furnace oil costs ₹400 and the carrying costs are estimated at 25 per cent. If the foundry uses a continuous review system of inventory control with a desired service level of 90 per cent, then

a. What will the reorder point and safety stock for furnace oil be if the lead time for supply is 1 week?
b. What will the service level be if the reorder point is changed to 3,100 litres?
c. If the reorder point is left unchanged when there is a 5 per cent increase in the mean demand, how will it affect the service level?
d. If the foundry estimates that the monetary value of the benefit that it may obtain is ₹3,000 when increasing the service level from 90 per cent to 95 per cent, what is the appropriate service level for the item?

11. The demand for springs in the coil form for an auto component manufacturer is continuous and uncertain. The manufacturer places orders for the springs with a local supplier who takes two weeks to deliver. The cost of the spring is ₹400. The weekly demand for the springs has a mean of 500 and a standard deviation of 100. The cost of ordering is ₹2,000 per order and the cost of carrying is 18 per cent. The supplier specifies a minimum order quantity of 2,000. Assume a service level of 90 per cent.

    a. Is it feasible to operate an EOQ based system for this item?
    b. Design periodic and continuous review systems of inventory control.
    c. What is the total cost of the plan in each of these cases?

12. Oriental Healthcare is a multi-specialty hospital catering to a variety of illnesses connected to the heart and respiratory system. The demand for a class of medical consumable is generally random. Initially, Oriental followed a practice of ordering 200 boxes every two weeks. This practice was not found to be satisfactory. After some review, they resorted to ordering 300 boxes every two weeks. Even this practice was not found satisfactory. Recently, an examination of the stores records over a period of 10 weeks revealed the following weekly consumption pattern (Table 17.8):

TABLE 17.8 Weekly Consumption Pattern.

Week no.	**Consumption (Units)**
5	110
6	145
7	144
8	120
9	160
10	110

The supplier of the item takes (on an average) two weeks to deliver once the order is placed. The item costs ₹450 per box. The ordering cost is ₹2,000 per order and the carrying cost is 20 per cent. What should Oriental do in the light of this information? Will they be better off with the new recommendation? Assume a service level of 90 per cent.

13. A pharmacy needs to decide on monthly procurement quantity of a critical yet a highly perishable drug that has a shelf-life of just one month. The unit price of drug is ₹ 7,000 and its cost is ₹6,000. As per the historical data, the monthly demand for the drug is random with a certain distribution. The details are given in Table 17.9. Since the drug is an emergency drug, the associated hospital offered to reimburse ₹3,000 for each unit of drug left unsold. At the same time, the store would be penalized ₹2,000 per unit by the hospital for any unmet demand.

TABLE 17.9 Historical Data on Demand Distribution

Demand	22	24	26	28	30	32	34	36
Proba-bility	0.05	0.10	0.10	0.15	0.20	0.20	0.12	0.08

What should be the monthly order size the pharmacy must plan for?

14. In problem number 13 consider the following. The hospital is contemplating a change in the contractual terms with the pharmacy. Suppose the hospital is willing to make an offer of either withdrawing the reimbursement or penalty. What should the pharmacy owner do now?

15. A manufacturer of electric ovens has made an estimate (shown in Table 17.10) for annual consumption and unit cost of the components that are used for manufacture. Perform an ABC analysis and advise how the manufacturer should plan and control for inventory.

TABLE 17.10 Annual Consumption and Unit Cost of Components

MINI PROJECTS

1. Identify a sector of industry of your choice and select three companies operating in that sector. Analyse their annual report and identify portions of the annual report that have a direct impact on inventory-related issues.

   a. Prepare a report highlighting your understanding of the performance of the companies with respect to inventory planning and control. Can you identify some possible explanations for your observations pertaining to the inventory data?
   b. Among the three, which one is better in managing their inventory? How do these firms compare with the industry average?
   c. Can you make some comparisons with similar firms elsewhere (outside the country)?
   d. What are your key inferences from this exercise?

2. Study the reports produced by ICICI (Financial Performance of Companies) and the Centre for Monitoring Indian Economy on performance of corporate sector.

   a. Identify the inventory investment across different sectors of our industry. Do you see any significant trends in these movements?
   b. How has the performance been in the last five years? What factors do you think might have contributed to this?
   c. Which sectors have performed better and which have performed the worst? Can you identify some reasons for these?

3. Analyse the multiplier effect of inventory using the Du Pont equation for return on investment for a pair of close competitors.[10] What are your key inferences from this exercise?

CASE STUDY

MML Limited

The Background

MML Limited was incorporated as a private limited company and later converted into a public limited company in 1988. Though the company started with the manufacture of soaps and perfumes, it has added a variety of products to diversify its product line. Today, it is a conglomerate with businesses in soaps, perfumes, plastics, petrochemicals, paints, industrial electronics, and agro-business. Their unit at Hosur manufactures electronic components. The inventory position has been deteriorating over the last few years. The year-end inventory position, as revealed by the annual reports of the conglomerate, showed an increase from ₹1,230 million as on 30 June 2004 to ₹2,490 million as on 31 March 2007.

The conglomerate has been operating in a highly centralized fashion. All major planning activities were done at the corporate office. However, many inputs for this decision making were made available by all the operating units. The headquarters sent the tentative monthly production plan two months prior to the commencement of production. The final production plan arrived 5 days prior to start of the production. It was not unusual for the corporate office to change the production plans while production was progressing. This was communicated through telephone, telex, fax, or mail. Once the production plan was made, the requirement of each item was also computed using the bill of materials. Table 17.11 presents the tentative and final plans, and the actual production of the Hosur unit for 2005–06 and Table 17.12 presents the consumption pattern of the "A-class" item.

The Existing Buying Process

The company has been following a centralized ordering system, which was operated from its headquarters. The advantages of this system according to the organization were:

1. Better control over inventory-related costs.
2. Since the corporate office compiled the net requirements of all operating units, the order quantities for the suppliers were large, sometimes inducing them to offer generous quantity discounts.

TABLE 17.11 Tentative Plan, Final Plan, and Actual Production for Some Products

	Final	7,500	3,500	12,000	13,000	40,000	5,000
	Actual	8,938	2,214	12,828	14,320	37,762	8,330
Jan 2006	Tentative	5,000	2,500	6,500	20,000	37,000	5,000
	Final	NA	2,500	2,500	33,500	38,000	2,500
	Actual	1,634	2,983	4,149	25,376	34,133	5,040
Feb 2006	Tentative	7,500	2,500	11,000	19,500	30,000	2,500
	Final	4,500	2,500	4,000	22,945	36,000	NA
	Actual	3,504	2,660	4,032	23,790	35,978	2,301
Mar 2006	Tentative	7,000	3,000	6,000	20,000	32,500	5,000
	Final	4,000	3,000	6,000	27,000	36,000	5,000
	Actual	2,004	3,101	6,079	26,138	39,393	5,070

TABLE 17.12 Consumption Pattern for A-Class Items

Notes:
*The lead time is an average figure based on six months' data.

- The consumption details are expressed in units of items. The units of measurement are different for the items. For example, the unit of measurement for Item 3 is boxes (each box contains 250 items) whereas the unit of measurement for Item 8 is kg.
- Item 6 is sold by all the suppliers in integral units of 250 only. This has been attributed to the fact that once the seal is broken it should be used within three days.
- Items 7 and 10 are supplied by the same supplier, who is the only available domestic source.

3. In case of sudden shortages of an item at a location, the corporate office could advise another location to transfer stocks because it knew the safety stocks at each location.

The corporate office advises the purchase departments at the units on the following:

1. What to order?
2. How much to order?
3. When to order?
4. On whom to place the order?
5. What should be the delivery date?
6. What will be the price?

On receipt of this, the purchase department at the operating units took the responsibility for the procurement of items on the basis of the advice and subsequently made the payment to suppliers.

For the corporate office to take decisions on these items, it needed the following:

1. Stock levels of each item under inventory management.
2. The production plan for the following month.
3. The maximum and the minimum stock levels to be maintained for each item.
4. The previous month's consumption.

The operating unit provided the information pertaining to Item 1. Items 3 and 4 were policy decisions made at the corporate office based on historical data and future plans and Item 2 was market-related information that was forecast.

The Hosur Unit

The unit manufactures electronic components that form part of the control devices of a variety of equipment. Basically, there are minor variations in the basic configuration, which result in 13 different products as they roll out of the assembly. The variations are mainly due to the differences in the rating and the number of various electronic components used to build the product and the variations in the electronic circuit design.

The Purchase Department

A senior manager (purchase) assisted by a manager (purchase) headed the purchase department of the Hosur unit. There were four buyers attached to the department. The buyers were given responsibility to procure materials of specific groups of materials. There was one buyer for semiconductor components, another for raw materials and a third buyer for imported components. Another buyer was looking after consumables, office equipment, and capital equipment. Although imported components formed a small percentage of the total purchase, the procedure and modalities were different, necessitating an exclusive buyer to handle them. Two clerical staff undertook the responsibility for all the typing, data preparation and entry into the computer, preparation of purchase orders, and other such support activities. The purchase department was provided with a desktop computer, which was connected to a local area network.

The senior manager was interacting with the corporate office concerning matters such as source development, supplier rating, and preparation of purchase budgets. In addition, he was liaising with other departments such as stores, quality control, finance, production planning, and design. This was an ongoing activity to help take many decisions on issues such as value engineering, make or buy, new material development, import substitution, etc.

Recently, there was an exercise carried out by the purchase personnel to collect data useful for making certain policy decisions. On analysing the past three years' records it was found that on an average, 450 purchase orders were sent out per year. An ABC analysis was carried out and the average lead time taken by the vendors for the supply of such items were computed. Table 17.12 presents the relevant data on the unit price, lead time, and consumption patterns of "A-class" items. It was also found that the currently the average investment in inventory is to the tune of ₹35 million.

Inward Goods Stores and Inspection Section

The Hosur unit had an inward goods stores and inspection section that performed the task of receiving consignments of supplies, conducting inspections, and initiating the necessary follow-up action. The section employed two load/unload workers on a temporary basis each for a monthly wage of ₹1,200. As soon as a consignment arrived, a goods received note (GRN) was prepared after inspecting the materials for any damages. If there were damages, the insurance details were verified and the consignment sent to the claims section. The claims section liaised with either the supplier or the insurance company for claims.

Those consignments that were free of damage were set aside for marking codes and placing at the desired location. Simultaneously, the details were filled in the GRN. The GRN details were used to update the stock position and copies of it were sent to other departments such as finance and purchase.

The stores employed a clerk, an inspector and an assistant manager. In addition one forklift truck operator was employed.

TABLE 17.13 Some Cost Details Extracted from the Study Group Report and Apportionment Details

Notes: * All values are yearly expenditure in rupees; ** All numbers are expressed as percentages. For limited purposes many departments have been combined with general administration.

Recent Developments

Recently, the company took a decision to decentralize most of the decision-making processes. Under this scheme, each unit was focused on certain areas of the business. The individual unit heads entered into an agreement with the corporate office regarding the target for sales turnover, profitability, and a few other broad parameters. The unit took all operational decisions with the required autonomy.

A study group was constituted at the Hosur unit to analyse the various expenditures incurred at the plant level. The unit head initiated this as soon as decentralization was put into effect. Until recently, such statistics was not compiled and analysed at the unit level. The units would merely send a host of weekly and monthly reports to the corporate office. The corporate staff performed the task of analysing the data and informing the various unit heads regarding the variances from budgetary provisions. A portion of the cost data gathered so far by the study group is given in Table 17.13. Certain service items such as forklift truck maintenance, insurance premiums freight, and demurrage were allocated to specific departments using the basis developed for costing purposes. Table 17.13 also shows the apportionment details for the items.

QUESTIONS FOR DISCUSSION

1. What are the reasons for high levels of inventory at MML Ltd.? Can you offer suggestions for bringing down the level of inventory?
2. Based on the data provided, compute the cost of carrying inventory at the Hosur unit of MML Ltd.
3. Design an appropriate inventory control system for the A-class items identified by MML Ltd.

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CHAPTER 18

Operations Scheduling

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What is the importance of scheduling in operations management?
- How are operations scheduled in a flow shop? What are the well-known algorithms used for flow-shop scheduling?
- How is the scheduling of a job shop done?
- What are the operational control issues in mass production systems?
- How is scheduling done using the principles of the theory of constraints?

"Shop configuration" refers to the manner in which machines are organized on the shop floor and the flow pattern of the jobs utilizing these machines. Two alternative configurations—flow shop and job shop—are available for configuring machines in a manufacturing system.

ideas at Work 18.1

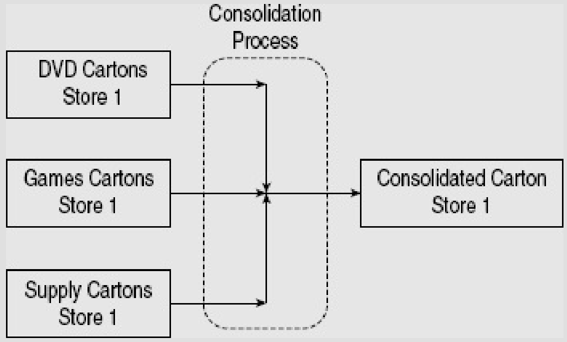
Scheduling the Order Processing Operation at Blockbuster Distribution Center

Blockbuster Incorporation, a chain of VHS, DVD, Blu-ray, and video game rental stores, has developed a highly specialized distribution network. The company maintains a single distribution center in which it receives products from suppliers, and processes and packs them for shipping to stores across United States. Because of a dynamic changes in product mix, Blockbuster’s weekly aggregate demand can experience a peak-to-average ratio of 4:1 or more. Forecasting this change in volume is difficult because each new product is truly a new release with no history. To accommodate the supply chain requirements, flexible methods and processes are adopted in order to handle the high level of volatility and to maintain sufficient robustness to virtually eliminate late deliveries. At the distribution center, processing and packing are scheduled through multiple processing departments that compete for use of shared merge conveyors and shared sortation systems. Blockbuster’s general processing and packing goal is on-time delivery of products to stores while controlling costs.

An order refers to a request to pick or process individual pieces of a product (e.g., 1,000 pieces of a particular DVD title) for a retail store. A job is a collection of orders for a set of stores. Once a job has been processed, the completed pieces of products are placed in cartons that proceed through a system of conveyors, merge, and sortation points to a consolidation area, where the contents from the individual cartons are combined with other same-store cartons. When the consolidation has taken place, cartons are shipped to retail stores using a third-party logistics network. Figure 18.1 schematically represents the consolidation process.

Typically, about 400 jobs must be processed in a week. Cartons produced in these departments must then compete for capacity in up to nine subsequent shared resources (merge and sortation points). The operating schedule consists of two 12-hour shifts per day, six days per week. Approximately 10.5 production hours are typically available per employee per shift. The penalty for late shipments is very high in this industry. Therefore scheduling the orders through the distribution network and shipping them on time are very important.

FIGURE 18.1 The consolidation process at Blockbuster distribution center



A feasible schedule would mean an assignment of each job to a department such that the capacity at each department and at each merge and sortation point is respected. Due to high volatile demand, the previous scheduling model often generated an unrealistic plan that required excessive resources. A new scheduling model was developed that can create a realistic schedule, thus eliminating the need to maintain significant additional staffing. The scheduling model was introduced for testing in October 2006 and was implemented in January 2007.

The cost savings resulting from implementing the scheduling solution were mainly on account of three reasons. Initially, it is cost savings due to reduced staffing. The total number of employee shifts was 31,445. In comparison, using the new scheduling approach, the actual staffing in 2007 was 23,229 employee shifts. Second, the capacity utilization improved because of the balanced workload solutions generated by the scheduling model. Prior to implementing the scheduling model, Blockbuster had to maintain capacity for wide fluctuations in peak volumes. The use of the model has effectively smoothed the fluctuations, resulting in improved capacity utilization. Third, Blockbuster has experienced savings because more cartons can flow through the entire process. This significantly increased the volume of cartons, thus reducing transportation costs.

Source: Adopted from Chung, C. Dawande, M., Rajamani, D. and Sriskandarajah, C. (2011), ‘A Short-Range Scheduling Model for Blockbuster’s Order-Processing Operation’, Interfaces, 41(5):466–484.

18.1 THE NEED FOR SCHEDULING

Operations management requires planning and control at various levels and time horizons. So far, we have discussed operations management issues in the long term and the medium term. Configuration of an operations system at the right location and choice of appropriate process and product designs are issues associated with the long term. On the other hand, aggregate planning and material and capacity requirements planning are issues associated with the medium term. In the same manner, there is a host of issues that one needs to address in short-term planning. In this chapter, we focus on planning and control issues associated with the short term. In the short term, there is more emphasis on operational control than on planning. This, however, does not imply that there is no planning involved. In fact, planning does half the job of control.

"Short term" denotes a time horizon close to real time. Typically, in a majority of manufacturing and service organizations, this would imply a horizon ranging from a day to at most a week or two. In some special cases, "short term" may mean a few hours or a shift, as in the case of a power transmission firm or an event management firm. One question that comes to our mind is: When we have exercised so much care in the previous stages of planning, why do we still need to continue with the planning exercise? Before we proceed with the concepts and techniques of operations scheduling, it is best to clarify this issue. Planning for the short term becomes inevitable for three important reasons:

1. As we approach real time, several kinds of additional information become available to an organization. Use of this new information makes the plans far more robust and representative of reality. For instance, some customer orders could be cancelled, some new orders booked, and the terms of the existing orders could be revised. Obviously, using this information makes operations more accurate than choosing to simply ignore them.
2. The occurrence of random events is inevitable in business. These include the sudden breakdown of a machine, absenteeism of skilled labour, delays in the supply of key raw material, and a sudden revision of job priorities. It is not possible to include these details accurately while planning for the medium term. Broad assumptions and approximations are made about these at that time of planning. Therefore, we need to revisit these assumptions and fine-tune our planning and decision-making methodology.
3. In the short term, we need to focus on micro-resources, a single machine, a set of workers, and so on. Such a focus is neither possible nor warranted in medium or long-term planning.

In the short term, several questions need to be answered. How can jobs be assigned to various work centres? Within each work centre, how can the jobs be rank-ordered? How can other resources such as skilled workers and special gadgets be assigned to the operating system? How do we react to a breakdown in the system? How can the performance of the operating system be measured? All these questions are equally applicable to both manufacturing and service systems. In this chapter, we address many of these questions and develop methodologies to address these questions using a defined framework. We refer to the collective framework for addressing these issues as **scheduling of operations**.

> **Operations scheduling** uses a defined framework to address issues associated with the use of available resources and the delivery of products and services as promised to the customers.

Operations scheduling has a direct linkage with MRP systems in an organization. Recall that the function of an MRP exercise is to generate feasible production orders and procurement notices. *Production orders* are nothing but specific sets of instructions to utilize a set of resources for the manufacture and/or assembly of the components under question during a particular period of time. Consider a sub-assembly, X. If the MRP schedule indicates that during Week 16 a designated shop, S1, should manufacture 200 units of X, then it is clear that during Week 16, the planner needs to ensure that the job is assigned to Shop S1 and provide capacity for manufacturing 200 units of X. During the same week, there could be several jobs assigned to Shop S1. Therefore, the shop planners also need to prioritize all such jobs in the shop with respect to each machine they visit, and ensure completion of the job without delay. This example indicates that the output of an MRP exercise becomes the input for job scheduling.

18.2 SCHEDULING: ALTERNATIVE TERMS

In practice and in literature, several terms are used in scheduling. These terms convey important concepts related to scheduling. Yet, those unfamiliar with the subject are often confused by these terms and experience considerable difficulty in understanding their significance. We will, therefore, define these terms here and use them consistently in the rest of the chapter.

Planning-related Terms

Planners often use a pair of terms—loading and scheduling. **Loading** is defined as a planning methodology that is used to assign an adequate number of jobs to the resources in an operating system during a planning horizon (of, say, a week). Loading is done to ensure that the resources in an operating system are utilized in the best possible way. Moreover, loading also ensures that the workload among competing resources is not lopsided, and hence does not create an uneven strain on the operating system. In a dental hospital, let us assume that there are three dental specialists visiting the outpatient department for four days. On each day, let us assume that they spend three hours advising or treating patients. The loading function will ensure that the specialists are adequately engaged and that no specialist is grossly over or underutilized. (We make the important assumption here that the patients do not make the choice of the consultant. If the patient has a choice, then the loading methodology will suggest shifting appointments from a particular day to another day or that the patient consult another specialist.)

> **Loading** is a planning methodology that is used to assign an adequate number of jobs to the resources in an operating system during a planning horizon.

Scheduling is defined as the process of rank-ordering the jobs in front of each resource with a view to optimize some chosen performance measure. If there are *n* jobs waiting in front of a machine, using scheduling, the planner could rank-order them for the purpose of processing. Rank-ordering could be done to minimize the waiting time of all the jobs in the queue. In the dental hospital example, if it is decided to allow 10 patients for consulting during a three-hour schedule, some rules are utilized to schedule the ten patients one after the other. In service systems, the rule is often first-cum-first served. But in manufacturing systems, several other possibilities exist.

> **Scheduling** is the process of rank-ordering the jobs in front of each resource to maximize some chosen performance measure.

Technological Constraints-related Terms

Two more terms are used in this field: routing and sequencing. These terms pertain to the technological constraints of the jobs to be scheduled in the operating system. **Routing** is defined as the order in which the resources available in a shop are used by the job for processing. The order is a function of the technological constraint associated with the job. The information is normally available in a routing file or a route card. In a manufacturing system, the routing denotes the order in which operations are performed on a component. For example, a spindle production may involve cutting the required length using a shearing operation, rough machining using a turning operation, heat treatment for stress relief, grinding for finishing the operation, and, finally, chromium plating—in that order. Similarly, routing information is utilized in a service system also. A person aspiring to obtain a U.S. visa from the U.S. Consulate needs to go through three or four stages of the process—submission of papers and drafts, initial verification of documents and basic clearance, interview by the visa officer, and final clearance for the visa. There could be rejections as a candidate proceeds through the system. This information is crucial for resource deployment and operations scheduling at the U.S. Consulate.

> **Routing** is the order in which the resources are used by jobs for processing.

Sequencing is the ordering of the operations of the jobs in the operating system. It combines the routing and scheduling information to provide a basis for the planners to ensure that jobs are processed in the shop without violating technological constraints.

> **Sequencing** is the ordering of the operations of the jobs in the operating system.

Administration-related Terms

In organizations, dispatching and expediting are terms frequently associated with the scheduling of operations. **Dispatching** is defined as the administrative process of authorizing the processing of jobs by resources in the operating system, as identified by the scheduling system. The authorization could be in the form of a shop order or information communicated electronically to the respective work centre. Dispatching physically signals the assignment of jobs to work centres and places, and the onus for reviewing the progress is on the controllers. *Expediting*, on the other hand, is the administrative process of reviewing the progress of the job in the operating system and ensuring that it travels through various stages of the process as indicated in the routing, without harming the performance measure. If there are deviations and delays, it calls for pushing the job forward through the system.

> **Dispatching** is the administrative process of authorizing processing of jobs.

18.3 THE LOADING OF MACHINES

When there are multiple copies of the same machine type, the first step in scheduling is to assign the jobs to the resources. As we have seen already, this is achieved by loading. Let us look at a simple illustration of this idea. Suppose three milling machines are available on a shop floor and each of them provide a weekly capacity of 45 hours (we assume that each day, 7.5 hours are available and the factory works for 6 days a week). During an upcoming week, let us say that 30 jobs require processing in the machine and a total of 110 hours of machine capacity is required. While the required capacity is available, it still requires some planning so that the jobs are assigned to these machines such that none of the machines are either overloaded or under-loaded. This is achieved using loading. For this purpose, one can use the assignment method, a variation of the linear programming model.

The assignment method is useful when one job is assigned to one machine and there are as many machines available for assignment as there are jobs. If there are fewer jobs than machines, one can still use the assignment method by adding some fictitious jobs and solving the standard assignment problem. On the other hand, if there are fewer machines than jobs, other methods are available for loading jobs on machines. In this case, several jobs are assigned to each machine as long as sufficient capacity is available for processing and other constraints are taken care of.[1]

EXAMPLE 18.1

A manufacturer of dies for the automotive component industry utilizes a job shop structure. During a planning horizon, the manufacturer needs to first assign five jobs to the five machines that are in one section of the factory. Table 18.1 provides details on the processing time of the jobs in each of these machines if assigned. The differences in the processing time are attributed to differences in the ratings of these machines. Use the assignment method to solve the loading problem.[2]

Solution

We use the standard assignment method for solving the problem. We first subtract each row by the minimum number in the row. The resultant table is as shown in Table 18.2.

After that, we subtract each column by the minimum number in the column. There is a change only in Column 2 as other columns already have a zero. The table after column subtraction is as shown in Table 18.3.

Since the minimum number of lines required to cover all the zeros is equal to the number of rows, we can use Table 18.3 to perform the final assignment. The assignments are as follows:

- Job 1 assigned to Machine 2;
- Job 2 assigned to Machine 1;
- Job 3 assigned to Machine 3;
- Job 4 assigned to Machine 5;
- Job 5 assigned to Machine 4.

This assignment results in a minimum total processing time of 80 time units.

TABLE 18.1 Processing Times for the Jobs

	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5
Job 1	15	17	16	22	18
Job 2	16	19	20	19	16
Job 3	19	20	17	19	20
Job 4	17	23	22	18	14
Job 5	20	19	24	16	17

TABLE 18.2 Resultant Matrix After the Row Operation

	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5
Job 1	0	2	1	7	3
Job 2	0	3	4	3	0
Job 3	2	3	0	2	3
Job 4	3	9	8	4	0
Job 5	4	3	8	0	1

TABLE 18.3 Resultant Matrix After the Column Operation

	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5
Job 1	0	0	1	7	3
Job 2	0	1	4	3	0
Job 3	2	1	0	2	3
Job 4	3	7	8	4	0
Job 5	4	1	8	0	1

18.4 THE SCHEDULING CONTEXT

The nature and the complexity of the scheduling problem are dependent on the context in which we solve the problem. Moreover, past research suggests that even the type of performance measure that we use for scheduling jobs can influence the ease with which we could obtain the solution. Therefore, a good introduction to the parameters of the problem is essential before we analyse the solution techniques available for scheduling. The following parameters adequately describe the scheduling problem that one tries to solve:

The nature and the complexity of the scheduling problem are dependent on the context in which we solve the problem.

- *Number of machines*: The number of machines, or more generally, the number of resources for which the planner proposes to perform the loading and scheduling function is the first parameter for the problem. Let us denote the number of machines by m. The simplest case is $m = 1$. In this case, the jobs that require processing in that machine need to be simply rank-ordered on some basis. However, as m becomes larger, the problem size increases as numerous combinations are introduced. Moreover, if multiple machines are available for the jobs as parallel resources for processing, we need to develop methods by which one out of those multiple machines is chosen for assigning the job.

> As the number of machines and jobs increases, the problem size also increases as numerous combinations are introduced.

- *Number of jobs*: The number of jobs is the second parameter for the scheduling problem. We denote the number of jobs by n. If the number of jobs increases, it introduces more complexity into the scheduling problem. As multiple jobs compete for the same set of resources, additional methods are required to assign the jobs to the resources.
- *Shop configuration*: "Shop configuration" refers to the manner in which m machines are organized on the shop floor and the flow pattern of the jobs utilizing these machines. Two alternative configurations—flow shop and job shop—are available for configuring machines in a manufacturing system.[3] Since these configurations differ in terms of the deployment of resources, the scheduling methodology also differs. Moreover, we shall also see that the complexity of the problem varies between these two configurations.

The simplest configuration is **flow shop**. In a flow shop, the resources are organized one after the other in the order the jobs are processed. In a flow shop, jobs start their processing at Machine 1. After completing processing, they visit Machines 2, 3, and so on before they exit the system from Machine m. Figure 18.2 graphically portrays a pure flow shop. A pure flow shop is one in which all the jobs visit all the machines in the same order (beginning at Machine 1 and ending at Machine m). However, in a mixed flow shop, some jobs are allowed to skip machines in between.

> The simplest shop configuration is **flow shop**. In a flow shop, the resources are organized one after the other in the order the jobs are processed.

Since in a pure flow shop all jobs follow the same order of visiting the machines, the scheduling function is essentially reduced to one of ordering the jobs in front of the first machine. Once the jobs are ordered in front of the first machine, it follows the same order in the rest of the machines. Since there are n jobs, there are $n!$ ways in which one can draw up alternative schedules in the shop. It is easy to note that scheduling complexity increases in the case of a mixed flow shop.

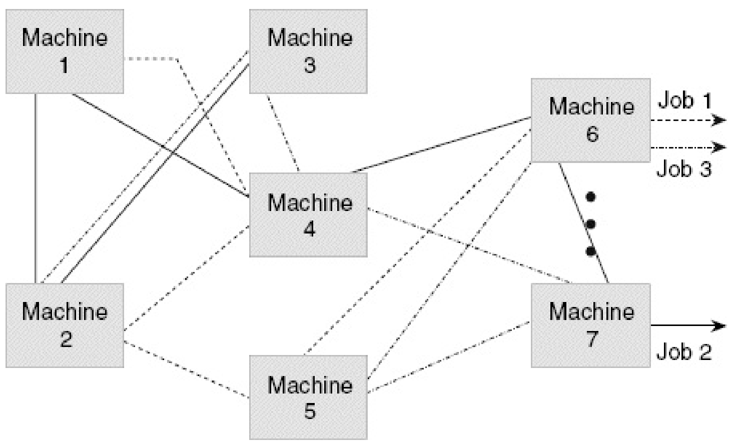
The second configuration is the **job shop**. In a job shop, machines are not organized in any processing order. Rather, similar types of resources are grouped together. Every job follows a unique order in which it visits the machines for processing. Moreover, there is no requirement for all jobs to visit a particular machine for their first operation or a particular machine for their last operation (as in the case of a flow shop). Figure 18.3 presents a simple illustration of a job shop consisting of seven machines. In this example, the route that Job 1 follows for processing is

1−4−2−5−6. On the other hand, Job 2 follows the sequence 3−2−1−4−6−7 and Job 3 follows 2−3−4−7−5−6.

In a **job shop**, machines are not organized in any processing order. Rather, similar types of resources are grouped together.

FIGURE 18.2 A pure flow shop

FIGURE 18.3 Illustration of a job shop with 7 machines and 3 jobs



Since each job has its own unique route, the set of jobs visiting each machine is not the same. Therefore, the ordering of jobs in front of each machine is to be separately determined. There are $n!$ ways of rank-ordering jobs in front of a machine. Since there are m machines in the shop, the number of alternative schedules that one can draw for a job shop is given by $(n!)^m$. Clearly, the number of alternatives is far too high for one to complete by enumerating these alternatives and arriving at the best schedule.

ideas at Work 18.2

Scheduling of Physician in the Emergency Depar tment of a Hospital

Physicians at a branch of the emergency department at Cincinnati Children’s Hospital Medical Center complained that their schedules were too erratic because of the multitude of operating requirements, regulatory constraints, physician preferences, and holiday requests. They wanted their work schedules to be more predictable by using repeating patterns. They also wanted more consideration given to both their working preferences and their need to fulfill personal life choices.

Crew scheduling in services is always more complex than scheduling manufacturing resources in a factory. For instance, in this case, the physicians had several considerations that needed to be honoured to build a workable schedule. Some of them are as follows: physicians never wanted to work in more than two consecutive weekends. They would prefer to be assigned, at the most four shifts in any given week. Furthermore, they would not like to have more than two consecutive overnight shifts assigned to them during Monday–Thursday.

One of the methods adopted to address crew scheduling is cyclic scheduling as it has certain advantages. For instance, the physicians might know their work schedules in advance so that they could organize their lives during their time-off better. On the downside, it is impossible to build a cyclic schedule that considers diverse requests for time-off and the assigned legal holidays, because the uniqueness of each period conflicts with the repetition of a predetermined cycle. A critical aspect of cyclic scheduling is the choice of cycle length. Short cycles provide more repeatability and can be more easily remembered by the workers. However, they offer fewer possibilities for the inclusion of all the required attributes, in particular for work-load and work-pattern necessities.

Based on several considerations, an eight-week cycle was finally selected.The physicians felt that this cycle length was neither too short nor too long, and would permit a balanced distribution of weekend shifts. A solution was developed using integer programming to build cyclic schedules that can be repeated throughout the year. These schedules are flexible enough to handle incorporating holidays, work assignments, and vacation requests ex post.

Three months after the cyclic schedule was implemented, the physicians were asked about their satisfaction with the cyclic schedule. The physicians stated that the new scheduling method provided them with more predictability over their work-week, which helped them plan their activities outside of work. Moreover, having a template for the entire year gives the physicians the ability to plan their vacation requests. They also found the new work patterns addressing their work-life balance better.

Source: Adopted from Ferrand, Y., Magazine, M., Rao, U.S. and Glass, T.F. (2011), 'Building Cyclic Schedules for Emergency Department Physicians', Interfaces, 41(6):521–533.

Scheduling Rules

A critical parameter for the scheduling problem is the basis on which competing jobs queueing in front of a machine are rank-ordered. Alternative rules can be used for establishing priorities. These rules are known as scheduling rules. The following are the most frequently used rules:

- *Shortest processing time (SPT)*: This rule simply chooses the job with the least processing time from the competing list and schedules it ahead of the others. For example, let us consider four jobs waiting in front of a machine for processing. If the processing times (in minutes) are 12, 9, 22, and 11, then the order in which the jobs will be scheduled using the

SPT rule is Job 2–Job 4–Job 1–Job 3.

- *Longest processing time (LPT)*: This rule is the reverse of the SPT rule. The job with the longest processing time is scheduled ahead of other competing jobs. For our example, the order in which the four jobs are scheduled is exactly in reverse (Job 3–Job 1–Job 4–Job 2).
- *Earliest due date (EDD)*: It is possible to establish priorities on the basis of the due date for the jobs. The logic here is that a job that is due tomorrow needs to be scheduled ahead of another that is due the day after even though the second job may require lesser processing time compared to the first. Therefore, jobs can be rank-ordered on the basis of due dates. If the chronological order of the due dates of the four jobs is Job 4–Job 3–Job 2–Job 1, then EDD rule will rank the jobs in that order.
- *Critical ratio (CR)*: The SPT and LPT rules take only the processing time information into consideration. On the other hand, EDD considers only the due dates of the jobs. In reality, it will be desirable to consider both while scheduling. A job with a long processing time due in the near future requires greater attention than a job with very little processing time but due at the same time. The critical ratio estimates the criticality of the job by computing this information using a simple ratio:

$$\text{Critical ratio (CR)} = \frac{\text{Remaining time}}{\text{Remaining work}} = \frac{\text{Due date} - \text{Current date}}{\text{Remaining processing time}} \qquad (18.1)$$

A smaller CR value indicates that the job is more critical. Particularly, if CR <1, it denotes that the available time is not sufficient and the job is already running late. On the contrary, a larger CR value (CR >1) indicates that some slack is available for the job.

A smaller CR value indicates that the job is more critical.

- *First-come-first-served (FCFS)*: This rule schedules the jobs simply in the order of job arrival. There will be no consideration of the processing time or any other information such as the due date of the jobs. This is akin to the working of Indian Railways' computerized passenger reservation system in various cities.
- *Random order (RAN)*: It is also possible to assign priorities on a random basis. Suppose we get four random numbers from a random number generator, as follows: 563, 125, 490, and 923. Then one can use this set of numbers for rank-ordering the four jobs (on the basis of ascending order of the three digit numbers). The resulting order will be Job 2–Job 3–Job 1–Job 4.

Table 18.4 illustrates these five rules for the four-job example. In reality, it is possible to construct alternative scheduling rules on the basis of the specifics of the problem that one is trying to solve.[4]

TABLE 18.4 Illustration of the Scheduling Rules (Current Time = 0)

Job No.	Processing Time (Minutes)	Order of Arrival	Due by	CR	Random Number	Rank Ordering of Jobs Based on					
						SPT Rule	LPT Rule	EDD	CR	FCFS	RAN
1	12	1	23	1.92	0.233	3	2	2	3	1	1
2	2	2	24	2.67	0.857	1	4	3	4	2	3
3	9	3	30	1.36	0.518	4	1	4	1	3	2

Performance Criteria

The scheduling problem needs to be solved for the purpose of meeting certain characteristics in the operating system. Therefore, the performance criterion is an important parameter for the scheduling problem. Three types of performance criteria are normally considered in operations scheduling. These include *completion-based*, *due date-based* and *inventory-/cost-based* measures.

> Three types of performance criteria are normally considered in operations scheduling: *completion-based, due date–based*, and *inventory-/cost-based* measures.

Completion-based measures

In completion-based measures, an assessment of the time taken to complete the operations is made and used for the purpose of evaluating the goodness of the chosen scheduling rule. Two measures are frequently used: flow time and make span. **Flow time** is the elapsed time between releasing a job into the shop and the time of completion of the job. Flow time equals the sum of processing time of all operations of the job and other non-productive time, including waiting and moving in the shop at various work centres. Consider the following notations for Job *i*:

> **Flow time** is the elapsed time between releasing a job into the shop and the time of completion of the job.

Release time of the job: R_i

Completion time of the job: C_i

$$\text{Flow time of the job: } F_i = (R_i - C_i) \tag{18.2}$$

Alternative variations of these measures can be computed. For example, maximum flow time, mean flow time, maximum completion time, and mean completion time can also be computed for the set of jobs under consideration. However, the maximum completion time is denoted by another measure known as make span.

Make span is the time taken to complete all the jobs released into the shop for processing. Even when all the jobs are released at the same time, jobs come out of the shop at different times due to time differences in processing. Therefore, make span is the completion time of the last job in the shop.

> **Make span** is the time taken to complete all the jobs released into the shop for processing.

Make span (maximum completion time):

$$C_{\max} = \max_i \{C_i\} \tag{18.3}$$

Flow time, also known as *throughput time*, is an appropriate measure for jobs that are continuously launched on the shop floor. It provides a good measure of the length of the time the job resides on the shop floor. This is directly related to the work-in-progress inventory likely to be accumulating in the shop. On the other hand, if the shop launches batches of components and requires setting up the entire system for another batch of components, then make span will be a more appropriate measure.

Due date–based measures

These measures evaluate the efficacy of the scheduling rule with reference to the due date of the jobs being scheduled. The completion date is compared with the due date and some assessment of the rule is made. *Lateness* is the difference between completion time and due date. If the due date for Job *i* is denoted as D_i, then

$$\text{Lateness of the job, } L_i = (C_i - D_i) \tag{18.4}$$

If a job is completed ahead of its due date, then there will be negative **lateness** (earliness) as per Equation 18.4. For the set of jobs being scheduled, one can compute additional measures such as mean lateness and maximum lateness.

> **Lateness** is the difference between completion time and the due date.

There is an alternative measure used in scheduling literature known as *tardiness*. If a job is completed ahead of time, instead of computing a negative value for L_i, if we take zero, then the resulting measure is known as tardiness. In other words, tardiness captures information of only those jobs that are late for the purpose of evaluation of the scheduling rule. Therefore,

$$\text{Tardiness of the job, } T_i = \max_i(0, L_i) \tag{18.5}$$

As in the case of other measures, one can compute the mean, maximum, and minimum values of tardiness for the set of jobs scheduled using a particular scheduling rule. The third measure is the number of tardy jobs, denoted by n_T.

Inventory-/Utilization-based measures

Inventory- or utilization-based measures are based on the actual inventory build-up in the shop or the utilization of the shop resources. The measures include the mean number of jobs waiting, the mean number of finished jobs, the mean number of unfinished jobs, and the mean utilization of machines (or other resources) in the shop. It is also possible to convert these numbers into monetary terms by appropriate cost-based measures. Although these measures are very meaningful, computing these numbers is neither straightforward nor easy. These measures are typically used while the scheduling problem is studied using a simulation model.

> It is possible to obtain optimum schedules for certain combinations of shop configurations, scheduling rules, and performance criteria.

EXAMPLE 18.2

A manufacturing organization is in the process of assessing the usefulness of SPT and EDD rules for the purpose of scheduling four jobs on a machine. Table 18.5 presents information on the processing time and due dates for the jobs. Assume that all the jobs are available for scheduling at the beginning of the planning horizon so that the release time is zero. Further, due dates in the table denote the time at which the component is due at its next stage of manufacturing.

Compute the relevant performance measures and comment.

TABLE 18.5 Processing Time and Due Dates for the Jobs

Job Number	Process Time	Due by
1	4	6
2	7	9
3	2	19
4	8	17

Solution

Job sequencing using SPT rule: 3–1–2–4.

Job sequencing using EDD rule: 1–2–4–3.

In order to understand when the jobs get completed, we need to estimate the beginning and end times for all jobs. In the case of SPT, Job 3 is first scheduled in the machine. At the end of 2 time units, Job 1 is scheduled and it takes 4 time units. Therefore, at the end of 6 time units, Job 2 is scheduled, and finally, at the end of 13 time units, Job 4 is scheduled. Job 4 completes its processing by 21 time units, which is the make span. Using this information we can compute all the measures. The workings for both SPT and EDD are given in Tables 18.6 and 18.7. It may be noted that all the jobs are indeed available for processing at time zero. Therefore, the release time for all the jobs is zero. Due to the scheduling rule, there are differences with respect to when they undergo the processing.

Some Observations:

Both the scheduling rules result in the same make span. This is because there is only one machine involved and all the jobs undergo processing in this machine. However, the rules differ in their performance. EDD rule performs better in due date–based measures even at the expense of increasing the number of tardy jobs by one.

TABLE 18.6 Performance of the SPT Rule

Scheduling Rule: SPT					
Processing Order	**Release Time (R_i)**	**Completion Time (C_i)**	**Flow Time (F_i)**	**Lateness**	**Tardiness**
2	0	6	6	0	0
3	0	13	13	4	4
1	0	2	2	–17	0
4	0	21	21	4	4
Mean		10.50	10.50	–2.25	2.00
Maximum		21.00	21.00	4.00	4.00
Minimum		2.00	2.00	–17.00	0.00
Number of tardy jobs = 2; Make span = 21					

TABLE 18.7 Performance of the EDD Rule

Scheduling Rule: EDD					
Processing Order	**Release Time (R_i)**	**Completion Time (C_i)**	**Flow Time (F_i)**	**Lateness**	**Tardiness**
1	0	4	4	–2	0
2	0	11	11	2	2
4	0	21	21	2	2
3	0	19	19	2	2
Mean		13.75	13.75	1.00	1.50
Maximum		21.00	21.00	2.00	2.00
Minimum		4.00	4.00	–2.00	0.00
Number of tardy jobs = 3; Make span = 21					

Past research in the area of scheduling has established that it is possible to draw optimum schedules for certain combinations of shop configurations, scheduling rules, and performance criteria. Therefore, choice of these parameters could significantly influence the complexity of the problem and the feasibility of obtaining optimum schedules.

18.5 SCHEDULING OF FLOW SHOPS

It is not an easy task to arrive at the optimum schedule for a manufacturing shop. Numerous combinations are possible for scheduling jobs in a shop. In a flow shop, the number of combinations grows non-linearly (on account of the $n!$ factor). Even for a small problem involving 10 jobs, the number of alternatives to be enumerated is 3,628,800. Therefore, it will not only be difficult but also futile to resort to complete enumeration of these alternatives. However, we have noted earlier that a combination of the shop configuration, the scheduling rule, and the performance measure could lend itself to identifying the optimum combination without much computational effort. We shall concentrate on one such algorithm pertaining to the flow shop here.

Development of context-specific scheduling rules is a better investment of managerial time to solve the scheduling problem in organizations.

Johnson's Rule

Let us consider a flow shop with two machines and *n* number of jobs to be scheduled. Let us also assume that we are interested in minimizing the make span. Johnson proposed a simple algorithm that will provide the optimum schedule for the shop.[5] The algorithm is as follows:

Step 1:Let t_{1i} denote the processing time of Job *i* in Machine 1 and t_{2i} denote the processing time in Machine 2.

Step 2: Identify the job with the least processing time in the list. If there are ties, break the tie arbitrarily.

a. If the least processing time is for Machine 1, place the job at the front of the sequence immediately after any jobs already scheduled.
b. If the least processing time is for Machine 2, place the job at the back of the sequence immediately before any jobs already scheduled.
c. Remove job *i* from the list.

Step 3: If there are no more jobs to be scheduled, go to Step 4. Otherwise, go back to Step 1.

Step 4: The resulting sequence of jobs is the best schedule to minimize the make span of the jobs.

Johnson's rule is quite simple and it applies to a restrictive set of assumptions about the number of machines and the shop configuration. However, there have been some extensions of Johnson's rule that apply to a wider set of situations involving flow shops. The first variation is Jackson's rule that generalized Johnson's rule to a situation involving two machines with jobs skipping one of the two machines.[6] Thus, the flow shop becomes a job shop with four sets of jobs possible. One set containing jobs visiting only Machine 1, the second set visiting only Machine 2, the third set visiting Machine 1 and then Machine 2, and the fourth set visiting Machine 2 first and then Machine 1. The second extension of the Johnson's rule is the CDS method.[7] This method extends Johnson's rule to a multi-machine situation and derives schedules that are near-optimal.

EXAMPLE 18.3

Five jobs are to be scheduled in two machines in a manufacturing shop. All the five jobs undergo processing in both the machines (flow shop). Table 18.8 provides information on the processing time in both the machines.

TABLE 18.8 Processing Time

Processing Time		
Job no.	**Machine 1**	**Machine 2**
1	4	7

2	6	3
3	2	3
4	7	7
5	8	6

a. Identify the best sequence using Johnson’s rule.
b. Develop a Gantt chart for the schedule and compute the flow times and make span for the jobs for this sequence.

Solution

Johnson’s Rule:
The least processing time is for Job 3. Since it is for Machine 1, we schedule the job at the front end of the sequence:

Job 3 – – – –

Job 3 is removed from the list. The next least processing time is for Job 2. Since the processing time is for Machine 2, we schedule the job at the end of the sequence:

Job 3 – – – Job 2

The next job with least processing time in Machine 1 is Job 1. Therefore, we schedule it immediately after Job 3 at the front:

Job 3 Job 1 – – Job 2

The fourth job with least processing time in Machine 2 is Job 5. Therefore, we schedule the job immediately before Job 2 at the back of the sequence:

Job 3 Job 1 – Job 5 Job 2

Finally, we schedule Job 4 in the remaining slot. Since no more jobs are available, we end the procedure with the following optimum schedule for the problem:

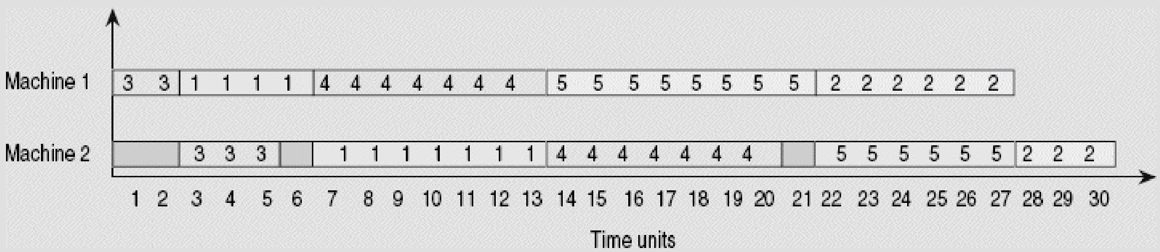
Job 3 Job 1 Job 4 Job 5 Job 2

Gantt Charts for the Schedule:
Graphical representations of the information on the start and end times of resource usage by various jobs are often used in practice. The Gantt chart is a simple graphical tool using which this can be accomplished. Gantt charts improve the understanding of the problem and aid in visual control of the problem. Moreover, they make communication of the schedules and monitoring of the progress much easier. We will demonstrate the use of Gantt charts using the schedule developed in this example.

In this example, the scheduling sequence has already been identified. Therefore, one can graphically plot the start and end times of the jobs in both machines. Job 3 takes two minutes in Machine 1, during which time Machine 2 is idle. The job requires three minutes in Machine 2. Therefore, Machine 2 will be processing Job 3 during minutes 3–5. One can proceed in this fashion to arrive at all the start and end times for the jobs. The resulting Gantt chart is shown in Figure 18.4.

The graphical representation of the schedule helps operating personnel in easy identification and control. The make span for the five jobs is 30 time units. Moreover, one can directly identify the flow time for each job. The flow time for the jobs is Job 1: 13, Job 2: 30, Job 3: 5, Job 4: 20, and Job 5: 27. The Gantt chart also shows the idle time for machines and waiting time for the jobs (if any). In this example, Machine 2 is idle for 4 time units in a cycle of 30 time units. No jobs are waiting for the machines in this case.

FIGURE 18.4 The resulting Gantt chart



There are several realistic assumptions that one needs to take into consideration while scheduling the jobs that makes the problem mathematically intractable. For example, there are situations of no job waiting during certain intermediate stages of processing as in the case of a heat treatment operation with a pre-heating schedule. There are other situations that warrant minimum waiting before being scheduled for the next operation, as in the case of a painting application. Further complications can arise on account of sequence-dependent set-up times between two jobs.

As more and more such constraints are introduced into the problem, obtaining optimum schedules evades the planner. The realistic alternative is one of obtaining good enough and workable schedules. Production planners benefit in this process by gainful exploitation of the available computing. Development of context-specific scheduling rules and heuristic procedures will serve the management better and save time in solving the scheduling problem in organizations.

18.6 SCHEDULING OF JOB SHOPS

As we have already noticed, scheduling is much more complicated in the case of a job shop. Unlike the flow shop, developing optimal methods is difficult and computationally complex. Complete enumeration is also not possible as the number of schedules $[(n!)^m]$ grows exponentially with *n* and *m*. Therefore, the use of appropriate scheduling rules and performance criteria are the only viable options for the planner. Use of graphical methods such as Gantt charts is very useful for job-shop scheduling. However, unlike the case of flow shops, the performance of various scheduling rules cannot be easily predicted in a job shop. Therefore, one can resort to simulation modelling of the system and evaluate alternative scheduling rules.

The use of graphical methods such as Gantt charts is very useful for job-shop scheduling.

EXAMPLE 18.4

Consider a job shop with five machines and four jobs. Each job has a processing sequence in which it visits three out of the five machines. Each job also has a due date for completion. The relevant information is given in Table 18.9.

a. Use SPT and EED rules to obtain the schedules for the jobs.
b. Compute the make span, mean lateness and number of tardy jobs.

Solution
We use a Gantt chart to develop the schedule for the shop.

SPT Rule:
Jobs 2 and 4 require processing in Machine 1. However, since the processing time of Job 4 is less than for Job 1 it is scheduled first in the machine using SPT. Similarly, Job 1 is first scheduled in Machine 2. The partial Gantt chart is shown in Figure 18.5.

TABLE 18.9 Details for each Job

	Processing Time (Machine Visited in the Sequence)*			
Jobs	**1**	**2**	**3**	**Due by**
Job 1	3 (2)	7 (4)	3 (5)	10
Job 2	6 (1)	3 (2)	7 (5)	12
Job 3	7 (2)	3 (4)	4 (3)	9
Job 4	5 (1)	4 (3)	5 (4)	14

Note: *The numbers in the parenthesis indicates the machine in which the job gets processed

At the end of time unit 3, Job 1 exits Machine 2 and it is time to take the next scheduling decision. Job 1 will be scheduled in Machine 4 as there is no other job competing for that machine. Similarly Job 3 will be scheduled in Machine 2. The Gantt chart in Figure 18.6 has these additional schedules included.

FIGURE 18.5 The partial Gantt chart for the SPT rule

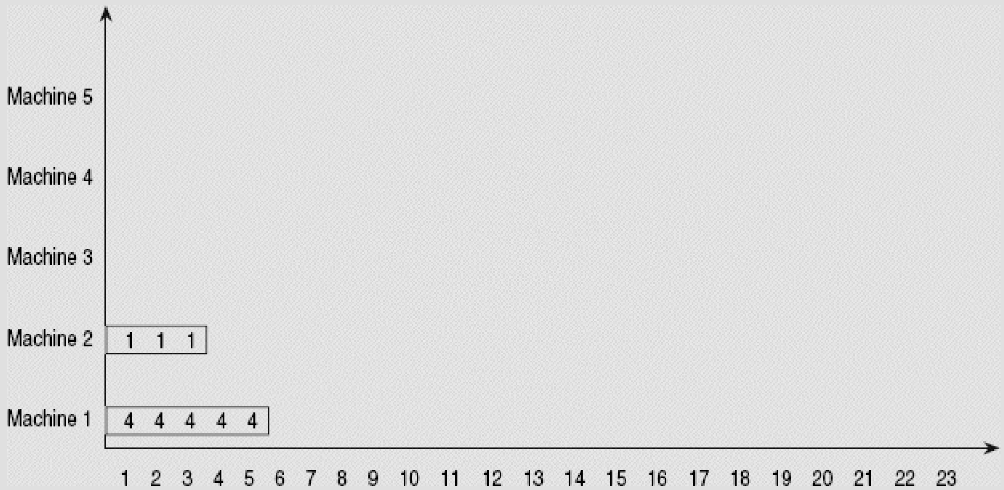


FIGURE 18.6 The Gantt chart with the additional schedules

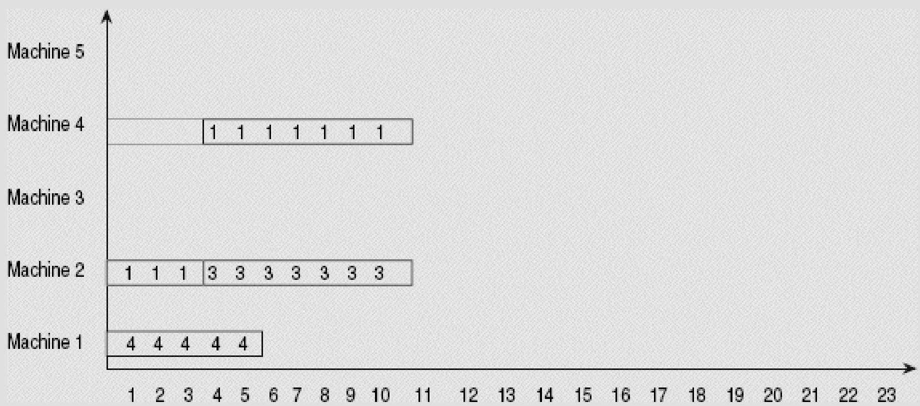


FIGURE 18.7 The final Gantt chart for the SPT rule

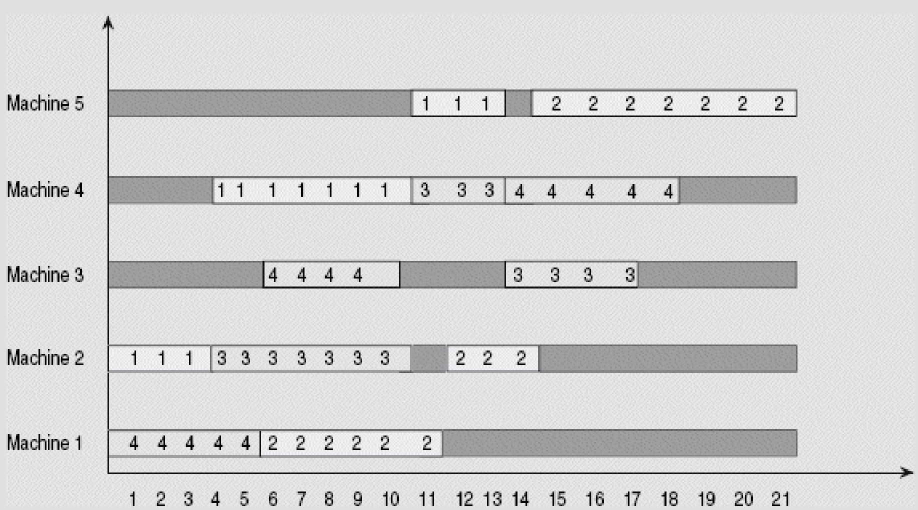
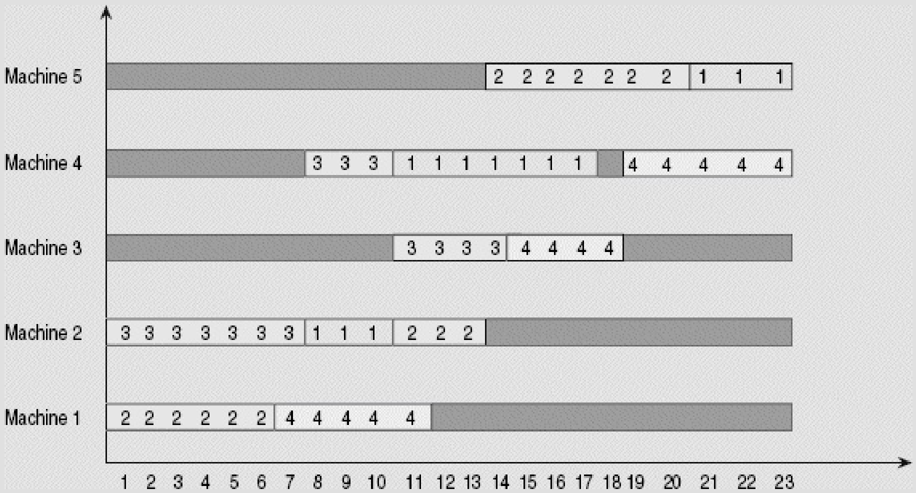


FIGURE 18.8 The Gantt chart for the EDD schedule



One can proceed in this fashion to arrive at the final chart for the SPT rule, as shown in Figure 18.7. It may be noted that the SPT rule is invoked only when more than one job competes for a resource. The make span for the problem is 21 units as evident from the Gantt chart.

The EDD rule schedule is drawn using a similar logic. When there are competing jobs for a resource, the EDD criterion is used. The Gantt chart for the EDD schedule is given in Figure 18.8.

In this case, the make span has increased by two time units to 23. Table 18.10 presents a summary of the performance measures for SPT and EDD rules. Interestingly, the EDD rule has fared badly on completion time, make span and lateness. This example clearly demonstrates the complexity of job shops. Predicting the performance of the rules is not as easy as in the case of a flow shop. In both the cases, all the jobs were tardy.

TABLE 18.10 Performance Measures for SPT and EDD Rules: A Summary

Job Number		SPT		EDD	
	Due	C_i	Lateness	C_i	Lateness
1	10	13	3	23	13
2	12	21	9	20	8
3	9	17	8	14	5
4	14	18	4	23	9
Average		**17.25**	**6.00**	**20.00**	**8.75**

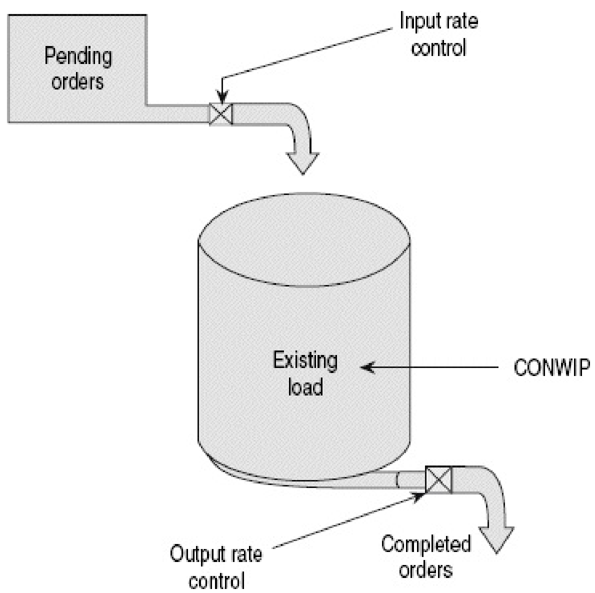
18.7 INPUT–OUTPUT CONTROL

Operational control in manufacturing systems is largely a function of the relationship between input and output rates. Let us look at a situation in which jobs are launched into system at the rate of one every four hours and the jobs leave the system one every three hours. Over a period of time one could expect build-up of inventory in the system leading to congestion at workstations and chaos in material flow. Build-up of WIP inventory in the system leads to several complications, which include the following:

a. Estimating the available capacity in the shop becomes difficult.
b. The lead time for manufacturing increases with increase in inventory.
c. Planning and control of operations becomes more complex as more jobs compete for limited resources.
d. Performing loading and scheduling functions also becomes difficult.

Therefore, input–output control is an important element of operational control in manufacturing systems, especially in batch manufacturing and job-shop systems. Figure 18.9 portrays the input–output control mechanism required for a manufacturing system with the analogy of a water-flow system that has a pair of control gates. The first control is at the input of pending orders into the system and the second control point is the output rate. By a judicious choice of the input and output rates, better planning and control can be achieved and lead times reduced to realistic levels. The basis on which the two control points will be adjusted is the quantum of constant WIP (CONWIP) in the system.

FIGURE 18.9 Input–output control: an illustration



18.8 OPERATIONAL CONTROL ISSUES IN MASS PRODUCTION SYSTEMS

So far, we have concentrated on flow shops and job shops and issues pertaining to scheduling and operational control in these systems. However, there are several examples of mass production systems in operation today. For example, a two-wheeler manufacturer such as Bajaj

Industries produces over 9,000 two wheelers everyday. Various sub-assemblies in the Bajaj plant need to be configured to match the production rate. Similarly, the final assembly stations should also have the required number of resources at each station to meet the targeted demand. In such a scenario, much of control and scheduling boils down to appropriately arriving at a balanced flow of components on the shop floor. There are two ways of achieving this objective:

a. Estimate the number of resources required at each station of the manufacturing system for a targeted production level. Conversely, if there are a certain number of resources available, estimate the production level and adjust the plans accordingly.
b. Given a certain availability of resources at various stages of the production system and a targeted daily production, estimate the rate at which the entire system should work and accordingly modify the work practices and resource deployment to meet the target.

The first method lays emphasis on designing operational control systems for mass production. On the other hand, the second method focuses on the ability to craft alternative operational control strategies to meet the changing targets on a period-to-period basis. The former is a traditional application of the concept and is often referred to as the *line-balancing technique*, while the latter is the modern Japanese approach to manage mass production systems. A detailed description of line balancing is available in Chapter 4 of the book.

The line-balancing technique does not solve all the operational control problems in a mass production system. It provides a basis for the initial design and deployment of resources. However, mass production systems face constant revisions in the production rate. These changes occur due to changes in the market demand and revisions in component off-take by customers. Consider an auto-component manufacturing firm, such as the Chennai-based Lucas TVS that supplies alternators to Maruti Udyog Limited (MUL). Suppose the daily requirement of MUL is 480 alternators during the first week of a month. If Lucas works for two shifts of eight hours each, then the hourly production of alternators is 480/16 = 30. Furthermore, the cycle time for alternator assembly is 60/30 = 2 minutes. This means that the production system responsible for manufacturing alternators for MUL should work at a uniform pace with a cycle time of two minutes everywhere. The final assembly will have to be tuned to two minutes, and so will all the feeder shops to the final assembly.

Suppose that there has been a revision in the daily requirement by the third week of the month. Due to increased production at their plant, let us assume that MUL wants a daily supply of 600 alternators. To cope up with the increase in the demand, Lucas will have to work with a new cycle time 20 per cent less than the earlier measure (that is, 1.6 minutes). The final assembly as well as all the feeder units will have to be tuned to this new requirement. This measure therefore provides a rhythm for the overall functioning of the shop. In mass production systems, this measure is known as TAKT time.[8] Operational control issues in mass production systems begin with the computation of TAKT time. Based on this, several choices are made to ensure that the actual cycle time is as per the computation of TAKT. These choices can be grouped under the following categories: machine redeployment, altering operator allocations, and adjusting material feed rates.

Operational control issues in mass production systems begin with the computation of TAKT time.

TABLE 18.11 An Illustration of Worker Deployment for Adjusted TAKT Time

Required output per day	400	450	371
Number of shifts per day	2	2	2
Required output per shift	200	225	185.5
Net available production time (minutes)	420	420	420
TAKT time (seconds)	126	112	136
Work content (seconds)	1,764	1,764	1,764
Number of operators required per shift	14	16	13
Total number of operators required	28	32	26

Machine Redeployment

Mass production systems lay emphasis on the flexibility of the varying deployment of resources to alternative product groups. Therefore, one method of responding to changing TAKT time is to alter the assignment of machines (or manufacturing cells) to specific product groups. By incremental addition/deletion of machines, it is possible to adjust the production rate and cycle time.

Altering Operator Allocations

Operators in a mass production system are often expected to be multi-skilled. Therefore, one way of adjusting the cycle time is to alter the worker allocations. If a worker was attending to three machines earlier, then by adding additional workers to the manufacturing cell, the cycle time can be reduced, and vice versa. Such practices are common in mass production systems. Table 18.11 presents an illustrative example of this. In this example, for a required daily output of 400 units, the output required per shift is 200 units. Since the net available production time is 420 minutes, the TAKT time comes to 126 seconds. When the daily output is increased from 400 to 450, it required adjustment of the TAKT time from 126 seconds to 112 seconds in order to continue working on a two-shift basis. However, the number of workers has increased from 28 to 32 (2 additional workers per shift). Typically, employees will be deployed from another product line to this one to meet the new daily requirement. On the other hand when the daily output falls to 371, two workers need to be taken out of the production line (one per shift) and redeployed elsewhere.

Adjusting Material Feed Rates

Mass production systems have a streamlined material flow, often achieved by installing a conveyor system. The speed at which the conveyor moves between stations is a function of the cycle time. For instance, if two stations are five metres apart and the TAKT time is 30 seconds, then the conveyor needs to move between stations at a speed of 1 metre every 6 seconds (10 metres per minute). On the other hand, if the TAKT time changes to 20 seconds, the conveyor speed should be adjusted to 1 metre every 4 seconds (15 metres per minute). Furthermore, the tasks to be completed at every workstation needs to be completed within 20 seconds.

18.9 OPERATIONS PLANNING AND CONTROL BASED ON THE THEORY OF CONSTRAINTS

In this chapter, we have discussed various techniques for scheduling operations in a job shop and a flow shop. However, despite the use of these, there is a common problem of high WIP inventory in several manufacturing organizations. Moreover, manufacturing organizations suffer from the "end-of-the-period" syndrome. Typically, as organizations approach the end of a reporting period (the year-end is a classic example, but there are monthly and quarterly reporting cycles also), workflow gets considerably complex and inventory piles up beyond normal limits. Several reasons are attributed to this and significant among them are the following:

a. Organizations do not use appropriate measures for performance.
b. Operations scheduling does not take into consideration some ground realities in the shop floor.

Measures based on standard costing, such as variances at the department or even work-centre level, promote local optimum at the expense of global optima. Therefore, it is possible to create mountains of inventory, yet products may not flow evenly out of the manufacturing system. Similarly, scheduling on the basis of balancing capacity at individual work-centre level may not ensure a smooth flow of material through the manufacturing system.

Measures of Performance

The **theory of constraints** developed by Eliyahu Goldratt addresses these concerns and proposes alternative methodologies for operations scheduling.[9] Goldratt also proposed three new measures of performance for manufacturing firms.

> According to the **theory of constraints,** it is possible to increase the throughput even while the operating expenses and inventory are being reduced.

- *Operational measures:* The operational measures for a company are the throughput, inventory, and operational expenses. These measures could be used to make all decisions pertaining to the use of manufacturing resources.
- *Throughput:* Throughput is the quantity of money generated by a firm through sales over a period of time. The standard definition of throughput is total output, but this definition considers only sales and not finished goods (FG). According to Goldratt, this is because finished googs do not generate revenue for the firm until they are sold.
- *Inventory:* The quantity of money invested in materials that a firm intends to sell is defined as inventory. Contrary to the traditional logic (where inventory valuation includes value-added components to estimate WIP and FG inventory), here, it is a simple measure of the value of the material only.
- *Operating expenses:* Operating expenses include all expenses incurred by a firm to convert inventory into throughput over a period of time.

According to the theory of constraints, it is possible to increase the throughput even while the operating expenses and inventory are being reduced. This is identified as the single most important goal of managing manufacturing organizations. The principles governing the theory of constraints are best explained using the analogy of marching soldiers.

The Analogy of Marching Soldiers

The problems associated with scheduling and operational control of manufacturing systems can be best explained using the analogy of a column of marching soldiers. Assume that a batch of 10 soldiers begin the march from a reference point. Initially, all the 10 soldiers will be one behind the other with an equal gap. However, as they begin to march, certain differences will be noticed. If we observe the marching soldiers, we may find that the distance between the first and the last soldier is more than what it was at the starting position. This is because as the soldiers engage in marching, differences in the speeds and capacities of each soldier begin to manifest. If the third soldier is slower than the first two, then the gap between the third and the other two soldiers ahead of him will increase with time. If we observe the marching soldiers after they have covered, say, 5 km, the gap will increase even further.

Scheduling and operational control problems in manufacturing organizations share considerable similarity with this analogy of marching soldiers. The ground to be covered in the marching-soldiers example is the same as the raw material in the case of manufacturing organizations, and the ground already covered corresponds to finished goods. On the other hand, the mounting gap between the first and the last soldier is equivalent to the work-in-process inventory in a manufacturing organization (see Figure 18.10 and Table 18.12 for a graphical representation of this).

FIGURE 18.10 Marching soldiers: an analogy for planning and control in manufacturing systems

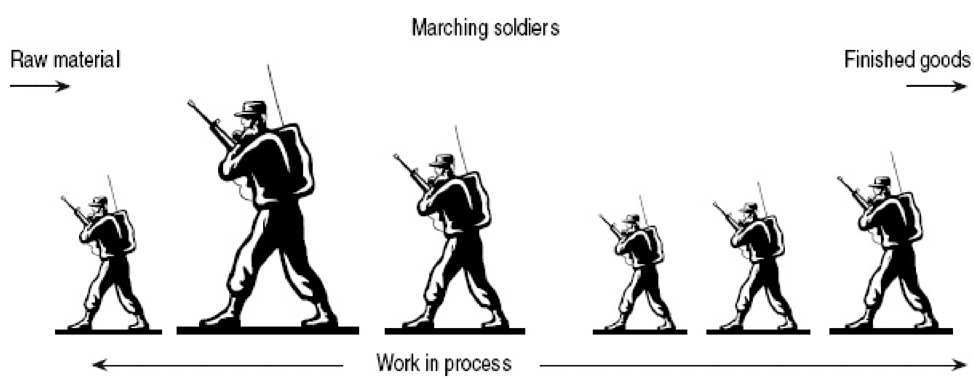


TABLE 18.12 A Comparison of Marching Soldiers and a Production System

Resource	Marching Soldiers	Production System
Processing	Ground to be covered	Raw material to be processed
WIP	Gap between the first and the last soldier	Work in process in the shop floor
Throughput	The extent of ground covered by the marching	Amount produced and sold by the production

	soldiers	system
Operating expenses	Amount of energy expounded by the soldiers to complete the march	Cost of transforming the raw material into throughput
Objective	To cover a certain extent of the ground in a given time	To achieve a certain throughput in a given time

As in the case of the soldiers, resources in manufacturing organizations differ from one another in their ability to process components. Some machines may have more than the required capacity to process in a planning horizon. Some other resources may have less than the total capacity required for the planning horizon. Statistical fluctuations and dependent events are characteristic of resources in a manufacturing organization. All these generate similar effects in a manufacturing system as that of increasing the gap between the soldiers. However, we know that increasing WIP inventory and manufacturing lead time is directly related to the increase in the gap between the soldiers as they march. Therefore, operational control is primarily a function of making sure that the gap between the soldiers does not increase with time.

The *theory of constraints* is a systematic body of knowledge that recognizes these effects in a manufacturing system and uses specific methods to improve the performance of the system under these conditions. **Synchronous manufacturing** is a specific application of the theory of constraints to scheduling and operational control of the manufacturing systems.

> **Synchronous manufacturing** is a specific application of the theory of constraints to scheduling and operational control of manufacturing systems.

Synchronous Manufacturing

The marching-soldiers example shows that the rate at which they can cover ground is a function of the slowest marching soldier in the column. If soldiers ahead of the slowest continue to march at their higher speeds, they will only contribute to increasing the gap between them and the slowest. On the other hand, those behind the slowest will be forced to march only at the speed of the lowest. One way to solve this problem is to first tie a rope connecting all the soldiers (from the first to the last), and provide a drumbeat at a rate equivalent to the slowest and enable the marching soldiers to respond to the rhythm of the drumbeat. By doing this we not only ensure that the gap does not increase with time, but also create a synchronized movement of the soldiers on the ground. Synchronous manufacturing deploys these features in the scheduling and operational control logic. In synchronous manufacturing, the focus is on synchronizing flow rather than on balancing capacities.

This discussion clearly brings out the need to address the scheduling problem in a different context. It is important to plan the scheduling and control of the entire manufacturing system on the basis of availability of resources. The following definitions are common in synchronous manufacturing literature.

- *Bottleneck resource:* Any resource whose capacity is equal to or less than the demand placed on it is a **bottleneck**

resource. On the contrary, any resource whose capacity is more than the demand placed on it is a non-bottleneck resource.

> Any resource whose capacity is equal to or less than the demand placed on it is a **bottleneck resource**.

- *Capacity constrained resource (CCR):* In a manufacturing system it is observed that some resources have the ability to significantly deviate the product flow, from the planned flow, if not properly scheduled. Any resource that can deviate the actual product flow from the planned flow is known as a **capacity constrained resource**. A bottleneck or a non-bottleneck resource may become a CCR.

> Any resource that can deviate the actual product flow from the planned flow is known as a **capacity constrained resource (CCR)**.

- *Activation of a resource:* Activation merely refers to the deployment of a manufacturing resource to process materials. Merely processing material may not in itself guarantee increase in throughput.
- *Utilization of a resource:* Utilization refers to the activation of a manufacturing resource that will lead to improving the throughput.
- *Process batch:* A process batch refers to the quantity of a product (or part) processed at a resource before that resource changes over to another product (or part). For example, if two parts—X and Y—are processed in Resource R1, then, if 300 units of Part X are processed before changing over to processing Part Y, then the process batch for Part X is 300.
- *Transfer batch:* A transfer batch indicates the quantity moved at the same time from one resource to another resource in a manufacturing system. For example, if 100 units of Part X are moved at a time from Resource R1 to Resource R2 for further processing, then the transfer batch of Part X is 100.

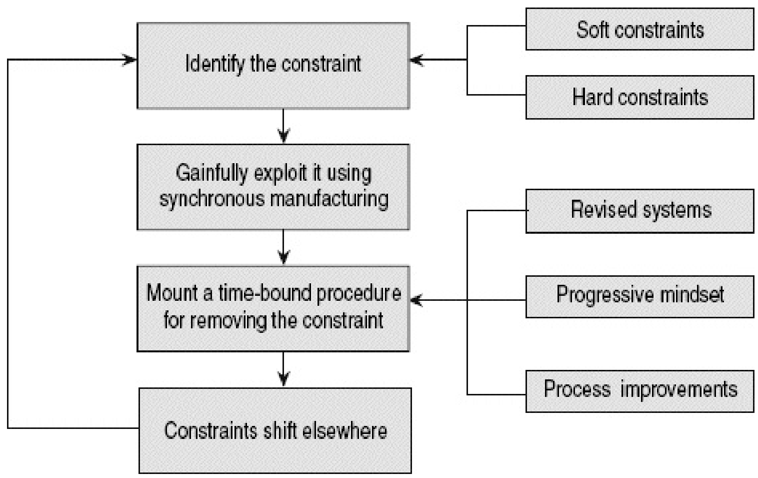
Constraints in a Manufacturing System

Before we address the issue of scheduling with bottleneck resources as the focus, it is helpful to understand how bottlenecks develop in an organization. In a broad sense, bottlenecks are nothing but the manifestation of constraints. In synchronous manufacturing, any element that prevents the system from increasing its throughput is identified as a constraint. There are several constraints in an organization—some of them are hard constraints and others soft. By hard, we mean constraints arising out of capacities, physical infrastructure, resource availability, and so on. On the other hand, soft constraints arise out of policy implications and poor managerial practices. For example, a peculiar and complicated approval process for purchase order release may result in severe material constraints (due to long lead time for procurement). Soft constraints are not obvious to the management. They manifest indirectly in other forms of hard constraints (as our purchase order example shows). It requires special attention to track and remove those constraints.

Market constraints are the limits of production imposed by the market demand. Capacity and material constraints arise out of physical limitations in capacity and material availability. For instance, the short supply of a key ingredient in a manufacturing process puts limits on the system. Similarly, the capacity of available machines and human resources may impose limits on the system. There are also soft constraints arising out of managerial, logistical, and behavioural issues.

Synchronous manufacturing may offer valuable help in scheduling a manufacturing system with constraints. However, in the long run, it is important to invest in methods to remove the constraints. Removing an existing constraint merely shifts the constraint elsewhere and is therefore an ongoing process, as indicated in Figure 18.11.

FIGURE 18.11 Constraint management in the long run



The guiding principles of synchronous manufacturing are as follows:

1. Do not focus on balancing capacities. Instead, focus on synchronizing the flow.
2. The marginal value of time spent at a non-bottleneck resource is negligible. Do not attempt to reduce time at a non-bottleneck resource.
   2a. An hour gained at a non-bottleneck resource is a mirage.
   2b. An hour lost at a non-bottleneck resource is an hour of throughput loss.
3. The level of utilization of a non-bottleneck resource is controlled by other constraints within the system
4. Resources in the system must be utilized, not simply activated.
5. A constraint is any element that prevents the system from achieving the goal of making more money.
6. The transfer batch need not, and many times should not, be equal to the process batch

From the definitions and the guiding principles we have discussed, a few important aspects can be inferred:

- The separation of resources as bottleneck and non-bottleneck is very important because while bottleneck resources determine the (planned) output of the system, CCR will ensure that the actual throughput does not deviate from the plan in a manufacturing system. Focusing on maximizing the utilization of a bottleneck resource is instrumental to maximizing the throughput in a manufacturing system. On the other hand, scheduling is done in synchronous manufacturing with reference to CCRs.
- Placing buffers in front of bottleneck resources will protect the throughput of the system
- Careful choice of the transfer and process batch sizes will ensure the protection of the throughput at the bottleneck as well as proper scheduling of the CCRs
- Once these aspects are determined, the rest of the system must work in tandem with these decisions A drum–buffer–rope (DBR) methodology helps one to achieve these while scheduling a manufacturing system.

The Drum–Buffer–Rope (DBR) Methodology

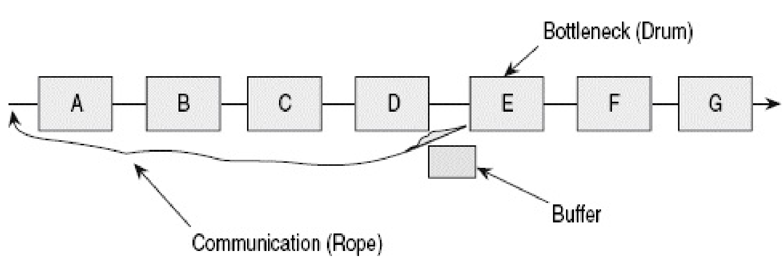
Once a preliminary production plan is established, synchronous manufacturing develops detailed schedules for the CCRs in the plant. On the basis of these schedules, the production plan can be finalized. The resulting modified production plan can become the master production schedule (MPS) and can be used as the basis for making promises to customers. This process of arriving at the MPS on the basis of the detailed schedules for CCRs is the drum in DBR methodology. The MPS, which is based on the processing capabilities and requirements of the CCRs, determines the pace and the sequence of production for the entire plant. The MPS itself is therefore analogous to the drumbeat of the march. The drumbeat ensures that all resources are not merely activated but utilized as per the throughput requirement.

Since statistical fluctuations are inevitable, there could be potential opportunities for the planned flow to deviate from the actual flow. To protect the schedule from disruptions, a time buffer is built into the system. The planned lead time is the sum of the process and set-up times and the time buffer. In effect, the time buffer increases the planned lead time by a sufficient amount so as to accommodate disruptions and fluctuations that are likely to happen in the manufacturing system. Since the bottleneck resource dictates the output of the entire system, an hour of capacity lost at the bottleneck translates directly into an hour of lost throughput. Therefore, the buffer is placed in front of a bottleneck resource. On the contrary, nothing is achieved by placing a buffer ahead of a non-bottleneck resource. It merely increases the inventory in the system but not the throughput.

Once the MPS is finalized, the product structure, routing sheets, and other production policies are used to determine the quantity and timing of planned production at each resource in the plant.[10] Since the MPS is based on the capabilities of CCRs, the entire plant operation is tied through this process to the drumbeat of the MPS. Through this methodology, we have ensured synchronization of schedules at all non-CCRs. Therefore, this is the rope component of the DBR methodology. Figure 18.12 illustrates the DBR methodology in the case of a bottleneck resource in a shop having seven resources. The DBR methodology can be outlined as follows:

a. Develop the MPS so that it is consistent with the constraints of the systems (Drum).
b. Protect the throughput of the system from statistical fluctuations through the use of buffers at some critical points in the system (Buffer).
c. Tie the production at each resource to the drumbeat (Rope).

FIGURE 18.12 An illustration of the DBR methodology



Several organizations have benefited from the use of the DBR methodology for scheduling operations in a manufacturing system. In response to the demand for easy application of these principles, several computer-based software packages have also been developed to implement the DBR methodology. Synchronous manufacturing principles represent a recent approach to addressing scheduling complexities in organizations. Moreover, the notion of the theory of constraints is also applicable to other operations systems such as management of large projects.

SUMMARY

- The focus shifts from operations planning to operational control in the short term. Scheduling aids operational control in manufacturing and service systems.
- The scheduling context relates to the number of jobs and machines in the system and the physical configuration of the machines. These factors greatly influence the complexity of scheduling.
- Flow shops and job shops are two alternatives for the configuration of a manufacturing system. The scheduling methodology and complexity differ vastly between these two. Job shops are far more complex to schedule than flow shops.
- Johnson's algorithm provides an optimal schedule for a two machine–*n* job problem using the shortest processing time rule for scheduling. Several variations of Johnson's algorithms are available for flow-shop scheduling.
- Operational control in mass production systems are primarily achieved through use of TAKT time–based scheduling.
- The theory of constraints indicates that scheduling of operations must take into account the existence of bottlenecks and statistical fluctuations in operations.
- Synchronous manufacturing principles apply the theory of constraints and develop alternative schedules using a drum–buffer–rope methodology.

FORMULA REVIEW

1. Critical Ratio $$(CR) = \frac{\text{Remaining time}}{\text{Remaining work}} = \frac{(\text{Due date} - \text{Current date})}{\text{Remaining processing time}}$$
2. Flow time of the job, $F_i = (R_i - C_i$
3. Make span (maximum completion time), $C_{max} = \max_i \{C_i\}$
4. Lateness of the job, $L_i = (C_i - D_i)$
5. Tardiness of the job, $T = \max(0, L_i)$

REVIEW QUESTIONS

1. How is scheduling linked to other aspects of production planning? Explain with the help of an example.
2. What do you mean by the loading of machines? What do you achieve by performing the loading function?

3. Classify the following as a job shop or as a flow shop for the purpose of scheduling. Also, identify the relevant parameters of the system that have a bearing on the scheduling complexity.

    a. Executive health check-up in a hospital
    b. Tirupati temple queue complex having multiple stages
    c. Breakfast buffet system at Taj Hotel
    d. Final assembly shop of a computer manufacturer
    e. Computerized passenger reservation system of Indian Railways
    f. Eye camps conducted by a local eye hospital
    g. A common heat treatment facility in a manufacturing plant
    h. Visa section at the US consulate office at Mumbai

4. How would you determine the complexity of the scheduling problem?
5. A firm is interested in choosing between the minimization of make span and minimization of flow time as the performance criterion. Prepare a short note advising them on the pros and cons of using these rules.
6. What are the implications of using completion-based measures as opposed to due date–based measures for evaluating scheduling rules?
7. Explain, by means of a simple example, the difference between lateness and tardiness. Which is a better measure? Why?
8. What is a Gantt chart? What is its use in scheduling?
9. What is cycle time? What are the practical implications of cycle time measure in mass production scenarios? How do they influence the scheduling of jobs in a manufacturing system?
10. An organization has a certain number of workstations in its final assembly for a desired production rate. If the desired production rate has gone up by 10 per cent, how would you respond to the new requirement? Will this change have an effect on cycle time?
11. What do you mean by soft and hard constraints in an organization?
12. How are synchronous manufacturing principles different from the traditional methods used for scheduling of jobs?
13. What is meant by the DBR methodology? What does it seek to achieve?

PROBLEMS

1. Consider a one-machine–six-jobs scheduling problem. All the jobs are available for scheduling at the beginning of the planning horizon itself. The processing times and due dates of the jobs are given in Table 18.13.

TABLE 18.13 Processing Times and Dates of Jobs

	Job 1	Job 2	Job 3	Job 4	Job 5	Job 6
Processing time (minutes)	12	10	15	13	12	9
Due (minutes from start of planning horizon)	25	45	55	30	90	70

    a. Use LPT, SPT, FCFS, RAN, EDD, and SR to arrive at a schedule
    b. For each of the schedules, compute the following performance measures:
        i. Mean flow time
        ii. Make span
        iii. Mean completion time
        iv. Mean lateness
        v. Mean tardiness

vi. Number of tardy jobs

c. Identify the rule that performs the best for each of these performance criteria.

2. A service provider has two stages in service delivery. Initially, the customers arrive at Stage 1, get the initial part of the service, and then reach Stage 2, where the remaining part of the service is completed. All arriving customers wait in a lounge and are called on some basis into the system once a batch of eight accumulates. All of them go through these two stages, although the time they spend in these two stages may vary depending on their specific requirements. The time spent by a set of eight customers on these two stages is shown in Table 18.14.

   a. Use Johnson's rule to schedule customers in the system.
   b. Develop a Gantt chart for the schedule.
   c. Identify key performance measures for this situation and compute them for the solution obtained using Johnson's rule.
   d. If you scheduled the customers using FCFS, what is its impact on the performance criteria?
   e. Evaluate and compare the performance of the random rule with Johnson's rule and the FCFS rule.

TABLE 18.14 Duration Spent by Customers on the Two Stages

	Customer Number							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Stage 1 (minutes)	11	10	9	13	12	10	9	11
Stage 2 (minutes)	9	14	10	12	14	14	11	10
Arrival time (minutes from start of batch)	0	1	3	4	5	7	8	10

3. A pure flow shop has three machines and all the jobs visit these machines. The processing time of each job in each machine is given in Table 18.15.

   a. Use the SPT rule to schedule the jobs in the flow shop and draw a Gantt chart for the schedule.
   b. Compare the performance of the SPT rule with the EDD rule using the following performance criteria:
      i. Mean tardiness
      ii. Mean flow time
      iii. Number of tardy jobs
      iv. Make span
   c. Compute the utilization of the three machines for both the schedules.
      (**Hint:** Convert it into a two machine problem. First alternative is to combine processing times of m/c1 and m/c2 into a single equivalent machine. Alternative 2 is to combine the processing times m/c2 and m/c3. Solve using Johnsons rule and choose the best alternative)

TABLE 18.15 Processing Time of Jobs, Machine-wise

Processing Time	Job Number 1	2	3	4	5	6	7	8
Machine 1 (minutes)	14	10	10	13	12	11	9	9
Machine 2 (minutes)	11	14	10	9	14	14	7	10
Machine 3 (minutes)	9	8	10	11	12	7	8	9
Due (minutes from start of planning horizon)	80	45	55	60	90	50	100	70

4. A job shop has five machines for processing. There are six jobs to be processed. However, current capacity constraints indicate that only five jobs can be processed out of the six. The planner needs to know which jobs to assign to the machines. Identify an optimal loading of the shop on the basis of Table 18.16, which contains data on the processing time of each job against each machine.

TABLE 18.16 Processing Time of Jobs

Jobs	Machines A	B	C	D	E
1	11	14	17	10	12
2	12	14	16	13	10
3	17	12	11	15	12
4	16	16	12	12	14
5	14	16	10	11	12
6	15	14	13	16	19

5. A job shop has five jobs for processing. There are four machines in the shop. The jobs visit the machines in a particular order (indicated by each job's routing file). Table 18.17 has details of the machines visited by each job and the processing time of each machine. The table also has information on the due dates.

 a. Develop a schedule for the jobs using (i) SPT, (ii) EDD, and (iii) FCFS rules.
 b. Use three appropriate performance criteria and evaluate these rules.
 c. Compute the machine waiting time and job waiting time for all the schedules obtained using the SPT, EDD and FCFS rules. If you were to select a scheduling rule on the basis of the minimum job waiting time, what will your recommendation be?
 d. If there is a penalty for delay at the rate of ₹250 per minute and a reward of ₹100 per minute for completing early, compute the cost of the schedules attributable to these.

TABLE 18.17 Processing Time of Jobs and Due Dates

Jobs	Machines Visited (Processing Time In Minutes) 1	2	3	4	Due by (minute)
1	1 (12)	3 (7)	4 (8)	5 (4)	45
2	2 (7)	4 (6)	3 (5)	5 (6)	35
3	1 (8)	2 (5)	3 (9)	4 (5)	37
4	3 (6)	1 (6)	2 (6)	5 (7)	29
5	2 (9)	4 (8)	5 (6)	3 (7)	40

6. A bulb manufacturer works for 25 days a month on a two-shift basis. Each shift is of 8 hours duration. The marketing demand estimates the monthly demand for the bulbs to be 48,000. If the manufacturing system is a continuous-flow mass-manufacturing type with feeder shops linked to the assembly shops through a material flow control system, then compute the following for the manufacturer:

    a. The TAKT time for all the shops in the manufacturing system.
    b. If the successive workstations in the manufacturing plant are uniformly placed at a distance of three metres, at what speed should the material handling system move between the work-stations?

MINI PROJECTS

1. A vast number of scheduling packages are available in the market today. Scan through the following sources:

    - Journals: *OR/MS Today* (a bimonthly magazine from the Operations Research Society) and *IIE Solutions* (a journal of the Institute of Industrial Engineering). These journals periodically bring out a survey of available software for specific areas of production management. Look for surveys pertaining to scheduling software.
    - American Production & Inventory Control Society (APICS).
    - Search engines: Search with keywords such as “APS”, “advanced production scheduling”, and “scheduling software”.
        a. Based on this exercise, prepare a technical note on a survey of the available software options for scheduling.
        b. Develop a classification scheme to list all the software that you have come across.

2. Visit a health management system (such as a multi-specialty hospital with facilities for in-patients, out-patients, laboratories for diagnostics, operation theatres, and special care systems) and study the scheduling practices with respect to the following:

    - The doctors and surgeons visiting the hospital
    - The support staff such as nurses, shift doctors, coworkers and laboratory staff
    - Major facilities such as operation theatres and laboratories
    - The outpatient department
        a. Prepare a note outlining the major findings of the study with respect to the aspects mentioned here. The report should highlight the relevance of scheduling techniques discussed in the chapter, the extent of usage, reasons for non-usage, and recommendations for removing some of the barriers to adopting the known techniques.
        b. Did you notice any significant patterns in the scheduling of personnel in the system that differs from a typical manufacturing system?
        c. If so, identify them and state the reasons for the differences.

3. Read the book *The Goal* by Goldratt and Cox.[11] After reading the book, write a book review. While writing the review, answer the following questions amongst other things that you may like to cover in the book review:

    a. What are the key elements of the alternative method by which Alex Rego tries to solve the problems at his manufacturing set-up? Clearly outline the key conceptual details of his alternative strategy that helped him find a solution.
    b. How do you link his strategies for controlling a manufacturing system to that of the notion of scheduling that we have discussed in the chapter?
    c. What are the key performance measures that Alex Rego uses for controlling his manufacturing system?
    d. Do you think that his concept has a wide applicability? If so, give some examples of situations where this concept can be applied.

SUGGESTED READINGS

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CHAPTER 19

Six-Sigma Quality Control

CRITICAL QUESTIONS

After going through this chapter, you will be able to answer the following questions:

- What is the underlying logic behind six-sigma quality initiatives in organizations?
- How do organizations set up processes to achieve six-sigma quality levels?
- What are the causes for variations in processes and how can organizations control them?
- What are the elements of a process control system? How do organizations set up such systems?
- What are the different types of control charts? How can one set up these control charts?
- How do fi rms predict the quality level of a process and make improvements in the long run?
- How do organizations design acceptance sampling plans?

In an organization like a five-star hotel, it is not enough to main tain a 99 per cent quality level. Six sigma helps such organizations to improve their quality to near-zero defect levels.

Source: stock.xchng

ideas at Work 19.1

Quality Control at Indian Food Specialties Limited

Indian Food Specialties Limited (IFS) introduced tools for quality control in May 2000 in response to the changing market conditions and poor profitability. The company's mission statement emphasized its commitment to produce and supply products to meet specifications. Despite this, high spoilage in the production process led to losses for three consecutive years at IFS.

IFS had a wide spectrum of brands selling in different regions of the world. In the past, in catering to the ethnic Indian population abroad, IFS could afford to be somewhat lax in its quality. However, this segment of customers was increasingly getting quality-conscious. Moreover, non-ethnic customers also demanded conformity to quality specifications.

Two parameters were critical for mango pickles: salt and acidity content. While high levels of salt and acidity content could result in a bad taste, low levels could spoil the pickle. Therefore, IFS decided to set up a system through which these parameters could be monitored for conformity to standard specifications. Based on 57 daily samples, each of size 7, it was possible to monitor the process of producing the pickles through the use of $\bar{X}$ – and R control charts. On several days, the sample observations were outside the control limits. In the case of acidity levels, nearly two-thirds of the data was outside control limits.

These pointed to an immediate need for better control at IFS. If the situation was out of control due to the process, further investigation might be required. On the other hand, if it was due to workers not adhering to specified procedures, better training and discipline might be required.

Every organization uses several of the ideas that IFS has tried to implement to improve quality control in its production processes. There are several tools and techniques available to monitor a process and detect situations when the process deviates from specifications or goes out of control. Furthermore, these tools also enable organizations to predict the quality level of the processes and target improvement towards zero defects in the long run.

Source: Based on S. Y. Deodhar and D. Tirupati, "*Indian Food Specialties Limited*," *Vikalpa* 27, no. 1 (2002): 55–68.

In Chapter 12, we discussed several issues that an organization needs to address to ensure that quality becomes an ingrained value among all its employees. TQM principles set the stage for an organization to build specific subsystems for quality management. Recall that one of the three pillars of TQM is the establishment of tools and techniques for quality assurance. In this chapter, we focus our attention on the application of statistical tools. Statistical tools and techniques play a central role in setting up a robust quality assurance system in any organization. Therefore, an operations manager should have a sound conceptual understanding of these techniques.

19.1 THE SIX-SIGMA APPROACH TO QUALITY CONTROL

In recent times, many organizations have been conducting special training programmes and undertaking a set of projects to attain what is popularly known as six-sigma quality. Multinational firms such as Motorola and GE pioneered the use of the six-sigma approach to quality. In 1988, Motorola Corporation was the winner of the Malcolm Baldrige National Quality Award. Motorola bases its quality effort on its six sigma programme.

> Multinational firms such as Motorola and GE pioneered the use of the six-sigma approach to quality.

Six sigma is a new approach to process control based on a set of principles that enables organizations to improve their quality to near-zero defect levels. These include understanding customer needs well, appropriate and disciplined use of data and statistical tools, statistical analysis, and a closer attention to managing and improving business processes using a set of tools. The basic unit of analysis with respect to the quality of any process is the defect. A **defect** is an unacceptable state of a product or service for a customer, arising out of a business process that produced it. Since the focus of six-sigma quality is primarily business processes, it is equally applicable to both manufacturing and service organizations. Since quality improvements have been happening in manufacturing shop floors ina big way due to the TQM movement, one can expect a greater overall impact of the six-sigma approach in the non-manufacturing portions of a manufacturing organization, as well as in service organizations. This in turn will greatly improve the competitive position of an organization.

> **Six sigma** is a new approach to process control based on a set of principles that enables organizations to improve their quality to near-zero defect levels.

> A **defect** is an unacceptable state of a product or service for a customer, arising out of a business process that produced it.

Six-sigma methodology seeks to provide a set of tools and techniques and an organizational framework to eliminate defects from any business process by ensuring that it is an “extraordinarily rare event”. We define a new metric to capture the essence of this notion of “extraordinarily rare event”. Six-sigma quality control differentiates itself from the traditional quality control methodology on the basis of three features:

a. A new metric, defects per million opportunities (DPMO), to predict/assess the quality of a business process.
b. A new methodology, “define–measure–analyse–improve–control” (DMAIC), to ensure that very high levels of quality could be assured in the chosen business processes thereby generating favourable outcomes to both the business and the customers.
c. An organizational framework for ensuring that these outcomes are generated on a sustained basis.

19.2 DEFECTS PER MILLION OPPORTUNITIES (DPMO)

The first step in improving quality to world-class levels is to get out of the mindset of measuring quality in percentage terms and to look for alternative metrics that will measure quality much more accurately. The basic metric of interest in six-sigma quality control is the DPMO. In simple terms, this measure indicates how many defects a process generates in a million opportunities.

Each business process involves certain steps and throws open a certain number of opportunities for defects to happen. In an accounts payable process, the vendor name or bank account could be wrong, the amount could be erroneous, or the shipping address could be wrong. Using this basic information one can compute the quality of the business process using a metric. While service industries find it convenient to use DPMO, manufacturing organizations use the term *parts per million (PPM)*. Both of them strive to achieve the same end.

If, in a process,

k = Number of opportunities for making a defect per unit of execution of that process

n = Number of units of observation of the process

d = Number of defects that occurred in that process during the observation (19.1)

$$\frac{\text{Number of defects } (d)}{\text{Number of opportunities per unit } (k) \times \text{Number of units of observation } (n)} \qquad (19.1)$$

$$\text{Defects per million opportunities (DPMO)} = \left(\frac{d}{k \times n}\right) \times 1{,}000{,}000 \qquad (19.2)$$

Six-sigma quality control differentiates itself from the traditional quality control methodology on the basis of three features:

a. A new metric, defects per million opportunities (DPMO)
b. A new methodology, DMssAIC
c. An organizational framework

Assume that we run a hotel business in a tourist destination such as a hill resort in Darjeeling or the backwaters in Kottayam, Kerala. Several business processes are involved in running the hotel. Let us consider one business process—the check-in and check-out of guests. The process may have a few steps and a certain number of potential opportunities to make errors leading to some defect. Assume that the check-in process has potentially 9 defect opportunities. During one peak season, the resort dealt with 1,142 guests and the number of defects was 361. From this data, one can compute the DPMO in the following fashion:

Number of defect opportunities per unit (k) = 9
Number of guests handled (n) = 1,142
Number of defects (d) = 361
Number of defect opportunities = 9 × 1,142 = 10,278

Defects per million opportunities (DPMO) = (361/10,278) × 1,000,000 = 35,123

One of the important requirements of a six-sigma approach quality control is to be able to predict the DPMO of a business process by observing the process characteristics and linking them to customer specifications. We shall see later in the chapter how this is possible by obtaining the voice of the process using control charts and mapping it on to the voice of the customer.

19.3 SIX-SIGMA METHODOLOGY (DMAIC)

Six-sigma quality levels are achieved using a structured five-step methodology in organizations. It is usually referred to as DMAIC (define–measure–analyse–improve–control). This resembles closely the PDCA cycle advocated by Deming. DMAIC provides a mechanism for making improvement in quality on a project-by-project basis. By the use of several tools available in the domain of quality management and continuous improvement, the DMAIC methodology combines group work, organizational focus towards customers, and process improvement into one. Thus it reaches far and wide compared to traditional quality control using mere statistical tools and is likely to generate a greater impact. For each project, a team utilizes the DMAIC methodology to improve quality. The five steps, as shown in Figure 19.1, are detailed here:

> The DMAIC methodology combines group work, organizational focus towards customers, and process improvement.

1. *Define*: The first step in a six-sigma project is to define the problem and the context for improvement. The activities involved in this step are:
   - Defining the problem, the requirements, the scope of the project, and the project charter.
   - Setting goals for improvement.
2. *Measure*: Once the problem is defined, the next phase is to obtain data. Six-sigma methodology is a data-driven employee-centred methodology. Furthermore, the analysis of process variations is critical to improve quality. Therefore, in the measure phase, the activities include:
   - Identifying variables to be measured and the type of measurement.
   - Data collection and synthesis.

     This forms the basis for further analysis and quality improvement.
3. *Analyse*: During this phase, the data collected is analysed to find possible causes for bad quality and identify areas that need improvement in order to reduce the defects. Several statistical, analytical, and graphical tools could be used in this stage. The main activities performed include:
   - Applying graphical tools of analysis
   - Identifying possible sources of variation and “vital” few root causes.
   - Exploring means of eliminating them.

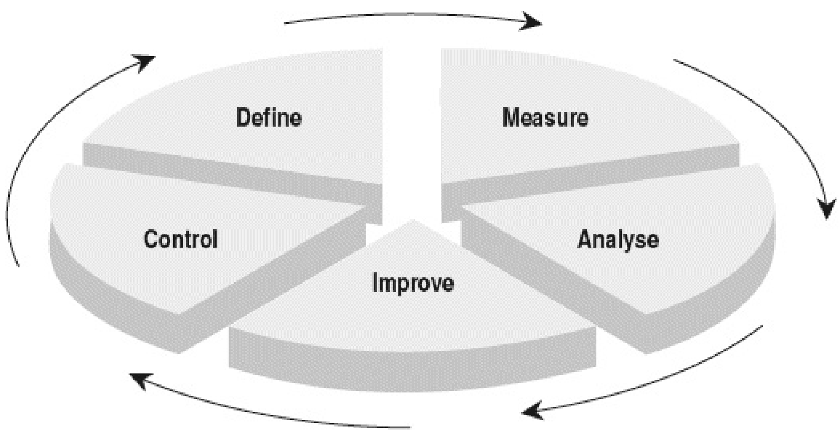
     Various QC tools described in Chapter 12 are typically put to use in this phase. Often, the analysis is triggered by the use of control charts and identification of situations where the process seems to be going out of control.
4. *Improve*: In the improvement phase ideas for eliminating the “vital” few root causes are further developed and solution methodologies devised for implementing the same. The activities include:
   - Generating and validating improvement alternatives.
   - Creating new process maps for the process.
5. *Control*: In the control phase, steps are taken to ensure that the process does not drift away from the newly improved standard. In order to achieve this, the following steps are taken:
   - Developing control plan

- Establishing revised standard measures to maintain performance
- Developing relevant training plans to maintain standards

Let us take a look at the people required and their roles in order to achieve this.

- *The process owner*: The process owner is the one who takes responsibility for the various steps of a process that is responsible for delivering some output to the customer. The process owner could be the supervisor or a manager in a particular work area where the improvement project has been identified.
- *The team leader and the members*: Six sigma is a small group improvement activity. Therefore, the team leader (the project leader) and the members will comprise the employees in the chosen work area. They will have day-to-day operational control of activities and knowledge of the process that they seek to improve.
- *The six-sigma coach*: A coach is a consultant who offers expert knowledge on various aspects of six sigma. This includes statistical tools, process design and analysis, change management, small group improvement, use of QC tools for improvement, etc. The coach could be a senior person within the organization or it could be a resource person external to the organization.
- *The sponsor*: A sponsor is a member of the senior management who oversees the overall progress and implementation of the improvement project by a six-sigma team. The sponsor helps the team refine the project scope, sorts out issues cutting across other parts of the organization, approves projects, and provides the necessary support in terms of resources.

FIGURE 19.1 The DMAIC methodology



ideas at Work 19.2

Defect Opportunities: The Case of Fixed Deposits

Fixed deposits (FDs) have low returns and risks. The investor profile typically includes senior citizens investing their retirement benefits, very young people who have just begun a career, members of the salaried class belonging to the lower/middle-income group, and people from rural areas who are agriculturists or those involved in other unorganized trades. Depositors by and large are not concerned with interest rates alone. Since FDs are unsecured, the depositors tend to worry more about the service and stability of the company. Thus, service quality can be a key differentiator in its own right, leading to market leadership, as in the case of players such as Sundaram Finance Limited.

Expectedly, customers have very low tolerance for defects in the FD process. As they experience more defects and hassles in rectifying them, they lose confidence in the company and shift their loyalty. However, what constitutes a defect is not an easy question to answer for a company offering FD facilities. The following list is an extract of the definition of defects in one company offering this facility.

- Non-receipt of fixed deposit receipts (FDRs)/ interest warrants (IWs) after 10 days of submission
- Errors in FDRs/IWs
- Delay in receipt of incentive cheques beyond five days of submission of application by the depositor
- Annual IWs for the year were to be sent to depositors by April 15—hence, for non-receipt of IWs after 1 May
- Tax deduction at source (TDS) certificates for the year were to be dispatched by April 30th—hence, for non-receipt of the certificates after 15 May
- Delay in receipt of cheque in the case of refund/ foreclosure beyond three days of submission of discharged FDR
- Error in cheque in the amount/name or date
- Periodically, communications were sent to depositors on interest rate change, submission of Form 15-H, interest credit advice in case of cumulative deposits, and so on—however, lack of clarity of the messages were reported by customers
- Delay in receipt of brokerage cheques beyond the 7th of every month
- Delay beyond two days in replying to letters written by brokers/depositors
- Wrong accounting entry
- Late remittance of tax deducted at source
- Dispatching FDRs in spite of cheques being dishonoured
- Late submission/wrong submission of statutory returns
- Violation of statutory guidelines
- Violation of internal policies
- Delay beyond two days in replying to e-mail queries from regional offices

Clearly, this example amply illustrates the fact that choosing an appropriate characteristic for measurement, monitoring, and control is not an easy task. It is important for a quality manager to realize that resolving this issue is fundamental to setting up a process control system.

Source: B. Mahadevan, "Personal Finance Limited" (Case #02-091, Centre for Development of Cases and Teaching Aids, IIM Banga-lore, 2002).

In six sigma, three terminologies are used to indicate these organizational entities. This includes *master black belt*, *black belt*, and *green belt*. The depth of training and experience differentiates these three. As soon as one completes a basic six-sigma training programme, he/she could be designated as a green belt. A black-belt candidate is supposed to have completed a certain number of improvement projects before earning this designation. In general, a master black belt is expected to be an expert in statistical tools with a good capability for change management. Team leaders are typically green belt, although occasionally even a black belt can be a team member. The coach is either a black belt or a master black belt. The sponsors are sometimes master black belts.

The depth of training and experience differentiates master black belts, black belts, and green belts in a six-sigma organization.

19.4 VARIATIONS IN PROCESSES

Any business process is bound to have variations from time to time. The vibration of a machine used for metal cutting in a machine shop will vary over time. The sharpness of the cutting tool used in the machine also decreases over time, resulting in variations in the surface finish. A process industry such as Reliance will experience variations in the temperature of the molten PVC resin being fed to a spinning machine in the PVC plant. The workers in the final watch assembly at the Titan plant will also go through variations in their work routines, thereby impacting the quality of the assembly. Service organizations go through similar problems of variations in their business processes. An insurance firm may see variations in preparing an insurance quote to new and existing customers leading to some quality problems. Hospitals experience considerable variation in processes pertaining to the registration and admission of patients. In the hospitality industry, customers experience considerable variations in the manner of the services delivered to them. Setting up a good six-sigma quality control mechanism in an organization requires a sound footing on the notion of variations in business processes and the use of well-known statistical tools to assess the nature and quantum of these variations.

> The collective set of tools and techniques used to develop a quality assurance system when business processes exhibit variations is known as **statistical process control (SPC).**

Variations happen because the operating system tends to deviate from the specifications. When variations are inevitable, how are we to ensure that the operating system produces quality output? Statistical techniques play a valuable role in addressing this issue. In this chapter, we will know more about these variations, the statistical principles that help an operations manager to develop methods to reduce variations and ensure quality even when variations exist. We will also see how an organization can set up a process for assuring quality. The collective set of tools and techniques used to develop a quality assurance system when business processes exhibit variations is known as **statistical process control (SPC)**.

Two types of variations are normally encountered in operating systems. These variations occur on account of two types of causes. The first type is known as chance variations. These variations arise on account of purely random events that are not in the control of the system designer or the operating personnel. Therefore, the causes of these variations are also known as common causes of variations. The second set of variations happen on account of assignable causes. Certain perceptible changes happen in the system, resulting in variations, and the system drifts away from the desired state. It is possible to identify these changes, take corrective measures, and restore the system back to its desired state of operation.

Common Causes

Since the **common causes of variations** stem from random behaviour of the system, one can utilize the laws of probability to understand, analyse, and predict the state of the system. Consider a machine used to fill the half-kilogram sachets of Surf Excel, a detergent manufactured by Hindustan Unilever Limited. Due to a variety of random occurrences in the system, the machine may not fill exactly 500 g in each sachet. In some cases it could be 499 g, in some other cases it could be 502 g, and so on. Random events are both unavoidable and uncontrollable. Therefore, the focus of maintaining quality in this example will shift to the following:

a. How do we know whether the observed changes are due to random variations or assignable causes?
b. How does one ensure that the random events are indeed rare events?

> Chance variations arise on account of purely random events that are not in the control of the system designer or the operating personnel. The causes of these variations are known as **common causes of variations.**

We will introduce some principles from probability to help us address the these questions associated with common causes of variations. More detailed application of these concepts will be taken up in later sections of the chapter.

Let us consider the detergent-filling machine. If we make *n* observations of the working of the machine and note the filled weight of each sachet, we can compute the mean and the standard deviation based on these observations. This set of observations is nothing but a sample from the detergent-filling machine. One can compute the standard deviation of these observations as follows:

x_i = The weight of the *i*th sachet (in grams)
– n = The total number of observations

$\bar{x}$ = Mean of the sample

s = Standard deviation of the sample

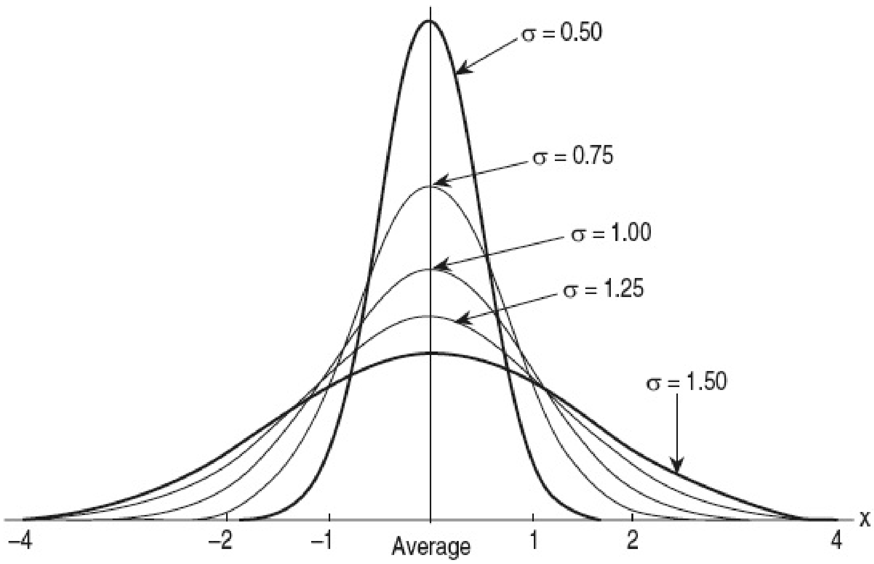
$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \qquad (19.3)$$

Furthermore, we can make use of several such samples of *n* observations and construct a distribution of the means of the samples. The distribution of the sample means follows a normal distribution.[1] Therefore, using the samples, we can compute the statisticalattributes (such as the mean and the standard deviation) of the "population" from which we have drawn this sample. In our example, the "population" is the half-kilogram sachets continuously coming out of the detergent-filling machine.

A normal distribution is characterized by the location of the average, the spread of the distribution, and the shape. The spread of normal distribution is a direct function of the standard deviation. If the standard deviation is large, the spread is also large and vice versa. Figure 19.2 illustrates these aspects of normal distribution.

It is well known that the area covered under three standard deviations on either side of the mean of normal distribution is 99.7 per cent. If the observed samples are within $\pm 3\sigma$, then one can conclude that there is a 99.7 per cent probability that the variations are due to random events. Conversely, if the observed values are outside $\pm 3\sigma$, one begins to suspect that the variations are due to random events.

FIGURE 19.2 Normal distribution: spread and shape



Assignable Causes

When the observed variations are not statistically found to be due to random effects, it clearly points to the existence of some assignable causes. In our detergent-filling machine example, if we found that the variations are beyond random effects, then several other issues may contribute to the variations. If the machine requires some operator intervention, then differences in the practices between two operators could be one cause. Alternatively, the viscosity of the detergent powder could have changed due to some changes in the previous stage of production. A third possibility is malfunctioning of the filling machine itself due to some structural disturbances in the operating conditions of the machine or the operating environment.

> When the observed variations are not statistically found to be due to random effects, it clearly points to the existence of some assignable causes.

From a statistical point of view, assignable causes of variations impact the distribution of the process in more ways than one. One possibility is that the average would have shifted out of the desired level. Instead of operating with an average of 500 g, the detergent-filling machine might have shifted to some other mean (say 497 g or 502 g). The second possibility is that the variance in the process increases significantly, leading to a wider spread. When the spread is wider, large variations in the process will be considered to be within the chance category, when it is not the case in reality. It is also possible that the process is skewed to one side, thereby having a greater tendency to fill more than 500 g, or less than 500 g, depending on the direction of the skewing.

In all the cases we just discussed, it is possible to trace the causes of the variations and take corrective actions. Once corrective action is taken, the system will return to normal operating conditions and variations will be only due to chance. A process having only chance variations is said to be in a state of control. Therefore, it is clear that when a process is under a state of control, the associated distribution of the process will not shift the average. Moreover, the spread of the process will also remain the same and the distribution will be symmetric.

19.5 PROCESS CONTROL FUNDAMENTALS

Before we proceed further in our understanding of the elements of process control, it is useful to know the terms associated with the techniques.

> The desired average for a process is known as the **nominal value.**

- *Nominal value*: The desired average for a process is known as the nominal value. In our detergent-filling machine example, the **nominal value** for the weight of the filled sachets is 500 g.
- *Specification limits*: **Specification limits** are nothing but the tolerances allowed in every process. These tolerances are arrived at after making a detailed design based on several considerations. The **upper specification limit (USL)** provides the upper limit for the measure under consideration, while the **lower specification limit (LSL)** provides the lower limit. In our detergent-filling machine example, the design for the process would have specified that the process could have a fill weight ranging between 496g and 504g. In this case, USL = 504 g and LSL = 496 g. The specification limits are nothing but the *voice of the customer*, pertaining to the process under consideration.
- *Process average*: How the process is operating is independent of what one desires the process to be. By actually sampling the process, one can establish the average at which the process is operating. This average is known as the centre line (of the process).
- *Control limits*: As we already saw, the process is considered to be under control when there are only chance variations. The **upper control limit (UCL)** is defined by the value of three positive standard deviations from the process average. Similarly, the **lower control limit (LCL)** is defined by three negative standard deviations from the process average.

> Specification limits are nothing but the tolerances allowed in every process. The **upper specification limit (USL)** provides the upper limit for the measure under consideration while the **lower specification limit (LSL)** provides the lower limit.

> The process average indicates how the process is operating. This average is known as the centre line (of the process).

> The **upper control limit (UCL)** is defined by the value of three positive standard deviations from the process average. Similarly, the **lower control limit (LCL)** is defined by three negative standard deviations from the process average.

Clearly, as actual observations fall within UCL and LCL, we conclude that there are only chance variations. The process average and the control limits represent the voice of the process. In our detergent example, if the process is centred at 500.5 g and the standard deviation is 0.25, then UCL = 501.25 g and the LCL = 499.75 g.

19.6 SETTING UP A PROCESS CONTROL SYSTEM

Setting up a process control system for any process involves a set of decisions that the quality manager needs to take. Figure 19.3 outlines a six-step methodology for this purpose.

Step 1: Choose the Characteristic for Process Control

The first step in setting up a process control system is to know the aspect of the process that needs to be monitored and controlled. Clearly, the choice is among those that have a direct bearing on the quality of the product or service offered to the customer. However, in reality, it is difficult to make an appropriate choice of the attribute purely on the basis of the quality dimension alone. There are other issues to be considered at the time of selecting an appropriate characteristic. These include ease of observation and measurement characteristic, the ease of adjustment of the process to alter characteristic value, the likely monetary impact on the quality, and the criticality of the characteristic to the process. In a service system such as a hotel, the impatience of the arriving guest at the check-in counter can be a good characteristic to measure and control, but it is almost impossible to measure and use for controlling the process. On the other hand, the waiting time at the check-in counter could be an alternative characteristic affecting the service quality, which is easy to measure.

In a polyester filament yarn manufacturing unit, measures such as viscosity of the resin and the heat loss in the process are characteristics that are not only easy to measure and adjust but also have a significant monetary impact on the quality. Variations in the process on these characteristics can affect the flow of the molten resin, leading to blockage of pumps, increase of pressure in the system, and eventual breakdown of the entire unit.

FIGURE 19.3 Steps involved in setting up a process control system

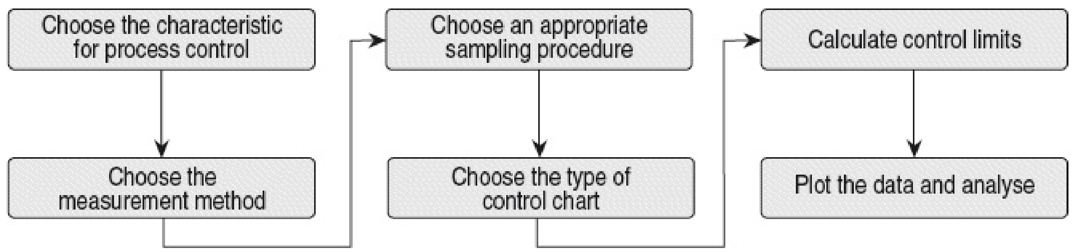


TABLE 19.1 Some Examples of Characteristics that are Measured, Monitored, and Controlled

Type of Applications	Characteristic for Measurement
Component manufacturing	Conformance of physical measurements of components and sub-assemblies to specifications
	Conformance to operating characteristics of machines and other resources involved in the process
Final assembly	Number of defects in the product
	Conformance to test specifications
	Number of missing elements
Process industries	Temperature, pressure, and heat specifications
	Conformance to product specifications
	Conformance to equipment specifications
	Vibrations and other variations in equipment and subsystems
	Conformance to specifications of the automation and control system
Service systems	Number of defects in various business processes
	Errors in processing documents
	Conformance to waiting time/lead time related specifications

Table 19.1 gives a sample set of characteristics that are applicable for various manufacturing and service settings. There is no rule that each process should have only one characteristic to be chosen for process control. As a rule, every process will have at least one equipment related measure and another measure for the component/product being produced in the process. Similarly, in a service organization, there should be at least one measure that is customer-related and another pertaining to the resources involved (primarily the human resource) in generating customer service in that process.

Step 2: Choose the Measurement Method

There are alternative ways of measuring the characteristic. One is by a simple clustering of the characteristic into a few categories (such as good or bad). This is known as *attribute-based measurement*. Two frequently used attribute measures are the proportion of defects (denoted as p) and the number of defects (denoted as c). The other is to make detailed observations of the characteristic. This is known as *variable-based measurement*.[2] Using the detailed measurements one can estimate the average of these measurements (denoted as $\overline{X}$ and the range of the measurements (denoted as R).

The choice of the measurement method has several implications for quality control. In order to understand this, let us take the example in a service setting. If the desired waiting time for a patient to be admitted to the general ward in a hospital is 15 minutes, then an attribute method will merely indicate what proportion of the arriving patients were indeed admitted within 15 minutes. On the other hand, a variable measurement would have revealed the exact distribution of the waiting times of the patients. Clearly, attribute measurements are easy to make, quick and less expensive. However, they provide very little information about the actual performance of the process with respect to the characteristic. In contrast, a variable measurement will be expensive and more time-consuming but will provide a wealth of information about the process. When it comes to quality improvements, variable measurements are much more valuable. In the final analysis, a quality manager needs to weigh these pros and cons before deciding the exact measurement method.

> Attribute measurements are easy to make, quick, and less expensive. However, they reveal very little information on the actual performance of the process with respect to the characteristic.

Step 3: Choose an Appropriate Sampling Procedure

Process control using statistical methods relies on techniques that make a judgement of the population on the basis of the observation of some samples from the population. Therefore, deciding on an appropriate sampling procedure is an essential step in setting up a process control system. The sampling procedure typically involves deciding on: the size of each sample or a sub-group (denoted as n), and the number of such samples to be taken (denoted as m).

The major consideration for deciding on n and m is that the observations within each subgroup should look alike and the observations across the sub-groups should look different.

Translating these requirements to practical conditions would mean that n cannot be large. If it is so, by the time the nth observation is made, there would have been a long time interval between the nth and the 1st sample. Therefore, the observations within a sub-group may not be homogeneous. Similarly, it can be argued that two consequent sub-groups cannot be sampled without sufficient time intervals. In consideration of these, generally n is kept small, in the range of 5–10 and m in the range of 10–20. Table 19.2 shows some of the notations pertaining to process control.

> A **control chart** is a graphical representation of the process status in terms of the UCL, LCL, process average, and the plot of the sample data. It helps to identify when the process goes out of control.

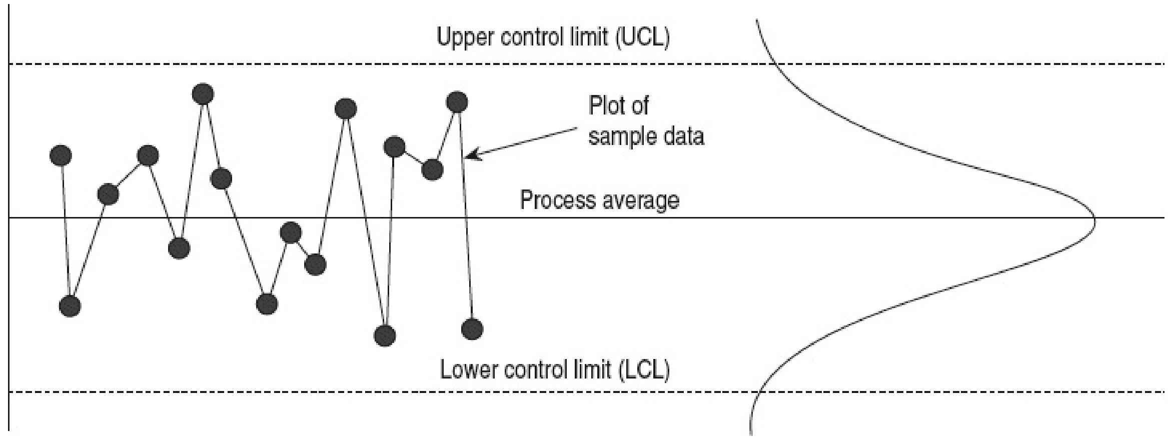
Step 4: Choose the Type of Control Chart

A **control chart** is a graphical representation of the process status in terms of the UCL, LCL, process average, and the plot of the sample data. Figure 19.4 is a generalized representation of a control chart. Irrespective of whether an attribute measure or a variable measure is used, the control chart structure remains the same. The only difference lies in the manner in which the process average, UCL, and LCL are computed. The plot of the sample data, once the control limits are established, is an integral part of setting up the control chart. It helps to identify when the process goes out of control. A plot outside the control limit is an indication of the possibility of assignable causes for the variations.

TABLE 19.2 Notations and Computations Used in Control Charts

Criterion	Notation	Explanation
Sub-group size	n	Each sub-group consists of n observations.
Sub-group measures	**Variable measures** • Mean: $\bar{X}$ • Range: R	Based on the n observations,each of these measures can be computed for each sub-group.
	Attribute measures • Proportion of defects: p • Number of defects: c	
Number of sub-groups	m	m measurements are used for establishing the sampling distribution and control chart.
Mean of the sampling distribution of the sub-groups	**Variable measures** • Mean, $\bar{\bar{X}} = \frac{\sum \bar{X}}{m}$ • Range, $\bar{R} = \frac{\sum R}{m}$	These means are nothing but the process average (centreline) of the respective control charts formed using each of these measures.
	Attribute measures	
	• Proportion of defects, $\bar{p} = \frac{\sum p}{m}$ • Number of defects, $\bar{c} = \frac{\sum c}{m}$	
Standard deviation of the sampling distribution of the sub-groups	**Attribute measures** • Proportion of defects, $\sigma_p = \sqrt{\frac{\bar{p}(1-p)}{n}}$ • Number of defects, $\sigma_p = \sqrt{\bar{c}}$	Three standard deviations on either side of the are the control limits for the respective charts.

FIGURE 19.4 A generalized representation of a control chart



Control charts are available for both attribute measures and variable measures.

Four types of charts are used for process control applications. The $\bar{X}$ chart and the *R* chart are used for variable measurements while the *p* chart and the *c* chart are used for attribute measurements.

Step 5: Compute the Control Limits

Once the type of control chart is selected, then, using Table 19.2, we can compute the relevant parameters for the control charts. In the following pages, we discuss the mechanism of computing the control limits for variable and attribute based control charts.

$\bar{X}$ *and R charts*

Variable measurement based process control systems use $\bar{X}$ and *R* charts. Using the equations available in Table 19.3, one can compute the mean for $\bar{X}$ and *R* charts. However, in order to establish the UCL and the LCL, the standard deviation of the sampling distribution is required. One method is to use readily available tables that provide coefficient values for computing the UCL and LCL for the $\bar{X}$ and *R* charts. The computational aspects of setting up $\bar{X}$ and *R* charts are as follows.

> The $\bar{X}$ chart and the *R* chart are used for variable measurements, while the *p* chart and the *c* chart are used for attribute measurements.

Computations for the $\overline{X}$ chart:

Process average or centre line, $\overline{\overline{X}} = \frac{\sum \overline{X}}{m}$

Upper control limit[3], $UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$

Lower control limit, $LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$

Computations for the ***R* chart:**

Process average or centre line, $\overline{R} = \frac{\sum R}{m}$

Upper control limit, $UCL_{\overline{R}} = D_4\overline{R}$

Lower control limit, $LCL_{\overline{R}} = D_3\overline{R}$

The values A_2, D_3 and D_4 can be read directly from Table 19.3.

TABLE 19.3 Coefficients for Computing the LCL and UCL in $\overline{X}$ and R Charts

Sample size (*n*)	A_2	D_3	D_4
2	1.880	0	3.268
3	1.023	0	2.574
4	0.729	0	2.282
5	0.577	0	2.114
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

EXAMPLE 19.1

A manufacturer of automotive transmission systems produces a component whose diameter is a critical dimension for quality. Samples are drawn during every shift from the process producing the component. Every time a sample of five components is drawn, the diameter is measured. Fifteen such measurements are taken during every shift. Table 19.4 presents the readings (in cm) taken during one shift. Set up relevant control charts and examine if the process is in control.

TABLE 19.4 Diameter Readings for Transmission Component

Sub-groups	Observations in each sub-group (in cm)				
	1	2	3	4	5
1	12.45	12.39	12.55	12.38	12.40
2	12.55	12.38	12.40	12.39	12.44
3	12.46	12.44	12.44	12.35	12.36
4	12.38	12.39	12.55	12.38	12.40
5	12.37	12.44	12.45	12.41	12.41
6	12.45	12.37	12.44	12.38	12.41
7	12.46	12.38	12.35	12.50	12.44
8	12.44	12.39	12.37	12.45	12.39
9	12.44	12.55	12.44	12.37	12.55
10	12.35	12.38	12.45	12.44	12.38
11	12.36	12.40	12.41	12.37	12.40
12	12.51	12.36	12.41	12.37	12.39
13	12.38	12.50	12.45	12.37	12.44
14	12.41	12.37	12.45	12.40	12.36
15	12.37	12.44	12.45	12.41	12.37

TABLE 19.5 Computation of Average and Range of Observations

Sub-groups	Observations in each sub-group (in cm)						
	1	2	3	4	5	Average	Range
1	12.45	12.39	12.55	12.38	12.40	12.434	0.17
2	12.55	12.38	12.40	12.39	12.44	12.432	0.17
3	12.46	12.44	12.44	12.35	12.36	12.410	0.11
4	12.38	12.39	12.55	12.38	12.40	12.420	0.17
5	12.37	12.44	12.45	12.41	12.41	12.416	0.08
6	12.45	12.37	12.44	12.38	12.41	12.410	0.08
7	12.46	12.38	12.35	12.50	12.44	12.426	0.15
8	12.44	12.39	12.37	12.45	12.39	12.408	0.08
9	12.44	12.55	12.44	12.37	12.55	12.470	0.18
10	12.35	12.38	12.45	12.44	12.38	12.400	0.10
11	12.36	12.40	12.41	12.37	12.40	12.388	0.05
12	12.51	12.36	12.41	12.37	12.39	12.408	0.15
13	12.38	12.50	12.45	12.37	12.44	12.428	0.13
14	12.41	12.37	12.45	12.40	12.36	12.398	0.09
15	12.37	12.44	12.45	12.41	12.37	12.408	0.08
Average values for sampling distribution of sub-groups						12.417	0.119

Solution

The measurement is variable-based. Therefore, the appropriate charts are $\overline{X}$ and R. We first compute the average and range of the observations in each subgroup and then the average of the sample means and ranges. Table 19.5 gives the details:

From this table we find that the process is centred at 12.417, with a $\overline{R}$ value of 0.119.

Using these and the table for coefficient values one can compute the UCL and LCL as follows:

n = 5, therefore, from Table 19.4 we obtain $A_2 = 0.577$, $D_3 = 0$ and $D_4 = 2.114$

Computations for the $\overline{X}$ chart

Process average (centre line)

$$UCL_{\bar{x}} = \overline{\overline{X}} + A_2\overline{R} = 12.417 + 0.577 \times 0.119 = 12.486 \text{ cm}$$
$$LCL_{\bar{x}} = \overline{\overline{X}} - A_2\overline{R} = 12.417 + 0.577 \times 0.119 = 12.348 \text{ cm}$$

Computations for the R chart

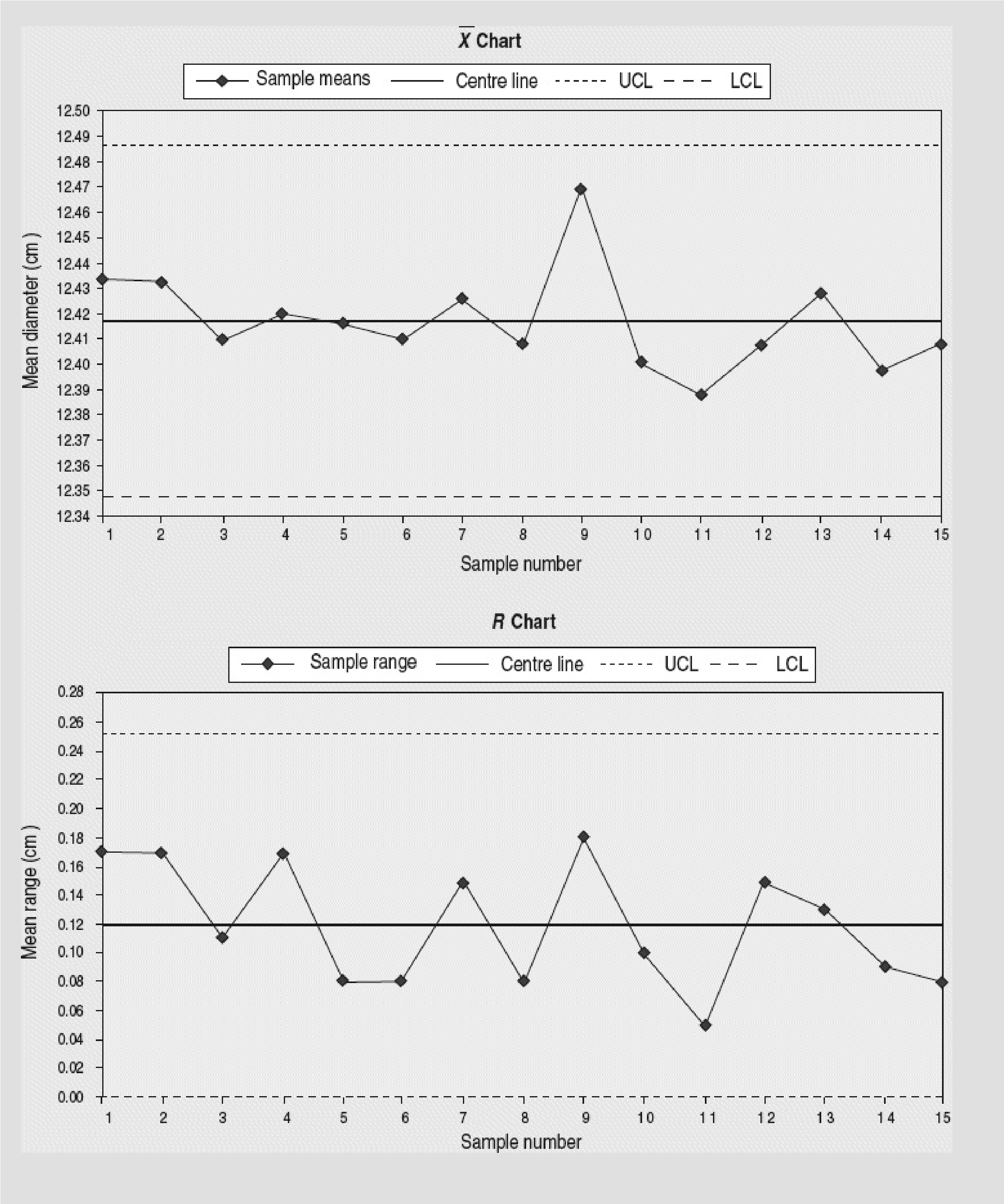
Process average (centre line) = 0.119 cm

$$UCL_{\bar{R}} = D_4\bar{R} = 2.114 \times 0.119 = 0.252 \text{ cm}$$
$$LCL_{\bar{R}} = D_3\bar{R} = 0 \times 0.119 = 0 \text{ cm}$$

Setting up the Chart

Since the required parameters of the charts are available, one can graphically represent the information and plot all the sample values. The graphical representation of $\bar{X}$ and *R* charts are given in Figure 19.5. Since no sample value falls outside the control limits, the process is in a state of statistical control. All variations observed are due to common causes only.

FIGURE 19.5 The graphical representation of the control charts



p charts for attribute measures

There are numerous occasions on which firms use a two-way classification of products and services while assessing quality. The products/services are either classified as conforming to specifications (good) or not conforming to specifications (bad). One way to represent this information is to compute the proportion of defects (p) in the process and establish a control chart for this measure. Such a measurement system follows a binomial distribution. Therefore, one can compute the mean and standard deviation of the population using a sampling distribution of the proportion of defects using known results for the binomial distribution. The relevant computations for establishing a p chart are as follows:

There are numerous occasions in which firms use a two-way classification of products and services when assessing quality. The products/services are either classified as conforming to specifications (good) or not conforming to specifications (bad).

$$\text{Process average or centre line, } \bar{p} = \frac{\sum p}{m}$$

$$\text{Upper control limit, } UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$\text{Lower control limit, } LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

EXAMPLE 19.2

A manufacturer of an electronic control system (ECS) for musical appliances uses a non-destructive testing mechanism to assess the quality of ECS. A lot of 100 ECSes is drawn periodically for testing. After testing, the ECSes will be classified as either defective or good depending on the outcome of the test. Table 19.6 gives the number of defects for 12 such samples. Establish a p chart for the process.

TABLE 19.6 Number of Defects for 12 Samples

Sample No.	Number of Defects
1	10
2	9
3	8
4	11
5	7
6	12
7	7
8	10
9	13
10	12
11	13
12	14

TABLE 19.7 Computation of the Proportion of Defects Per Sample

Sample No.	Number of Defects	*p*
1	10	0.10
2	9	0.09
3	8	0.08
4	11	0.11
5	7	0.07
6	12	0.12
7	7	0.07
8	10	0.10
9	13	0.13
10	12	0.12
11	13	0.13
12	14	0.14

Solution

We first compute the proportion of defects in each sample. The computations are in Table 19.7:

The mean and standard deviation of the sampling distribution of the proportion of defects is computed as follows:

Mean of the sampling distribution =

$$\overline{p} = \frac{\sum p}{m} = \frac{1.26}{12} = 0.105$$

Standard deviation of sampling distribution =

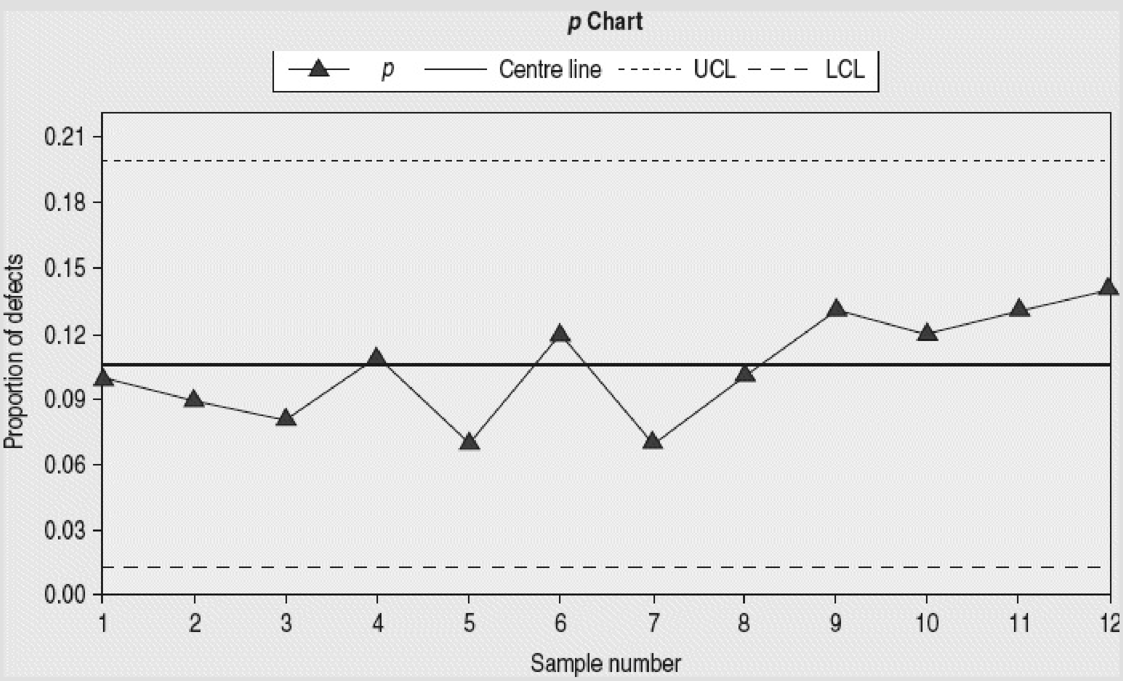
$$\sigma_p = \sqrt{\frac{\overline{p}(1-\overline{p})}{n}} = \sqrt{\frac{0.105 \times (1-0.105)}{100}} = 0.031$$

Therefore, the UCL and LCL values for the *p* chart can be computed. Further, one can set up the chart and plot the sample proportions to investigate whether the process is in control. The computations and the graphical representation of the chart are shown in Figure 19.6.

$UCL_p = 0.105 + 3 \times 0.031 = 0.198$

$LCL_p = 0.105 - 3 \times 0.031 = 0.012$

FIGURE 19.6 Graphical Representation of the Chart



c charts for attribute measures

There is an alternative method of classifying good and bad items. Instead of estimating a proportion of defects in each sample, it is possible to merely count the number of defects. In several situations, it would be meaningful to measure the defects in this manner because multiple defects may occur in a single unit. For example, in every finished garment one can detect a number of defects. In a square metre of cloth or a painting, one can count the number of defects and use this measure for setting up a process control. A *c* chart is utilized under such conditions and the number of defects per unit is denoted as *c*. The relevant computations for setting up a *c* chart are as follows:

$$\text{Process average or centre line, } \bar{c} = \frac{\sum c}{m}$$

$$\text{Upper control limit, } UCL_c = \bar{c} + 3\sqrt{\bar{c}}$$

$$\text{Lower control limit, } LCL_c = \bar{c} - 3\sqrt{\bar{c}}$$

A *c* chart is utilized when it is possible to count the number of defects.

Step 6: Plot the Data and Analyse it

Once the relevant control chart is set up, the management needs to equip itself with analysing the data and deciding on the appropriate course of action. Refer to Example 19.3. Sample 6 was outside the control limits. Therefore, the question that arises is whether the management should take action immediately. Even when the plot of samples lie within the control limits, an intelligent quality manager will sense impending problems by identifying unusual (non-random) behaviour in the process and alert the process owners of theimpending problems. One such example is the plot of the *p* chart in Example 19.2. In this case, all the samples lie within the control limits. However, if we carefully observe the plot (see Figure 19.6), beginning with Sample 7, there is a rising trend.

What should the quality manager do when such patterns emerge even when a process is in control? Are there some patterns that suggest non-random behaviour in the process, eventually leading to some assignable causes? It has been widely accepted that changing the process parameters may often deny the opportunity for the process control team to make reliable observations of the process. Moreover, the process may not reach a stable state of operation. Therefore, a few guidelines are useful to alert the quality manager to stop the process and study peculiar behaviour in the process. It should be understood, however, that every time the process is stopped for some investigation, there is no need to alter the process parameters.

EXAMPLE 19.3

A manufacturer of colour televisions has a final inspection before the product is packed for shipping. The final inspection involves testing the television on several parameters and verifying if the set performs satisfactorily in all the tests. It is possible that every television may fail to fulfil all the parameters. Therefore, a *c* chart is used at this stage to control the process. Periodically, 10 television sets are drawn for testing. Table 19.8 shows the performance during one such test. Use this data to set up a control chart.

TABLE 19.8 Number of Defects Per Sample

Sample No.	Number of Defects
1	11
2	9
3	12
4	9
5	12
6	22
7	7
8	10
9	13
10	6

Solution

As in the previous cases, we first compute the mean and the standard deviation of the sampling distribution of the number of defects per unit (*c*).

Process average or centre line,

$$\bar{c} = \frac{\sum c}{m} = \frac{111}{10} = 11.10$$

Upper control limit,

$$UCL_c = \bar{c} + 3\sqrt{\bar{c}} = 11.10 + 3 \times \sqrt{11.10} = 21.095$$

Lower control limit,

$$LCL_c = \bar{c} - 3\sqrt{\bar{c}} = 11.10 - 3 \times \sqrt{11.10} = 1.105$$

The graphical representation of the chart is given in Figure 19.7. We note that Sample 6 falls outside the UCL. Therefore, the process does not appear to be in control. Management must investigate the reasons for this and decide if any corrective actions are required. If so, the process needs to be adjusted and a new control chart needs to be established. If no corrective actions are immediately warranted, then the chart needs to be plotted again by deleting Sample 6 and recomputing the control limits.

It can be verified that after removing Sample 6, the process average and the control limits have shifted down. The revised control chart, after deleting Sample 6, is shown in Figure 19.8.

FIGURE 19.7 Graphical representation of the chart

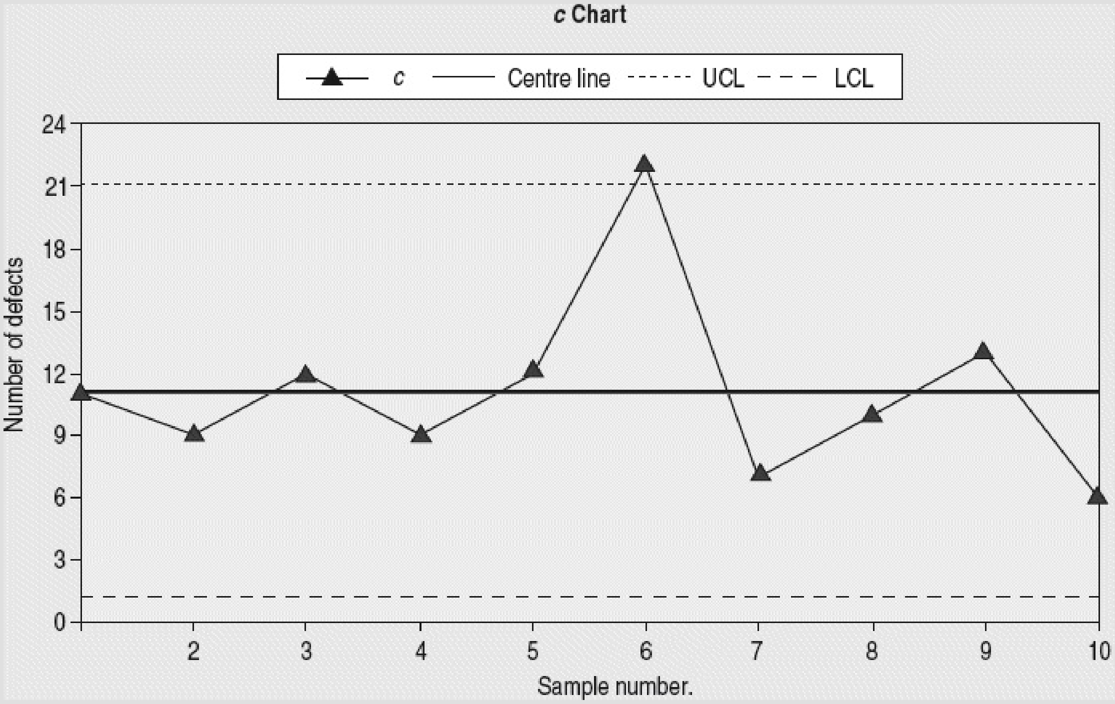
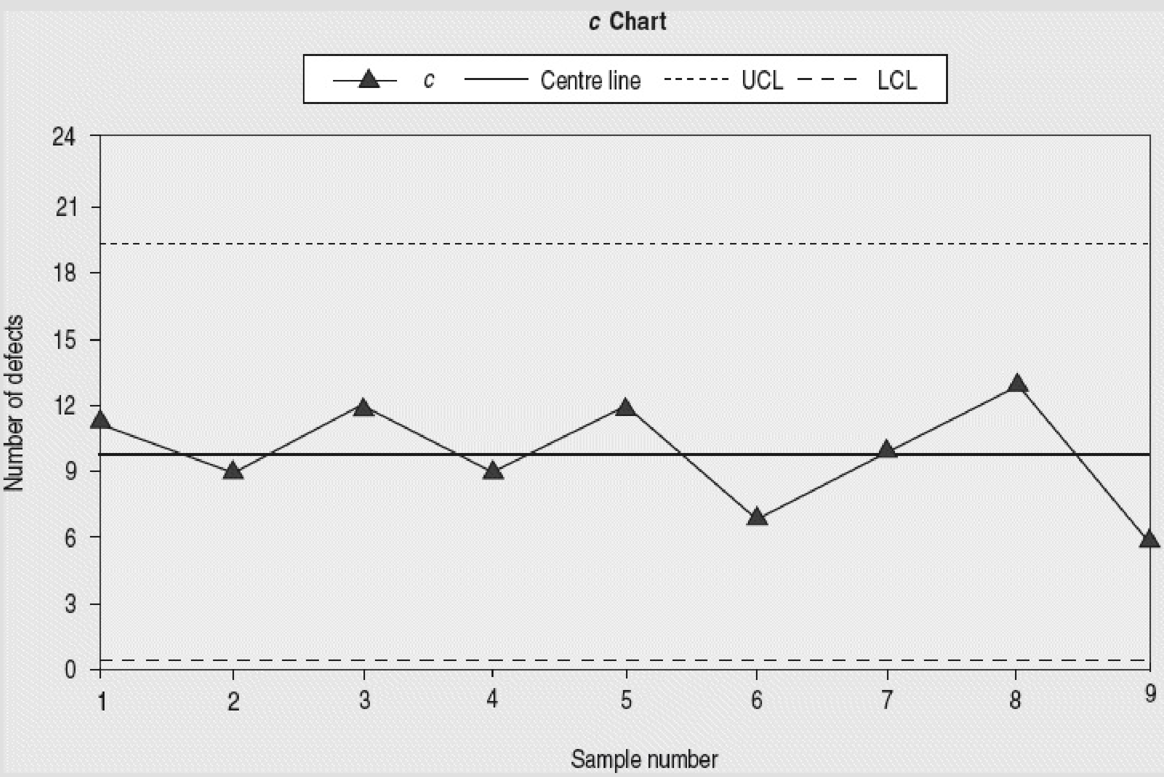


FIGURE 19.8 The revised control chart



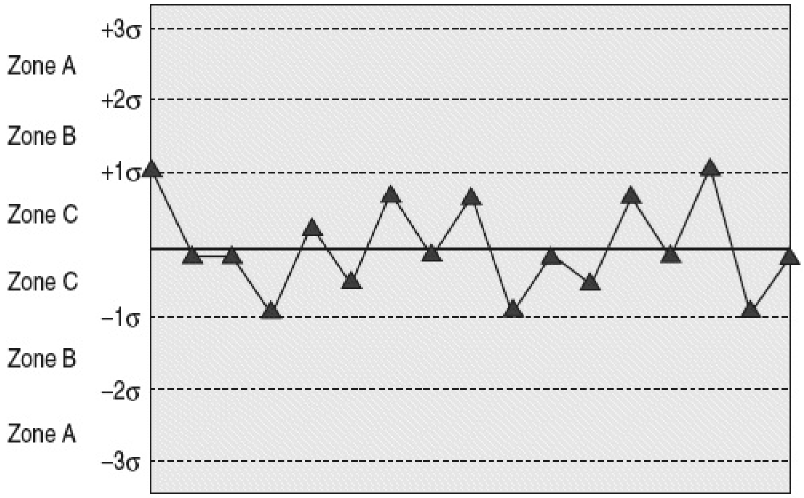
When samples are outside the control limit, a question that arises is whether the management should take action immediately.

Let us see when a process should be stopped for investigation. In order to specify some simple rules, we need to split the control chart into three zones. Zone C is the area between one standard deviation on either side of the centre line. Zone B is the next standard deviation on either side of Zone C, and Zone A is the next standard deviation on either side of Zone B. The following guidelines are useful for deciding when to stop the process of investigation:

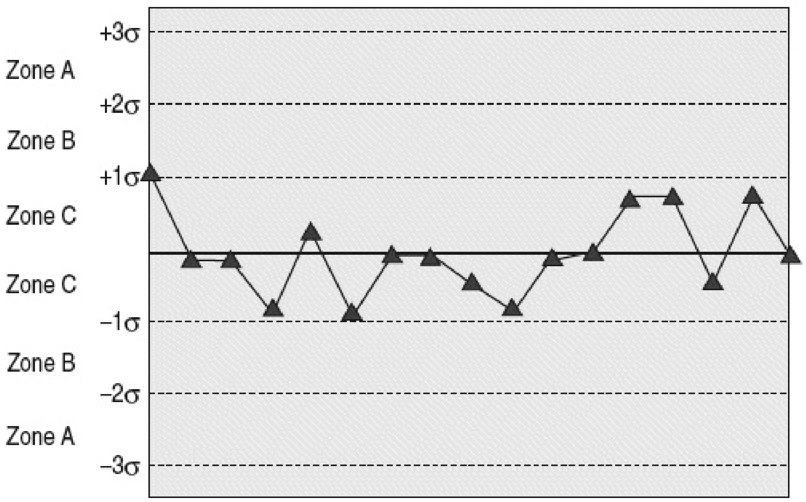
a. One point beyond Zone A (as in the case of Example 19.3)
b. Nine points in a row in Zone C, or more
c. Six points in a row, steadily increasing or decreasing
d. Fourteen points in a row, alternating up and down [see Figure 19.9(a)]
e. Two out of three points in a row in Zone A or beyond
f. Four out of five points in a row in Zone B and beyond
g. Fifteen points in a row in Zone C [see Figure 19.9(b)]

We know from the elementary probability theory that every one of the occurrences listed is a rare event and, therefore, the causes are likely to be of the assignable category.

FIGURE 19.9 When to Stop the Process: Some Rules



(a) 14 points in a row alternating up and down



(b) 15 points in a row in zone C

19.7 PROCESS IMPROVEMENTS IN THE LONG RUN

So far, we have discussed one aspect of the control chart, that is, to ensure that the process is in statistical control. If a process is in statistical control, it merely indicates that there are no assignable causes of variations to the process and that the process is stable. Having a statistically stable process is the foundation on which superior quality improvements could be launched in any organization. If a process is in control, it provides additional predictive capabilities to the organization. Before we understand the notion of predictive capability, let us try to differentiate between accuracy and precision.

A statistically stable process is the foundation on which superior quality improvements can be launched in any organization. It provides additional predictive capabilities to the organization.

Let us assume that there is a component manufactured using a process. The design specification is that the diameter of the component should be in the range of 15 ± 0.05 cm. If we set up a variable-based process control chart for this process, we may get to know the process average, UCL and LCL. Let us now consider two scenarios of the process. In the first scenario, the process is centred at 15.3 cm, with a spread of ± 0.04 cm. In the second scenario, the process is exactly centred at 15, but with a spread of ± 1.2 cm. What do we infer from these two scenarios? Scenario A is precise but not accurate, whereas Scenario B is accurate but not precise. *Accuracy* is a function of how far the process average is from the designed average. On the other hand, *precision* is a function of how well the process lends itself to repetition. A process with high repeatability will have narrow standard deviation and therefore narrow spread.

Which one of the two is better? Clearly, a process with high precision is better than a process with low precision. The issue of accuracy can be sorted out by shifting the process average (through some process adjustments) to the desired average. Moreover, the lower spread characteristic of a precise process provides certain advantages to an organization and enables it to predictably produce goods of a certain quality. Using these ideas, it is possible to use a control chart as a useful tool for managers to make long-term and sustained improvements in the process performance. We shall dwell on these aspects in some detail.

From our discussion, we infer that superimposing the process performance (as evidenced by the process average and the spread) on the design specifications can throw up some useful measures for a manager to understand the ability of the process to generate good-quality components in the long run. Before addressing this issue, let us look at some related definitions.

Process Capability

Process capability is the spread of the process. If the standard deviation of the process is s, then the process capability is $6s$. This merely indicates that the process can produce goods within $\pm 3s$. To understand the notion of process capability, it is important to relate it to the design specifications, usually indicated by the process centre, USL, and LSL. Let us consider two processes A and B (see Figure 19.10). Process A has a larger spread and Process B has a smaller spread. If the $6s$ of a process lies within the USL and LSL, then the process is capable, as 99.73 per cent of the goods produced will be within the specification, limits. In our example, Process A is not capable of producing the components as per specifications, whereas Process B is. It is clear from this example that, in general, processes with narrow spreads are likely to be more capable than those with larger spreads. This has been one of the motivating reasons for reducing process variations in practice.

> **Process capability** is the spread of the process.

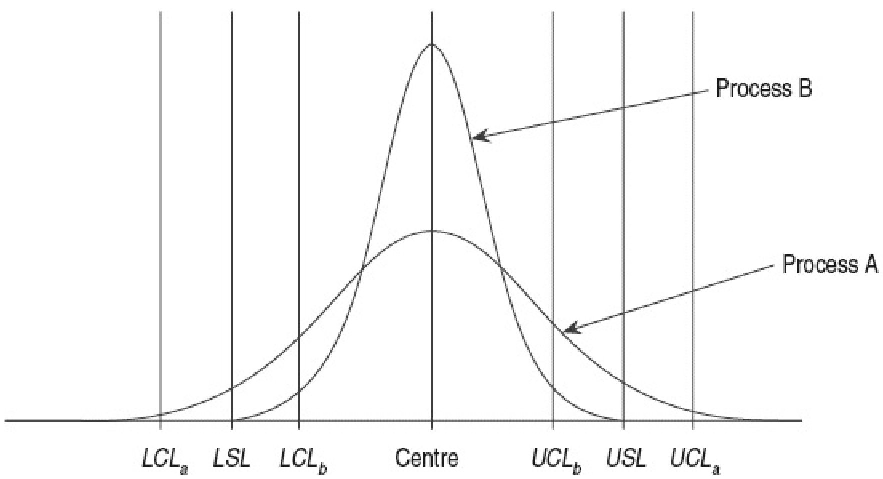
Potential Capability

As we see in the example we just discussed, the process spread alone does not completely capture the capability of the process. It also needs to be related to the specification limits. Therefore, an alternative measure is the potential capability of the process. **Potential capability *(C_p)*** is the ratio of the difference in the specification limits to the process spread.

Potential capability (C_p) is the ratio of the difference in the specification limits to the process spread.

$$\text{Potential capability } (C_p) = \frac{\text{Specification range}}{\text{Process capability}} = \frac{(USL - LSL)}{6\sigma} \tag{19.4}$$

FIGURE 19.10 An example of two processes with different process spreads



As potential capability takes on larger values, the process capability increases. It is customary to use a measure of parts per million (ppm) to measure defects these days. It can be shown that a process with a C_p value of 1.33 will produce 64 ppm, whereas a process with a C_p value of 0.67 will produce 45,500 ppm (4.55% defects) and a process with C_p = 1 will produce 3,000 ppm. The quality improves exponentially as C_p values increase.[4] However, improving the C_p value requires exponential efforts too.

Actual Capability

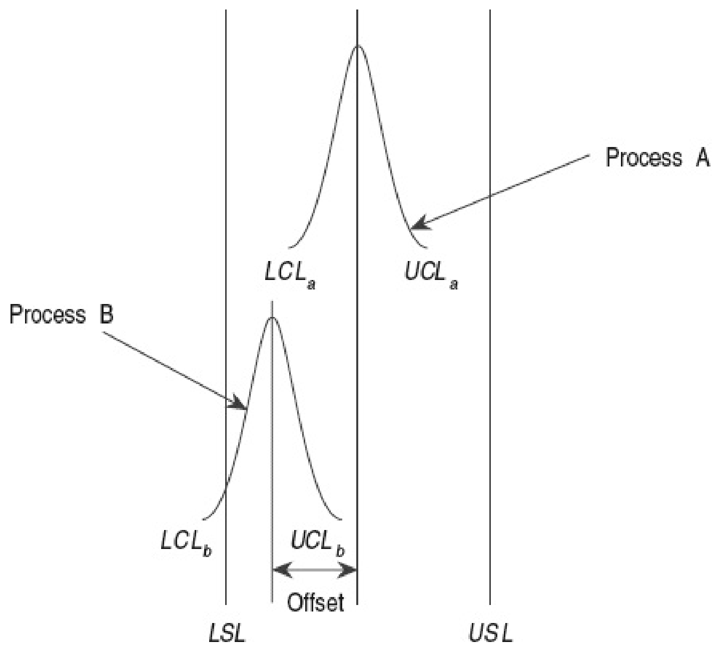
In our analysis of process capability, we have made a very important assumption about the process. We have implicitly assumed that the process centre exactly coincides with the nominal value (centre as per design specifications). In reality, this need not be the case. Let us examine the situation portrayed in Figure 19.11. We consider two identical processes with the same spread. However, Process A is centred along the nominal value and Process B is offset from the nominal value to the left. Process A is capable of producing components without defects as the spread is well within the specification limits. Although Process B is also capable by virtue of having an identical spread, it will produce defective components as the LCL is outside the LSL. It is clear from these two cases that C_p merely indicates that the process is capable of producing components as per specifications but may not reveal if it indeed does so. That is why C_p is referred to as potential capability.

One can compute the actual capability of a process by incorporating the additional information pertaining to the extent to which the process has deviated from the nominal value. Such as measure is known as actual capability (C_{pk}). An expression for C_{pk} is given by:

$$\text{Actual capability } (C_{pk}) = \text{Min}\left[\frac{\text{Process centre} - \text{LSL}}{3\sigma}\right],\left[\frac{\text{USL} - \text{Process centre}}{3\sigma}\right] \tag{19.5}$$

In Equation 19.5, we compute the offset and identify the side to which the process has drifted and use it as the basis for computing the process capability. It is easy to infer that if the C_{pk} value is equal to C_p, then the process is exactly centred at the nominal value. As in the case of C_p, a higher value of C_{pk} denotes fewer defects coming out of the process.

FIGURE 19.11 Potential and actual process capabilities: an illustration



EXAMPLE 19.4

A manufacturer of ball-bearings has the following specifications for the diameter of finished ball bearings. The nominal value = 245 mm. USL = 245.85 mm, LSL = 244.15 mm. The process planning department proposed two processes for manufacturing the ball bearings. After extensive pilot runs, the processes were statistically stabilized. The performance of the two processes is given in Table 19.9.

TABLE 19.9 Performance of Processes A and B

	Centre	s.d (σ)
Process A	244.90	0.25
Process B	244.98	0.27

The production department wants to know which of these two processes is suitable for commercialization. Compute the relevant measures and offer appropriate recommendations to the production department.

Solution

Let us first compute process capability measures for the two processes.

Process capability = 6σ

For Process A, process capability = 6 × 0.25 = 1.50

For Process B, process capability = 6 × 0.27 = 1.62

Process B exhibits greater spread although it is centred close to the nominal value of 245. Therefore, while Process B is more accurate than Process A, it is less precise.

Potential Capability of the Processes

Using Equation 19.4, we can compute C_p values for the two processes as follows:

$$\text{Potential capability for Process A } (C_p)^a$$

$$= \frac{(USL - LSL)}{6\sigma_a} = \frac{245.85 - 244.15}{1.5} = 1.133$$

$$\text{Potential capability for Process B } (C_p)^b$$

$$= \frac{(USL - LSL)}{6\sigma_b} = \frac{245.85 - 244.15}{1.62} = 1.049$$

Process A is more capable of producing components as per specifications (as it has the potential to produce fewer defects than Process B).

Actual Capability of the Processes

Using Equation 19.5, we can compute Cpk values for the two processes as follows:

$$(C_{pk})^a = \text{Min}\left(\left[\frac{244.90-244.15}{0.75}\right],\left[\frac{245.85-244.90}{0.75}\right]\right)$$

$$= \text{Min}\left(\frac{0.75}{0.75},\frac{0.95}{0.75}\right) = 1.000$$

$$(C_{pk})^b = \text{Min}\left(\left[\frac{244.98-244.15}{0.81}\right],\left[\frac{245.85-244.98}{0.81}\right]\right)$$

$$= \text{Min}\left(\frac{0.83}{0.81},\frac{0.87}{0.81}\right) = 1.025$$

When we compute the actual capability, we find that Process B is marginally better than Process A. This is because Process B is more accurate than Process A. While it may be tempting to prescribe Process B to the production department, we must remember that a precise process is always better than an accurate process with less precision. By taking some additional steps to move the centre of Process A close to the nominal value, one can achieve better results in the production. Therefore, the following recommendations will be in order.

a. Both the processes exhibit low C_p and C_{pk} values. There should be efforts to reduce the variations in the process and improve the process capability. This is a long-term requirement for installing a better process for production.
b. If the costs of the adjusting the centre of the process are not significant in the case of Process A, then it should be preferred over Process B. Otherwise, immediate action is to be taken to reduce the variations in Process B, if it needs to be used for the production of ball bearings.

19.8 SIX SIGMA AND PROCESS CAPABILITY

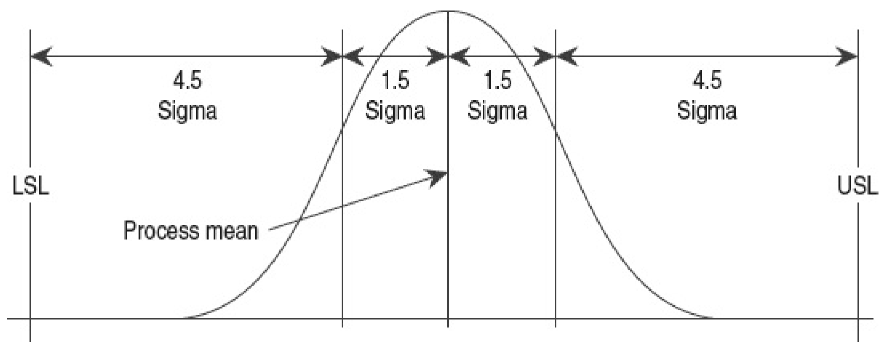
The idea of six sigma comes directly from the understanding of the C_p measure, which we have already discussed. A process with six-sigma quality level is one that has a C_p value of 2. Rewriting Equation 19.4, for a C_p value of 2, we get,

$$C_p = \frac{(USL-LSL)}{6\sigma} = 2$$

$$\Rightarrow (USL-LSL) = 12\sigma = \text{A spread of } \pm 6\sigma$$

Therefore, in order to attain six-sigma quality, we need to ensure that the design specification width is ± 6σ (see Figure 19.12). Thus, even if the process centre does not coincide with the nominal values (as per design specifications), a further spread of 4.5σ available on both sides will ensure that minimal defect opportunities are created in the process. In the worst-case scenario, the process will have 3.4 ppm non-conformance on either side of the distribution (6.8 ppm total) and in the best-case scenario, it will have 1 non-conforming part per billion (ppb) on either side of the distribution (2 ppb total). Motorola has made significant progress towards this goal across most processes, including many office and business processes.

FIGURE 19.12 Graphical representation of six-sigma quality



This requires a two-pronged approach. First, product designers should succeed in creating designs with the widest possible tolerances. At the same time, process designers should be able to design processes with the narrowest possible variation.

The greatest advantage of using these measures is the predictive power of these measures with respect to the number of defects that the process is likely to produce if it is in statistical control. Multinational companies belonging to several manufacturing and service sectors use these measures to assess the processes of the vendors for vendor selection and for pegging the level of incoming inspection required when the selected vendors supply products and services.

Modern-day initiatives in continuous improvements in the long run revolve around the use of measures such as C_p, C_{pk}, and six sigma. More and more manufacturing and service companies are using these principles and setting targets to improve the quality of product and service offerings.

19.9 ACCEPTANCE SAMPLING

Earlier approaches to quality control did not rely much on process control. Instead, quality was measured after the processing was completed and components were ready for use. Let us consider a simple example of a manufacturer of grey iron castings supplying an automobile component manufacturer. In this case, the castings manufacturer is the supplier to the automobile component manufacturer. The question of whether or not the castings supplied were as per specifications (and hence of right quality) could be answered in two ways. One method is to put a set of appropriately designed control charts in the casting manufacturing plant at various stages and monitor the process. We have discussed various issues pertaining to this in earlier sections.

The other alternative is to request the supplier to deliver the finished castings at the automobile component manufacturer's stores and use statistical methods to assess the quality of the lot based on the information obtained from a sample drawn out of the lot. For instance, if a lot consisted of

100 castings, then the automobile manufacturer may choose to draw a sample of 5 castings and subject it to some tests. Based on the outcome of the test, the fate of the entire lot will be decided. This approach to quality assurance is known as acceptance sampling as the decisions with regard to acceptance or otherwise of a lot is based on a sample. The key assumption behind the approach is that the sample is random and every item in the overall lot has an equally likely probability to get sampled.

Setting up a system for acceptance sampling requires that the following questions are satisfactorily answered:

a. What is the size of the sample required for assessing quality?
b. What should be the criteria for acceptance of the lot?
c. Is it enough to have just one sample or is it desirable to go for multiple samples?
d. How do we assess the impact of the choice of the above parameters on the quality level in the long run?

The first three questions are answered by the choice of an appropriate sampling plan. A **sampling plan** describes the lot size (N), size of the sample to be assessed (n), the acceptance number (c), that is, the number of defects permissible in the observed sample, and whether it is a single sampling plan or a multiple sampling plan. In the case of multiple sampling plans, for each, the sample size (n_1, n_2, and so on) and the acceptance number (c_1, c_2, and so on) needs to be specified. Furthermore, the plans could be sequential with a stopping criterion. The actual number of defects detected in the sample is denoted by d.

> A **sampling plan** describes the lot size (N), size of the sample to be assessed (n), the acceptance number (c), that is, the number of defects permissible in the observed sample, and whether it is a single sampling plan or a multiple sampling plan.

Single Sampling Plan

The simplest sampling plan is denoted by (N, n, c). The sampling plan works as follows. From a lot of N items, sample n items for assessing the quality. If the number of defects (d) observed in the sample is less than or equal to c, the lot is accepted. On the other hand, if $d > c$, then the lot is rejected and is subjected to 100 per cent quality assessment. We know that the quality assurance problem that we have stated here exactly follows the hyper-geometric distribution. If the proportion of defectives of the incoming lot is known, then it is possible to compute the probability of acceptance (P_a) of the lot based on a sampling plan.[5]

It is often difficult to know the proportion of defects in the incoming lot. However, we know that the incoming lot will have a proportion of defectives ranging anywhere between 0 and 1. Therefore, we can perform a “what-if” analysis of the probability of acceptance for several scenarios of proportion of defects ranging from 0 to 1.

AQL and LTPD

As the decision for accepting or rejecting the entire lot is based on a sample drawn out of the lot using a sampling plan, the choice of the parameters of the sampling plan has important implications for both the supplier and the buyer, as can be seen in Example 19.5. Let us formalize these ideas by introducing two parameters associated with acceptance sampling.

Acceptable quality level (AQL) is the percentage of defects that the buyer is willing to tolerate in the lot delivered by the supplier. For instance, in Example 19.5, the buyer may say that 1 per cent defect is tolerable in the long run. Arriving at this number is crucial as it has implications for the buyer's product quality, market, and customer reactions.

> **Acceptable quality level (AQL)** is the percentage of defects that the buyer is willing to tolerate in the lot delivered by the supplier.

Lot tolerance per cent defective (LTPD) is the worst quality beyond which the buyer is not willing to accept the incoming lot. In Example 19.5, the manufacturer may say, that even in the worst case, he may not want to have a lot with more than 10 per cent defects.

> **Lot tolerance per cent defective (LTPD)** is the worst quality beyond which the manufacturer is not willing to accept the incoming lot.

Since the decision making on the entire lot is based on imperfect information (obtained from a random sample), it becomes inevitable to work with a bandwidth of quality levels for acceptance. Only if the buyer can manage a 100 per cent inspection is it possible for him to specify a single parameter. For instance, he may say that he would require lots that are 1 per cent or less defective, and all lots more defects will be rejected and the rest accepted.

EXAMPLE 19.5

A manufacturer of electronic control instruments for musical systems sources an electronic component from a supplier. The supplier delivers the components in lots of 1000. The manufacturer subjects the components to an acceptance sampling procedure with a sampling plan of (1000, 50, 2). The manufacturer wants to know how good the sampling plan is. In order to help the manufacturer, answer the following questions:

a. If the incoming lot has 1 per cent defective parts, what is the probability of acceptance?
b. If the incoming lot has 5 per cent defective parts, what is the probability of acceptance?
c. Compute the probability of acceptance of the lot for various values of incoming defect percentages.
d. Plot the probability of acceptance against various values of the per cent defective. Do you infer anything from this exercise?

Solution

Since the sample size is much smaller than the lot, we use the binomial approximation for computing the probability of acceptance.

Probability of Acceptance When *p* = 0.01

The sampling plan specifies that up to two defects will be tolerated (c = 2). Therefore, the lot will be accepted if the number of defects in the sample is 0, 1, or 2. We can compute these three and add these up to get the probability of acceptance.

Probability of zero defects in the sample = $50C_0 \times (0.01)^0 \times (0.99)^{(50-0)} = 0.605$

Probability of one defect in the sample = $50C_1 \times (0.01)^1 \times (0.99)^{(50-1)} = 0.306$

Probability of two defects in the sample = $50C_2 \times (0.01)^2 \times (0.99)^{(50-2)} = 0.076$

Therefore, the probability of acceptance of the lot = 0.605 + 0.306 + 0.076 = 0.987

Probability of Acceptance When p = 0.05

Probability of zero defects in the sample = $50C_0 \times (0.05)^0 \times (0.95)^{(50-0)} = 0.077$

Probability of one defect in the sample = $50C_1 \times (0.05)^1 \times (0.95)^{(50-1)} = 0.202$

Probability of two defects in the sample = $50C_2 \times (0.05)^2 \times (0.95)^{(50-2)} = 0.261$

Therefore, the probability of acceptance of the lot = 0.077 + 0.202 + 0.261 = 0.540

TABLE 19.10 Probability of Acceptance for Various Values of *p*

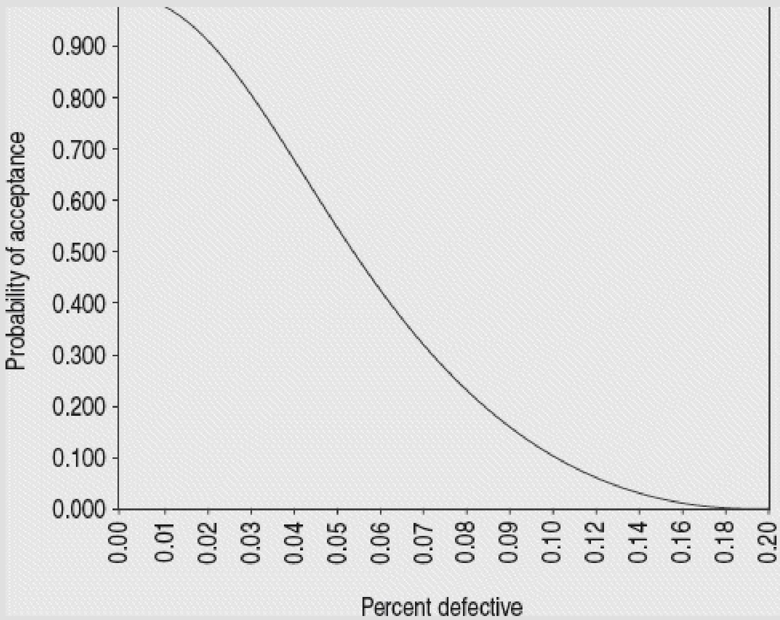
p	*Pa*
0.00	1.000
0.01	0.987
0.02	0.922
0.03	0.811
0.04	0.677
0.05	0.540
0.06	0.416
0.07	0.311
0.08	0.226
0.09	0.161
0.10	0.112
0.12	0.051
0.14	0.022
0.16	0.009
0.18	0.003
0.20	0.001

Probability of Acceptance for a Wide Scenario

All values of *p* ranging from 0 to 1 can be computed in a similar manner. However, in reality, in a good sampling plan the probability of acceptance is almost zero when *p* value exceeds 0.20. Table 19.10 has the probability of acceptance for various values of *p*.

The graphical representation of the table (see Figure 19.13) portrays the operational characteristics of the chosen sampling plan. That is why it is referred to as operating characteristics (OC) curve.

FIGURE 19.13 The OC curve



We are able to infer that if the incoming quality level of the electronic component in the long run is 1 per cent defective, then choosing the sampling plan will ensure that the organization accepts the lot on 98.6 per cent of the occasions. On the other hand, if the incoming quality level is 12 per cent defective, the organization will still accept the lot on 5.1 per cent of the occasions. These have important implications for the management in the long run.

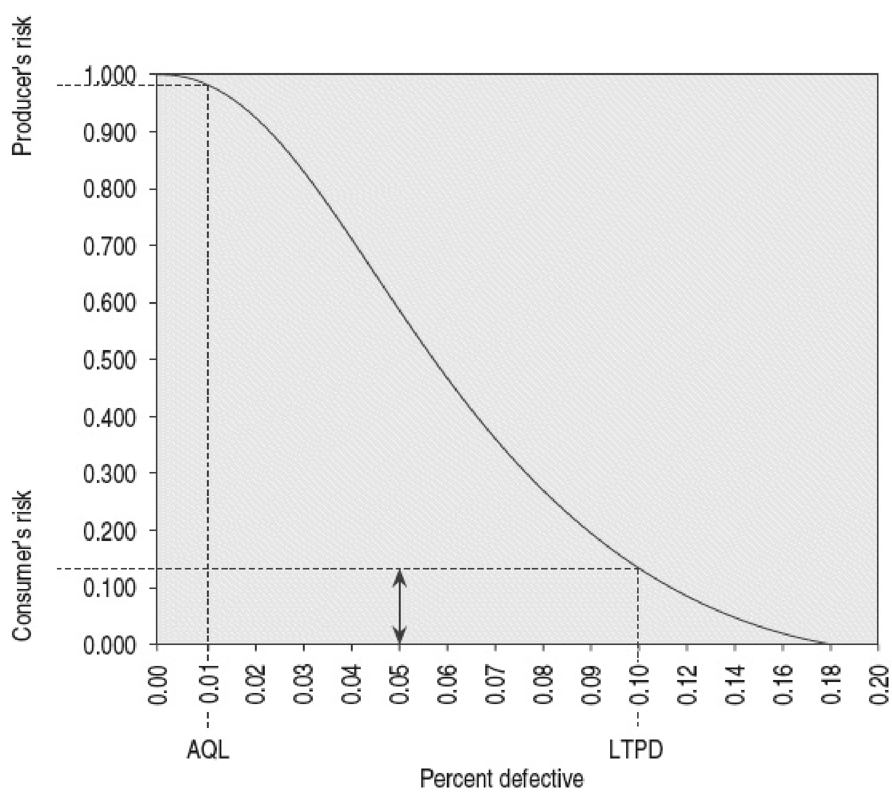
However, specifying a pair of measures introduces an element of risk for both the supplier and the buyer. In order to understand this, let us return to Example 19.5. Let us suppose that AQL = 1 per cent and LTPD = 10 per cent for the problem. This means that as long as the lot contains up to 1 per cent defects, the buyer is willing to accept the lot without any hesitation. However, we noticed that instead of accepting the lot 100 per cent, the sampling plan would have rejected it on 1.3 per cent occasions. Thus, the supplier faces the risk of having his/her lot rejected when it was indeed conforming to the agreed terms. This is known as *producer's risk* (or Type I error in statistical terms, indicated by *a*).

When the supplier faces the risk of getting his/ her lot rejected when it conforms to the agreed terms, it is known as *producer's risk.*

On the other hand, we also notice that when the incoming lot had more than 10 per cent defects, the sampling plan would have accepted the lot on 11.2 per cent occasions. This is the risk that the buyer faces when the lot is beyond his/her tolerance level. This is known as *consumer's risk* (or Type II error in statistical terms, indicated by *b*). Therefore, an appropriate choice of sampling plan is important to reduce both the producer's and consumer's risks. Figure 19.14 graphically depicts these ideas using the problem in the example.

The risk that the manufacturer faces by accepting a lot when it is beyond his/ her tolerance level is known as *consumer's risk.*

FIGURE 19.14 Producers' and consumers' risks in using an acceptance sampling plan



SUMMARY

- Six sigma is a new approach to process control based on a set of principles that enables organizations to improve their quality to near-zero defects level.

- Six-sigma quality control differentiates itself from the traditional quality control methodology on the basis of three features: A new metric, defects per million opportunities (DPMO), to predict/assess the quality of a business process, a new methodology, DMAIC (“define–measure–analyse–improve– control”), to ensure that very high levels of quality could be assured in the chosen business processes, and an organizational framework for ensuring that these outcomes are generated on a sustained basis.
- All processes exhibit variations on account of two causes. Common causes of variations happen on account of random events. Assignable causes introduce variations that can be detected and eliminated.
- Setting up a process control system involves choosing a characteristic to control, identifying a measurement method, and developing a relevant control chart.
- A plot of the data helps a quality manager to assess if the process is in control and also helps her to detect any impending shift in the process parameters.
- Superimposing the specification limits on the control chart helps an organization to assess the process capability and the likely number of defects that the process will produce. It also helps to target for a six sigma quality improvement programme.
- Acceptance sampling is used to accept a lot of items based on the observed number of defects in the sample drawn out of the lot.
- The performance of an acceptance sampling plan could be judged by developing an operating characteristics (OC) curve for the plan.
- An acceptance sampling design results in a certain amount of risk for both the customer and supplier.

FORMULA REVIEW

1. Defects per Million Opportunities (DPMO) = $\left(\frac{d}{k * n}\right) * 1{,}000{,}000$

2. Computations for the $\overline{X}$ chart

$$\text{Process average or centre line: } \overline{\overline{X}} = \frac{\sum \overline{X}}{m}$$

$$\text{Upper Control Limit: } UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$$

$$\text{Lower Control Limit: } LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$$

3. Computations for the *R* chart

$$\text{Process average or centre line: } \overline{R} = \frac{\sum R}{m}$$

$$\text{Upper Control Limit: } UCL_{\overline{R}} = D_4\overline{R}$$

$$\text{Lower Control Limit: } LCL_{\overline{R}} = D_3\overline{R}$$

4. Computations for *p* chart

$$\text{Process average or centre line: } \overline{p} = \frac{\sum p}{m}$$

$$\text{Upper Control Limit: } UCL_p = \overline{p} + 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

$$\text{Lower Control Limit: } LCL_p = \overline{p} - 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

5. Computations for *c* chart

$$\text{Process average or centre line: } \overline{c} = \frac{\sum c}{m}$$

$$\text{Upper Control Limit: } UCL_c = \overline{c} + 3\sqrt{\overline{c}}$$

$$\text{Lower Control Limit: } LCL_c = \overline{c} - 3\sqrt{\overline{c}}$$

6. $$\text{Potential Capability } (C_p) = \frac{\text{Specfication Range}}{\text{Process Capability}} = \frac{(USL - LSL)}{6\sigma}$$

7. Actual Capability (C_{pk}

$$= \text{Min}\left[\frac{\text{Process Centre} - LSL}{3\sigma}\right], \left[\frac{USL - \text{Process Centre}}{3\sigma}\right]$$

REVIEW QUESTIONS

1. What do you understand by the term six-sigma quality control?
2. Often several managers comment that six sigma is nothing but an alternative version of TQM, Kaizen, JIT, and other such continuous improvement initiatives undertaken in an organization. How do you react to this comment?
3. Distinguish between assignable and common causes of variations. Why is this distinction important in quality control?
4. Give three examples for assignable causes of variation.
5. In the broad scheme of TQM, where do you find a role for statistical process control?
6. What are specification limits? Why do we need them in SPC?
7. Are specification limits and control limits the same? Explain.
8. A manufacturer of garments wants to set up a quality control system using control charts for process control. The manufacturer has three options to choose from:

    a. Measure the critical dimensions of the garment for establishing its quality
    b. Segregate every batch of production into good quality and seconds quality
    c. Estimate the number of defects per bale of cloth issued for production

    The manufacturer is not sure about what it means to choose each of the above. Prepare a report explaining the pros and cons of each of the choices, the nature of efforts required to set up control charts, and the implications of their use.
9. Suppose an organization utilizes a variable-based measurement system for process control. During a period, it was found that while all the plotted observations fell within the control limits in $\overline{X}$ chart, one point was lying outside the control limits in the *R* chart. What should the organization do in this case?
10. Under what conditions should one take action while using control charts for process control?

11. Distinguish between accuracy and precision. As a process control engineer, which of the two would you prefer? Why?
12. What are the uses of computing alternative process capability measures?
13. A process is being monitored using process control charts. It was observed that the potential and actual process capability were the same. What do you infer from this?
14. What do you mean by acceptance sampling?
15. What are the relative advantages and disadvantages of using acceptance sampling and statistical process control for establishing a quality assurance system in an organization?
16. What is the significance of AQL and LTPD in acceptance sampling?
17. An organization currently uses a sampling plan (*N*, *n*, *c*). Will the OC curve change due to a change in the sampling plan? Explain.

PROBLEMS

1. An insurance service provider monitors the process of handling customer queries for new insurance quotes using a control chart. The process has five steps and after preliminary analysis a set of parameters was identified as critical. If these parameters were not properly addressed, then the process is considered defective. Every day, samples are drawn from the process and defects measured. Each sample is of size 100. Table 19.11 has 30 such samples drawn over a two-month period.

TABLE 19.11 Number of Defectives Per Sample (Problem 1)

Sample	Number of Defects	Sample	Number Sample
1	12	16	3
2	13	17	7
3	10	18	6
4	16	19	10
5	12	20	26
6	18	21	14
7	14	22	20
8	20	23	22
9	19	24	24
10	17	25	18
11	9	26	18
12	11	27	19
13	14	28	20
14	12	29	17
15	8	30	18

a. Set up a control chart for the process
b. Is the process under control? Plot the samples on the control chart.

2. A manufacturer of hair oil has an automated process consisting of a filling machine for filling the 200-ml bottles and a sealing unit. After filling the bottle, it is automatically sealed with a metallic cap. To monitor the quality of the process, samples of size 5 are drawn periodically from the process and the quantity filled is measured. Table 19.12 has data on 12 such observations.

TABLE 19.12 Sample Data (Problem 2)

Sample	1	2	3	4	5
1	9.21	8.87	8.71	9.08	9.34
2	9.06	8.97	9.13	8.46	8.85
3	9.35	8.95	9.20	9.03	8.44
4	9.21	8.71	9.05	9.35	8.87
5	9.01	9.17	9.21	9.05	9.53
6	8.74	8.35	8.50	9.06	8.89
7	9.21	9.05	9.00	8.78	9.23
8	9.15	9.20	9.23	9.15	9.06
9	8.98	8.81	8.90	9.13	9.05
10	9.03	9.10	9.26	9.44	8.48
11	9.49	9.05	9.12	8.88	8.93
12	8.95	9.10	9.02	9.04	8.96

Construct a variable control chart and investigate if the process is in control.

3. In Example 2, the organization wants to also assess the process of fitting the caps. Let us assume that the samples are drawn after the process and a count is made of the number of defective metallic caps per batch. Table 19.13 has details of the number of defective caps in the last ten batches. Assume that the batch size is 100.
   a. What type of control chart will you recommend for controlling the quality of the cap fitting process?
   b. Compute the relevant parameters for the chart and plot the data in the chart.
   c. Is the process in control? If not, revise the control chart by recomputing the chart parameters.

4. Table 19.14 presents some details on the mean and range of 11 samples drawn from a process during routine sampling and inspection. The readings are the weight of a certain metal deposited on the surface of a component used in an electro-mechanical device. The lower and upper specification limits for the weight of metal to be deposited are 10.7 g and 13.3 g, respectively. The standard deviation for the process is found to be 1.28. Assume the sample size to be four.

TABLE 19.13 Number of Defective Caps in the Last 10 Batches

Batch no.	Number of defects
1	12
2	8
3	11
4	14
5	12
6	23
7	7
8	10
9	16
10	6

a. Develop relevant control charts for the process (**Hint:** Since the standard deviation of the population is known, the control limits can be directly established, see endnote 3 for details)).
b. Is the process under control? If not, explain why and suggest what could be done.
c. Compute the potential and actual capabilities for the process. What do you infer from this computation? Do you have any recommendations to make to the organization?

5. The critical design specification for the manufacture of a component is the length of the component. The current specifications are 15 ± 0.05 cm. The organization currently employs a manufacturing process with the centre at 14.98 and a standard deviation (**σ**) of 0.02.
   a. What is the process capability of the process?
   b. Are its potential capability and the actual capability the same? What is the ratio of the actual capability to potential capability? What does this ratio indicate?
   c. If the organization is interested in ensuring a quality level of 64 ppms and is unable to shift the process average, what should the spread be to achieve this quality level?
   d. If the process is centred to the nominal value (design specification), what will the actual capability be?

TABLE 19.14 Mean and Range of 11 Samples

Sample no	1	2	3	4	5	6	7	8	9	10	11
Mean	12.5	11.8	12.6	12.7	11.9	10.9	11.2	11.6	10.9	12.2	11.6
Range	0.25	0.45	0.31	0.26	0.39	0.34	0.40	0.29	0.41	0.37	0.29

6. A manufacturer of computer accessories sources certain plastic components from a supplier. The manufacturer subjects the components to an acceptance sampling procedure with a sampling plan in which a sample of 50 components is drawn from the supply and the lot is accepted if the number of defects detected in the sample is not more than three. Answer the following questions:
   a. If the incoming lot is 1 per cent defective, what is the probability of acceptance?
   b. If the incoming lot is 5 per cent defective, what is the probability of acceptance?
   c. Make the necessary computations and plot an operating characteristic curve for the sampling plan.
   d. If the manufacturer sets an AQL of 1 per cent, what is the implication of the sampling plan to the supplier?
   e. Suggest an appropriate LTPD so that consumer's risk is not more than 10 per cent.
   f. If the LTPD is unacceptable to the manufacturer (because it is too high) what changes would you like to propose in the sampling plan?
   g. Suppose the manufacturer wants to tighten the plan by reducing the acceptance number from 3 to 2. What are the long term implications of this decision?
   h. Construct another OC curve for an acceptance number of 4. Based on these computations, what do you think is the relationship between the alternative sampling plans and the OC curve? What are its implications for practice?

NET-WISE EXERCISES

1. Wikipedia has a collection of articles, references and multiple perspectives on six sigma. Go to http://en.wikipedia.org/wiki/Six_Sigma to learn more about this. Study the material available on this page carefully, and then look up the references that it provides.

Based on this, prepare a report for a public-sector bank in India on the issue of implementing the six-sigma approach in their organization. Indicate the steps that they need to take, the nature of training that they may need, and the tools and technologies that they need to acquire. Select one potential pilot project in banking operations as a context for covering the six-sigma implementation part of the report.

MINI-PROJECT

Visit the local branch of a nationalized or a private-sector bank. Study the working of the system from a customer perspective and identify three critical measures of quality. Use the six-step approach to developing process control described in the chapter and establish a method for process control. Elicit the manager's views on desired specifications for the three chosen parameters.

a. Collect sample data and analyse the process. Is the process in a state of statistical control?
b. Share the data with the bank manager. What are the manager's key observations on your work?
c. How capable is the process now?
d. Identify methods by which the process capability could be increased by 25 per cent.

Prepare a report based on the work done along the lines suggested.

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- E. L. Porteus and A. Angelus, "Opportunities for Improved Statistical Process Control," *Management Science* 43, no. 9 (1997): 1214–1228.
- G. Tennant, *Six Sigma: SPC & TQM in Manufacturing and Services* (Burlington, VT: Gower, 2001).

- C. Wozniak, “Proactive versus Reactive SPC,” *Quality Progress* 27, no. 2 (1994): 49–50.

Operations Management: Trends and Issues

1. For details, visit http://www.servicetax.gov.in
2. M. Sharfman, R.T. Ellington, and M. Meo, “The Next Step in Becoming ‘green’: Life-Cycle Oriented Environmental Management,” *Business Horizons*, May–June 1997, pp.13–22.
3. V. D. R. guide and L. N. Wassenhove, “Managing Product Returns for Remanufacturing,” *Production and Operations Management* 10, no. 2 (2001): 142.

Operations Strategy

1. “Precariously Poised,” *Business India*, 24 March–6 April 1997, pp. 69–72.
2. For a detailed analysis of the performance of automobile manufacturers during 1980–1990 and its implications for operations management, see J. P. Womack, D. T. Jones, and D. Roos, *The Machine That Changed the World* (New York: Rawson Associates, 1990).
3. For more details see P. Kumar, R. Batra, and A. Narain, “State Bank of India: Kohinoor Banjara Branch”, *Indian School of Business Case*.
4. For more details, see R. J. Schonberger, *World Class Manufacturing: The Lessons of Simplicity Applied,* (New York: The Free Press, 1986); and R. J. Schonberger, *World Class Manufacturing: The Next Decade* (New York: The Free Press, 1996).
5. *Poka yoke* and total quality management are discussed in Chapter 12, and just-in-time philosophy is discussed in Chapter 13.
6. For an idea on the issues involved see, B. Mahadevan, “Journey to the Deming: Implications for Corporate Transformation and Competitiveness,” *IIMB Management Review* 17, no. 2 (2005): 59–70.
7. K. Mitra, “Bloodbath in White Goods,” *Business Today*, 17 July 2005, pp. 118–122.
8. T. V. Mahalingam, “The China Effect,” *Business Today*, 25 March 2007, pp. 86–95.
9. S. Srivastava, “Just Click Away”, *Businessworld*, 26 June 2006, pp. 48–49.

Sustainability in Operations

1. The periodic review inventory control model (known as p-system) is discussed in detail in Chapter 17. See Section 17.6 for details.
2. For one such example see, B. Mahadevan, D.F. Pyke, and M. Fleischmann, "Periodic Review Push Inventory Policies for Remanufacturing", *European Journal of Operational Research*, 2003, 151, pp. 536–551.

Project Management

1. For the purpose of the discussions in this chapter, we analogously use the terms “a work package”, an element of a project and an activity in a project. In reality, it is possible to attribute differences to these terms by alternative definitions. However, such differences do not matter at the level of treatment of the concepts and techniques in the chapter.
2. For a discussion on the concept of bill of materials, please refer to Chapter 16 of the book.
3. For a detailed analysis of the matrix organization structure and its benefits to a project organization, readers are referred to standard textbooks in the area of organization, structure, processes, and design.
4. For a good treatment of the fundamentals of project management tools, the reader is encouraged to refer to J. D. Weist and F. K. Levy, *A Management Guide to PERT/CPM*, 2nd edition (Englewood Chiffs, NJ: Prentice-Hall, 1988).
5. Software packages for project management, such as MS Projects, could depict both versions. However, they use AON more often.
6. We use AOA for the purpose of constructing the network in this example and in all the others that follow in this chapter. However, interested readers can develop the equivalent network in AON. The analysis and interpretations, however, do not change.
7. The process of computing early schedules by proceeding from the “start” node to the “end” node is known as forward pass. Similarly, the process of computing late schedules by proceeding from the “end” node to the “start” node is known as reverse pass.
8. There are two types of slack; total slack and free slack. In this book, our definition of slack pertains to total slack. Free slack, on the other hand, is the amount of time by which an activity’s earliest finish times could be altered without affecting the early start times of its successors. We refer readers to any standard textbook on project management for finer differences and implications of these two definitions of slack.
9. A discerning reader will note that many of the alternatives proposed for altering the supply capacity of an organization, discussed in Chapter 15 on aggregate planning, could be applied for crashing a project.
10. The assumption here is that $(t_p - t_0)$ spans 6σ in the distribution. By Chebyshev’s inequality, this will cover at least 89 per cent variations in the time estimate.
11. This assumption is statistically reasonable in several real life examples due to the central limit theorem, which states that the distribution of a random variable constructed using the sum of random variables from an unknown distribution follows a normal distribution when the sum involves a large number of random variables from the parent distribution. For practical purposes, any number above 10 is considered satisfactory to apply central limit theorem.
12. A good description of the general methodology of studying risks applicable in a capital budgeting situation is available in D. B. Hertz, “Risk Analysis in Capital Investment,” *Harvard Business Review* 57, no. 5 (1979): 169–181. Readers are encouraged to go through the article for a good understanding of how risks and uncertainties could be incorporated in a managerial decision making framework.

Supply Chain Management

1. *Product markdown* is the term used to denote the downward revision of the selling price at the end of a season to clear leftover stocks. We see frequent examples of this in the textile industry.
2. This is due to what is known as the risk pooling effect. In simple terms, if we accumulate multiple data points having uncertainty, the resultant variance will be lesser than the sum of individual variances.
3. For details see, H. L. Lee and C. Billington, “Evolution of Supply Chain Management Models and Practice at Hewlett-Packard Company,” *Interfaces* 25, no. 5 (1995): 542–63.
4. For an excellent introduction to this subject, see, H. L. Lee, V. Padmanabhan and S. Whang, “The Bullwhip Effect in Supply Chains,” *Sloan Management* Review 38, no. 3 (1997): 93–102.
5. The term order-to-order is frequently used in business process reengineering literature to denote the elapsed time between a customer placing an order and the time when the order was finally fulfilled by the organization.
6. M. L. Fisher, “What is the Right Supply Chain for Your Product?” *Harvard Business Review* (March– April 1997): 105–116.
7. We discuss these issues in detail in Chapter 17.

Facilities Location

1. For more details, refer to A. Pal, “ABB Global Factories,” *Business Today*, 22 June 2003, pp. 122–126.
2. Michael Porter argued this issue in greater detail by proposing that industrial clusters can add a competitive dimension to location. For more detail see, M.R. Porter, “Clusters and the New Economics of Competition,” *Harvard Business Review* 76 no. 6 (1998): 77–90. For some Indian experiences of benefiting from clusters, see R. Dubey, “Clustering for Competitiveness,” *Business Today*, 22 April 1999, pp. 50–63.
3. This figure is adapted from the model proposed by the World Economic Forum to assess the competitiveness of various countries during the year 1996. For more details about this model refer to “Why Competitiveness Matters,” *Business Today*, 22 June 1996, pp. 71–73. The model used for assessing the competitiveness rating has undergone some changes since then.
4. See H. A. Taha, *Operations Research: An Introduction*, 7th edition (New Delhi: Pearson Education, 2003), or A. Ravindran, D. T. Philips, and J. J. Solberg, *Operations Research: Principles and Practice*, 2nd edition (New York: Wiley, 1987) for more details on the structure and solution methodologies for the transportation problem. Microsoft Excel has an add-in utility called “Solver.” One can also use solver to obtain the solution for this problem.

Sourcing and Supply Management

1. For more details on this, see J. P. Womack, D. Jones and D. Roos, *The Machine that Changed the World* (New York: Rawson Associates, 1990).
2. For details see T. Minahan, "Is this the Future of Purchasing?" *Purchasing*, 12 March 1998, pp. 42.
3. Paul Snell, "Sourcing Hotspots," *Supply Management* 12, no. 8 (2007): 24–26.
4. For details see Sue Welch, "The 5 Stages of Global Sourcing Step-by-Step," *World Trade* 19, no. 12 (2006): 60–63.
5. Throughout this chapter, we use terms such as "supplier", "vendor", and "supply chain partner" in an interchangeable fashion. All of them essentially mean suppliers of goods and services for an organization.
6. For a good introduction to the use of the Web for procurement, see J. Hazra, "Supply Chain Management in the Internet Era," *IIMB Management Review* 16, no. 4 (2004): 54–74.
7. In the chapter on inventory planning and control, we show that long lead times will result in high investment in pipeline inventory. For more details, see Section 17.2 in Chapter 17.
8. Just-in-time (JIT) philosophy is discussed in detail in Chapter 13 of this book.
9. A good source to know how single sourcing will successfully handle such calamities is T. Nishiguchi, "The Toyota Group and the Aisin Fire," *Sloan Management Review* 40, no. 1 (1998): 49–59.
10. For more details see J. H. Dyer, "Dedicated Assets: Japan's Manufacturing Edge," *Harvard Business Review* 72, no. 6 (1994): 174–178.
11. For a detailed set of criteria that could be used for vendor rating, see G.W. Dickenson, "An Analysis of Vendor Selection Systems and Decisions," *Journal of Purchasing* 2, no. 1 (1966): 5–17. Even after 30 years, several vendor rating systems are using only a subset of the factors identified in this study.
12. For a good description of the concept of total cost of ownership, refer to L. Ellram, "Purchasing: The Cornerstone of the Total Cost of Ownership Concept," *Journal of Business Logistics* 14, no. 1 (1993): 163–184. Also refer to Ideas at Work 11.5 for an actual implementation of the total cost of ownership in an auto-component manufacturing unit.
13. For more details see http://en.wikipedia.org/wiki/Business_process_outsourcing_in_India#cite_note-feout-0, accessed on 5 March 2010.
14. For a detailed treatment of this subject, refer to B. Mahadevan, "Making Sense of the Emerging Market Structures in Business-to-Business E-Commerce," *California Management Review* 45, no. 3 (2003): 86–100.

Process and Capacity Analysis

1. M. Hammer and J. Champy, *Reengineering the Corporation* (London: Nicholas Brealey Publishing Ltd, 1993). For a good description of BPR in the Indian context, refer to M.S. Jayaraman, G. Natarajan and A. V. Rangaramunajam, *Business Process Reengineering*, (New Delhi: Tata McGraw-Hill, 1994).
2. For a five-step methodology to implement BPR, see Chapter 2 of M. S. Jayaraman, G. Natarajan and A. V. Rangaramunajam, *Business Process Reengineering*, (New Delhi: Tata McGraw-Hill, 1994).
3. Practitioners widely use an alternative term known as *value stream mapping*, which is the same as process mapping. This is evident from the following definition of value stream mapping: Value stream mapping allows the user to see his/her organization's core processes and understand how to best satisfy customer needs. This perspective allows managers to evaluate which activities add value for the customer and to identify waste as well as areas of opportunities for improvement.
4. For a detailed discussion of the notion of economies and diseconomies of scale, refer to any standard textbook on managerial economics.
5. No attempt has been made in this book to define each source of waste and methods of eliminating them in detail. Interested readers are referred to C. E. Dyer and A. T. Campbell, *Canon Production System: Creative Involvement of the Total Workforce* (Cambridge, MA: Productivity Press, 1987).
6. There is a well-known Japanese management concept known as total productive maintenance (TPM), which addresses issues related to eliminating wast-ages arising out of breakdowns and poor equipment maintenance.
7. Detailed discussions on alternative forecasting techniques and methods of computing the forecast requirements are available in Chapter 14.
8. Instead of a simple yes or no, organizations can also introduce a five-point scale to reflect the proficiency of the skill acquired by each employee. In such a situation, the method of computing the multi-skilling index needs to be slightly modified. It may be desirable, in any case, to start with this simple scheme before graduating to other forms.

Design of Manufacturing Processes

1. The first Indian company to obtain the PM Prize, an award from Japan for excellence in maintenance management, is a process-industry organization (a cement-manufacturing unit). Furthermore, a number of PM prize winners in the country belong to the process industry. Given the importance of maintenance in process industries, this is hardly surprising.
2. Refer to Chapter 13 for more details on JIT.
3. The idea of the process–product matrix was first proposed by Hayes and Wheelright. For details on this, refer to R. H. Hayes and S. C. Wheelright, "Link Manufacturing Process and Product Life Cycles," *Harvard Business Review* 57, no.1 (1979): 133–140.
4. For a good description of the various problems than an organization faces while adopting a process layout, see Chapter 3 of B. Mahadevan, *The New Manufacturing Architecture* (New Delhi: Tata McGraw-Hill Ltd, 1999).
5. The Russians pioneered the concept of group technology. As early as 1948, nearly 800 factories in the USSR were organized on the basis of group technology. The credit of popularizing the concept of group technology among the non-Russian speaking nations goes primarily to the late Professor J. L. Burbidge.
6. The layout problem described here belongs to a class of problems known as quadratic assignment problems (QAP). For details on QAP, refer to S. Nahmias, *Production and Operations Analysis*, 3rd edition (Englewood Cliffs, NJ: McGraw Hill International Editions, 1997), pp 580–581.
7. This is just an expectation and not a definite outcome as we are merely computing average numbers for each workstation. The precedence relationships among tasks sometimes may not allow combining tasks into the desired number of workstations for a targeted cycle time. Therefore, unless we assign tasks and compute cycle time, we may not know the exact picture.
8. Several heuristic solution techniques have been developed to solve this problem. For example, there is a rank positional weight method. For details on this method readers are referred to S. Nahmias, *Production and Operations Analysis*, 3rd edition. (Englewood Cliffs, N. J.: McGraw Hill International Editions, 1997), pp. 447–452.
9. For an exhaustive coverage on the methods available for the cell formation problem, readers are encouraged to refer to B. Mahadevan and S. Venkataramanaiah, "Realigning Research Objectives In Cellular Manufacturing System Design: A Users' Perspective," *Technology, Operations and Management*, (2007), 17-29.

Design of Service Systems

1. In terms of the probability theory, a finite source corresponds to sampling without replacement and an infinite source corresponds to sampling with replacement. As is known, there are significant differences between these two cases with respect to the arrival rate and probability distributions pertaining to arrival.
2. We do not intend to elaborate on the properties of probability functions and methods of deriving cumulative distribution functions based on the probability-density function. We assume that the readers are conversant with these basic details pertaining to probability distributions.

   Interested readers are referred to any standard textbook on the theory of probability.
3. For an alternative and detailed view on the demand versus capacity management issue in operations, readers are referred to Chapter 15 of the book.
4. The idea was first published in the form of an article in the *Journal of Marketing*. Interested readers may refer to A. Parasuraman, V. A. Zeithhaml and L. L. Berry, “A Conceptual Model of Service Quality and Its Implications for Future Research,” *Journal of Marketing*, no. 49 (Fall 1985): 41–50.

PRODUCT DEVELOPMENT PROCESS

1. A good description of this is available in the book that was brought out at the culmination of this work. Interested readers can refer J. P. Womack, D. T. Jones and D. Roos, *The Machine That Changed the World* (New York: Rawson Associates, 1990).
2. For more details, see S. C. Wheelright and K. Clarke, "Competing Through Development Capability in a Manufacturing-based Organization," *Business Horizons* 35, no. 4 (1992): 29–43.
3. For more details, please visit the Web site: http://tatanano.inservices.tatamotors.com/tatamotors/index.php?option=com_content&task=view&id=215&Itemid=207
4. This is merely a calendar representation of the duration of the product development process. In reality, the requirement in each stage is calculated either in man-months or man-hours: In this example, if eight people work on the concept generation stage, then the requirement is 56 man-months.
5. Multi-dimensional scaling (MDS) is a standard statistical technique that helps an organization analyse the competitive offerings in the market on any number of dimensions. Knowledge of this technique may help the design team in assessing the strength of their proposed product offering in comparison with the existing ones in the market. For more details on MDS, refer to any standard textbook on multivariate statistical analysis.
6. For a very good description of quality function deployment and its applications, readers may consult Y. Akao, *Quality Function Deployment: Integrating Customer Requirements into Product Design* (New York: Free Press, 1990).
7. For more details, see "The Story Behind the Nano," *Business Week*, 9 May 2008.
8. DFM principles were first developed by Professors Geoffrey Boothroyd and Peter Dewhurst during the early 1980s. For more details on their work, a useful source is G. Boothroyd and P. Dewhurst, *Product Design for Assembly* (Wakefield, R.I.: Boothroyd Dewhurst Inc, 1987).
9. For a good description of the design for the localization concept, its application, and the impact that it is likely to have on an organization, refer to the paper, H. L. Hee, C. Billington, and B. Carter, "Hewlett-Packard Gains Control of Inventory and Service Through Design for Localization," *Interfaces* 23, no. 4 (1993): 1–11.
10. For a good discussion on the various aspects of mass customization, readers are referred to J. H. Gilmore and B. J. Pine II, "The Four Faces of Mass Customization," *Harvard Business Review* 75, no. 1 (1997): 91–101. Mass customization also demands certain organizational structure changes. Refer to the paper by B. J. Pine II, B. Victor, and A.C. Boynton, "Making Mass Customization Work," *Harvard Business Review* 71, no. 5 (1993): 108–117 for more details.
11. A study reported that a Dell Inspiron 8100 G1200VT notebook computer can be configured online into 2,080,899,072 unique alternatives using the options available for various system components such as the base system, the OS, optical drives (fixed and removable), the carry case, battery, zip drive, video card, mouse, keyboard and hardware maintenance option. For details, see B. Mahadevan, "Making Sense of Emerging Market Structures in B2B E-Commerce," *California Management Review* 46, no. 1 (2003): 86–100.
12. For a good introduction to product platforms, readers are encouraged to consult D. Robertson and K. Ulrich, "Planning for Product Platforms," *Sloan Management Review* 39, no. 4 (1998): 19–31; and M. H. Meyer and A. P. Lehnerd, *The Power of Product Platforms* (New York: The Free Press, 1997).
13. Interested readers can refer to R. S. Pressman, *Software Engineering: A Practitioner's Approach* (New York: McGraw-Hill, 1997) for more details on these models.

TOTAL QUALITY MANAGEMENT

1. For more details on this study, see D. Garvin, “Quality on Line,” *Harvard Business Review* 61, no. 5 (1983): 64–75.
2. Visit the website http://www.juse.or.jp/e/deming/index.html to know more about the Deming Prize and other categories of prizes instituted by the Union of Japanese Scientists and Engineers (JUSE).
3. These 14 points were originally published in W. E. Deming, *Out of the Crisis* (Cambridge, MA: MIT Centre for Advanced Educational Services, 1986).
4. A detailed description of process control charts follows in Chapter 19.
5. For details, see D.A. Garvin, “What Does Quality Really Mean?” *Sloan Management Review* 26, no. 1 (1984): 25–43.
6. In this chapter, we do not cover all QC tools in detail. This is partly because some of them are fairly simple and straightforward to use. Moreover, there is plenty of published literature available on this topic. For a sample, readers are referred to K. Ishikawa, *Guide to Quality Control* (Tokyo: Asian Productivity Organization, 1991). Another useful source is K. Suzaki, *The New Shop Floor Management* (New York: Free Press, 1993). Control charts are discussed in detail Chapter 19.
7. The details pertaining to construction of a histogram have not been included in this write-up. This is because, it is not only a widely known and a simple procedure, but also available in any standard elementary textbook on statistics. On the other hand, we focus on actual examples where the tool has been used and explain its relevance to quality management. We take a similar approach to several other tools described in the book.
8. N. Ravichandran, “A Framework for Creating A Competitive Advantage Through Throughput Time Reduction” (MPT Report, IIM Bangalore, 1996).
9. For more details on CEDAC, readers are encouraged to refer to R. Fukuda, *CEDAC–A Tool for Systematic Improvement*, (Cambridge, MA: Productivity Press, 1990). Another useful source is K. Suzaki, *The New Shop Floor Management* (New York: Free Press, 1993).
10. This illustration is based on an unpublished report submitted in the Management Programme for Technologists at the Indian Institute of Management Bangalore during 1996.
11. For a good description of QFD, readers may refer to J. R. Hause and D. Clausing, “The House of Quality,” *Harvard Business Review* (May-June, 1988): 63–73.
12. For more details, see Y. A. Akao, *Quality Function Deployment: Integrating Customer Requirements into Product Design* (New York: Productivity Press, 1990).
13. A detailed discussion on the house of quality is available in Chapter 11. Therefore, we merely provide a contextual description of the tool here.

LEAN MANAGEMENT

1. For a detailed treatment of the notion of waste, see *The Canon Production System: Creative Involvement of the Total Workforce* (New York: Japanese Management Association, Productivity Press, 1997).
2. M. Hammer and J. Champy, *Reengineering the Corporation* (London: Nicholas Brealey Publishing Ltd, 1993). pp39-44.
3. For a very good description of the productivity descriptions and improvement profiles of Japanese and U.S. automobile manufacturers, see J. P. Womack, D. Jones, and D. Roos, *The Machine that Changed the World* (New York: Rawson Associates, 1990).
4. B. Mahadevan, “Journey to the Deming: Implications for Corporate Transformation and Competitiveness,” *IIMB Management Review* 17, no. 2 (2005): 59–70.
5. There are a number of studies that deal with the various factors required for JIT. For a representative paper on this, refer to B. Mahadevan, “Are Indian Companies Ready for JIT?” *IIMB Management Review* 9, no. 2&3 (1997): 85–92.
6. For a detailed treatment of the subject of manufacturing architecture, refer to B. Mahadevan, *The New Manufacturing Architecture* (New Delhi: Tata McGraw-Hill, 1999).
7. For a detailed explanation of issues related to focused manufacturing, refer to Chapter 3 of R. J. Schonberger, *Building Internal Chain of Customers* (New York: Free Press, 1990), pp. 34–64.
8. Therefore, in this chapter we use set-up time to also denote changeover time. This is obvious because any changeover from one variation to another requires a new set-up to be made for the manufacturing process.
9. For a detailed analysis of SMED, refer to S. Shingo, *A Revolution in Manufacturing: The SMED System* (Cambridge, Mass: Productivity Press, 1985).
10. Please note that we have discussed the key elements of push type scheduling at great length in Chapters 14 to 18.
11. The fixed order quantity (FOQ) system is described in detail in Chapter 17 of this book. We merely use some of the results from that discussion here to motivate the computation of number of *Kanbans*.
12. Various QC tools utilized for reducing the defects in an operating system are discussed in detail in Chapter 12 of this book.
13. For a good understanding of various issues related to *Kaizen*, readers are encouraged to visit the web site of the Kaizen Institute at *http://www.kaizen.com* (Web site last accessed on June 25, 2014).
14. For example, see B. Mahadevan, “Are Indian Companies Ready for Just-in-Time,” *IIMB Management Review* 9, nos. 2&3 (1997): 85–92.

DEMAND FORECASTING

1. For more details, see S. Makridakis, A. Anderson, R. Carbone, R. Fildes, M. Hibon, R. Lewandowski, J. Newton, E. Parzen, and R. Winkler, “The Accuracy of Extrapolation (Time Series) Methods; Results of a Forecasting Competition,” *Journal of Forecasting* 1 (1982): 111–153.

OPERATIONS PLANNING

1. The term “heat” refers to one cycle of charging a furnace with all the required material so that molten steel is ready for pouring into the required applications.
2. Organizations carry inventory for a variety of reasons. In this example, we build inventory in anticipation of the future surges in demand. See Chapter 17 for a discussion on the other reasons for carrying inventory.
3. In the terminology of IT firms, it is referred to as “sitting on the bench”. There are cases of billable benches and non-billable benches. A non-billable bench represents the UT costs arising out of lost productivity.
4. We do not make an effort to describe the solution methodologies available for solving transportation problems in this book. Readers can refer to any standard textbook in operations research for details. However, we have briefly demonstrated the use of the transportation model in Chapter 6. Refer to Section 6.3 and Example 6.4 for details.
5. LDR is also known as the HMMS method (from the first letter of the names of four authors). A detailed description of LDR is available in C. C. Holt, H. Modigliani, J. F. Muth, and H. A. Simon, “Planning, Production, Inventories and Workforce,” (Englewood Cliffs, NJ: Prentice Hall, 1960).

RESOURCES PLANNING

1. For a detailed treatment of this subject, readers are advised to consult Chapter 17 of this book.
2. Chapter 15 has a discussion on master production schedules (MPS) and the manner in which information contained in the MPS could be put to use for the purpose of planning.
3. For a good treatment of this subject, readers are referred to the book, O. W. Wight, *Manufacturing Resource Planning: MRP–II* (Essex Junction, VT: Oliver Wight Publishers, 1984).

INVENTORY PLANNING AND CONTROL

1. In Chapter 15 of the book, we show how build-up of this type of inventory is planned through an aggregate planning exercise, and its cost implications.
2. It is easy to note that this level of inventory represents the reference for initiating action for repeatedly replenishing the cyclic inventory. This is referred to as the reorder point (ROP).
3. The number of orders need not be strictly an integer, as it indicates an average value. In this case, it merely means that 25 orders would have been placed every two years. However, we round off the number of orders to the nearest integer just for convenience.
4. For instance, if the "in-house" manufactured item has a demand rate of d/unit time and the production facility is capable of a production rate of p/unit time (p > d), then the economic run length is given by:

$$ERL = \sqrt{\frac{2C_0D}{C_c\left(1-\frac{d}{p}\right)}}$$

For more details, please see Russell, R. S. and B. W. Taylor III (1998), *Operations Management*, 2nd ed. Prentice-Hall International Inc. pp 581–584.

5. Note that variance is an unbiased estimator, whereas standard deviation is not. Therefore, when the demand distribution data and lead time data pertain to different time periods, the standard deviation needs to be converted to variance. After mathematical manipulations, finally one can obtain the standard deviation. In simple terms, if the demand attributes (mean and standard deviation) are in days and the lead time is L days, then an expressions for $\mu_{(L)}$ and $\sigma_{(L)}$ are given by $\mu_{(L)} = \mu \times L$ and $\sigma_{(L)} = \sqrt{L} \times \sigma$ where μ is the mean daily demand and σ is the standard deviation of daily demand.
6. Note that inventory position in the system could be different from physical inventory. When there is a pending order, then the inventory position in the system is more than the physical inventory. Inventory position in the system = Inventory on hand + Inventory on order.
7. Please note that the definition for inventory position in the system is the same as it is for the Q system. Inventory position in the system = Inventory on hand + Inventory on order.
8. This phenomenon of a small percentage by volume accounting for a large percentage by value appears to be universal. Pareto, an Italian philosopher, observed this phenomenon when he plotted the income distribution of individuals in the 18th century.
9. A more general case can be described as follows:

$$TC(Q) = C_{os}\int_0^Q (Q-x)f(x)d(x) + C_{us}\int_Q^\infty (x-Q)f(x)d(x)$$

where TC(Q) is the total cost of stocking Q units and $f(x)$ is the probability density function for demand. The first term on the RHS corresponds to the total cost of overstocking and the second term corresponds to the total cost of understocking. By taking the first derivative of the total cost function with respect to Q, and equating it to zero, one can arrive at an equivalent expression for a continuous density function for demand. For more details see, Nahamias, S. (1997), *Production and Operations Analysis*, 3rd ed., McGraw-Hill International ed. pp 272–275.

10. For a relevant discussion on this topic, please see, N. Venkatraman, "Multiplier Effect in Inventory Management,", *Management Accountant*, September 1986, pp 548–549.

OPERATIONS SCHEDULING

1. There is a plenty of literature available on the mathematical formulation and solution for the loading problem. For an illustration of this, readers are referred to M. Berrada and K. E. Stecke, “A Branch and Bound Approach for Machine Load Balancing in Flexible Manufacturing Systems,” *Management Science* 32, no. 10 (1986): 1316–1335.
2. In this chapter, we demonstrate the use of the assignment method for loading using this example. We assume that readers have a basic understanding of the solution methodology of the assignment method. In any case, one can use a standard OR software such as LINDO to obtain these solutions by appropriate input of the data. Interested readers may want to practice the problems at the end of the chapter which deal with the assignment method.
3. Readers are referred to Chapter 9 of this book, which has more details on these alternative configurations. Other configurations are also available, but we focus only on these two for the purpose of discussing scheduling methodologies.
4. Panwalker and Iskander have reported nearly 300 scheduling rules. For more details, readers are referred to S. S. Panwalker and W. A. Iskander, “A Survey of Scheduling Rules,” *Operations Research* 25, no. 1 (1977): 45–61.
5. For Johnson’s original paper, please refer to S. M. Johnson, “Optimal Two and Three Stage Production Schedules with Set-Up Time Included,” *Naval Research Logistics Quarterly* 1 (1954): 161–168.
6. Interested readers are referred to J. R. Jackson, “An Extension of Johnson’s Results on Job-Lot Scheduling,” *Naval Research Logistics Quarterly* 3 (1956): 201–203.
7. The CDS method derives its name from the authors who proposed this variation of Johnson’s rule. Interested readers are referred to H. C. Campbell, R. A. Dudek, and M. L. Smith, “A Heuristic Algorithm for the n Job m Machine Sequencing Problem,” *Management Science*, 16, no. 10 (1970): B630–B637.
8. “TAKT” is a word of German origin that means rhythm. The choice of this word is therefore very appropriate. However, Taiichi Ohno, the father of the Toyota Production Systems, spells this as “TACT”. Therefore, both spellings are used.
9. References of some of the books written by Goldratt are given at the end of the chapter.
10. As discussed in Chapter 16 of this book, the MRP logic does this job.
11. E. M. Goldratt and J. Cox, *The Goal*, (Madras: Productivity Press India Pvt. Ltd., 1993).

Six-Sigma Quality Control

1. This is based on the well-known central limit theorem. We skip the statistical aspects pertaining to these details in this writing. However, interested readers can refer to any standard book on business statistics for more details.
2. Alternative measurement scales are available. The *nominal scale* is a simple categorization of observed values (such as good and bad). An *ordinal scale* is a method of ranking the observations (for example from poor to excellent on a 5-point scale). A third option is to use a *ratio scale* where exact measurements are possible (such as the length of a rod is 23.54 cm and the length of another rod is 22.78 cm). Interested readers may refer to any standard textbook on business statistics for more details. In this chapter, we deal only with nominal and ratio scales.
3. If the standard deviation of the process (*s*) is known, then the standard deviation of the sample means is given as $\frac{\sigma}{\sqrt{n}}$, where *n* is the size of the sample. The three stand-*n* ard deviations of the sample means on either sides of the mean of the sample means provides the upper and lower control limits for the $\bar{X}$ chart.
4. There are several other benefits of higher C_p values. For instance, Juran and Gryna show that the nature of inspection efforts required will be vastly reduced at higher C_p values. For details, see J. M. Juran and F. M. Gryna, *Quality Planning and Analysis* (New Delhi: Tata McGraw-Hill Co. Ltd, 1995), pp 393–396.
5. The probability of finding *x* defects in a sample of *n* drawn from a lot of *N* follows hyper-geometric distribution— one of the well-known discrete probability distributions. However, when the population is large compared to the sample, it can be approximated to a binomial distribution. Therefore, the expression for the probability of finding *x* defects in a sample of *n* with a proportion of defects in the lot as *p* is given by: $P(x|n, p)5\ {}_{n}C_{x}\ p^{x}q^{n-x}$ Since in a sampling plan, up to *c* defects will be accepted, the probability of acceptance of a lot base on the sample is given by $\sum_{x=0}^{x=c} P(x\,|\,n,p)$. Readers may refer to any standard text-book on probability for more details on the hyper-geometric distribution and its approximation to binomial.

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