Master of Business Administration

(Open and Distance Learning Mode)

Semester – II

Operations Management

Centre for Distance and Online Education (CDOE)

DEVI AHILYA VISHWAVIDYALAYA, INDORE

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IET Campus, Khandwa Road, Indore - 452001

www.cdoedavv.ac.in

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CDOE-DAVV

Program Coordinator

Dr. Manishkant Arya
Centre for Distance and Online Education (CDOE)
Devi Ahilya Vishwavidyalaya, Indore – 452001

Content Design Committee

Dr. Sangita Jain
Institute of Management Studies
Devi Ahilya Vishwavidyalaya, Indore – 452001

Dr. Yamini Karmarkar
Institute of Management Studies
Devi Ahilya Vishwavidyalaya, Indore – 452001

Dr. Geeta Neema
International Institute of Professional Studies
Devi Ahilya Vishwavidyalaya, Indore – 452001

Dr. Manishkant Arya
Centre for Distance and Online Education (CDOE)
Devi Ahilya Vishwavidyalaya, Indore - 452001

Language Editors

Dr. Arti Sharan
Institute of Engineering & Technology
Devi Ahilya Vishwavidyalaya, Indore – 452001

Dr. Ruchi Singh
Institute of Engineering & Technology
Devi Ahilya Vishwavidyalaya, Indore – 452001

SLM Author(s)

Ms. Rashmi Modi
MBA
EMRC, Devi Ahilya Vishwavidyalaya, Indore – 452001

Mr. Neal Jain
MBA
EMRC, Devi Ahilya Vishwavidyalaya, Indore – 452001

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OPERATIONS MANAGEMENT

SYLLABI-BOOK MAPPING TABLE

Operations Management

Syllabi	Mapping in Book
Unit: 1 **Introduction:** Concept of planning for production, technology importance of production functions.	**Unit 1:** Production and Operations Management **(Pages 5-20)**
Unit: 2 **Manufacturing Systems:** Process design and process selection adoption of appropriate technology as per market requirements.	**Unit 2:** Manufacturing Systems **(21-37)**
Unit: 3 **Planning and Control:** Functions of production planning and control, routing and scheduling of planning, production automation technology, concept and importance of product design, production, and quality.	**Unit 3:** Production Planning and Control **(Pages 39-66);** **Unit 4:** Product Design and Forecasting **(Pages 67-78)**
Unit: 4 **Project Analysis:** Introduction PERT/CPM, concept of critical path.	**Unit 5:** Project Analysis – PERT/CPM **(Pages 81-110)**
Unit: 5 **Capacity Planning and Work Study:** Plant location, plant layout, importance of maintenance management, objectives of work study, importance of method study and work management.	**Unit 6:** Plant Location and Layout **(Pages 111-131);** **Unit 7:** Capacity Planning and Maintenance Management **(Pages 133-148);** **Unit 8:** Work Study **(Pages 149-162)**
Unit: 6 **Objectives of:** Supply chain management, just in time system forecasting, computer system and packages.	**Unit 9:** JIT and Quality **(Pages 165-188);** **Unit 10:** Supply Chain Management, Computer Systems and Packages **(Pages 189-205)**
	Unit 11: Random Variables and Probability Distributions **(Pages 207-238)** **Unit 12:** Inventory Management **(Pages 239-281)**

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INTRODUCTION

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Production and operations management, popularly referred to as POM, has become an important subject of study. To a layman, POM can be explained as the planning, coordination and controlling of the resources of an organization in a manner that will facilitate the production process. Simply put, POM is concerned with the transformation of production and operational inputs into outputs that will meet the requirements of consumers, when distributed. It is also an area of business that is concerned with the production of quality goods and services. Among other things, it ensures that all the business functions such as production, design and product performance operate smoothly in a manner that is not only efficient but also effective.

This book, *Operations Management*, discusses topics such as manufacturing systems, production planning and control, product design, plant location and layout, capacity planning and maintenance management, work study, JIT and quality as well as supply chain management, computer systems and packages.

The book has been put together in the self-instructional format wherein each unit begins with an Introduction to the topic. The Unit Objectives are then outlined before going on to the detailed content, interspersed with Check Your Progress questions to test the understanding of the student. The study material is presented in a simple and organized manner to facilitate easy comprehension. A Summary, a list of Key Terms and a set of Questions and Exercises are provided at the end of each unit for recapitulation.

MODULE - 1

UNIT 1 PRODUCTION AND OPERATIONS MANAGEMENT

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Structure

1.0 INTRODUCTION

The word 'production' immediately conjures up images of large rooms filled with machines of every shape and size, materials of all hues and colours, and people working to fulfil their targets. The coordination between all these five Ms (i.e., man, machine, materials, money and method) takes place with the help of the sixth 'M', i.e., management. This is what production and operations management is all about. It is concerned with the production of goods and services and is responsible for ensuring that these operations are efficient and effective. Thus, in this unit, you will learn about the production process, the objectives of production and operations management, its scope, and the importance of technology in production.

In other words, production and operations management refers to the management of the efforts and activities of people, equipment and other resources of the organization in changing raw materials into finished goods and services.

1.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand the meaning of 'production' and 'operations'
- Know about the developments that have taken place in this field of study

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- Understand the logic behind every production process
- Analyse the differences between goods and services
- Explain the scope of activities in this field of study
- Describe what is efficiency and effectiveness
- Understand the concept of productivity

1.2 HISTORY OF PRODUCTION AND OPERATIONS MANAGEMENT

Before learning further, it is important to take a look at the history of production and operations management. This will help you to understand that technology is the backbone of all production functions.

1.2.1 The Era of Industrial Revolution

The Industrial Revolution of Great Britain during the late eighteenth century brought about extensive mechanization of production systems. It resulted in a shift from home-based production to large-scale production outside the home. Equipment were created that could produce in large quantities. Workers reported to a supervisor, who planned the work to be done and issued orders to workers. Inventions such as James Watt's steam engine, Jenny Cartwright's power looms, Maudslay's cutting lathes etc., contributed to the era of Industrial Revolution.

During this period, Adam Smith, the father of modern economics published his book *An enquiry into the Nature and causes of Wealth of Nations*, popularly called *The Wealth of Nations*. The three main concepts propounded by him were division of labour, pursuit of self-interest, and freedom of trade. He felt that costs other than wages, such as rent and profit, also affect the price of a commodity.

Smith believed that division of labour could greatly increase production. He wrote that 'If one worker could make twenty pins a day and if ten people divided up the eighteen steps required in making a pin, they could make a combined amount of 48,000 pins in one day.'

1.2.2 The Era of Scientific Management

It began in the United States in the early 20th century. Fredrick Winslow Taylor, is called the father of scientific management. His four principles are listed as follows:

1. Replace rule-of-thumb work method with methods based on scientific study of tasks.
2. Scientifically select, train and develop each employee rather than leaving them to train themselves.
3. Instruct and supervise each worker in detail.
4. Divide work nearly equally between managers and workers; the duty of establishing standards and enforcing them rests with the management alone.

He propounded the 'Time and Motion Study' which involves breaking up a job into its component parts and measuring each component in terms of the time required to do it.

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This study was carried forward by his associates, Frank B.Gilbreth and his wife Lilian Gilbreth who coined the term 'Motion Study'. The Gilbreths used the camera to record and examine detailed micro-movements, and invented cyclographs and chronocycle graphs to observe rhythm and movements.

Another pioneer of Scientific Management was Henry Gantt. The 'Gantt Chart' that he created is a visual display chart used for scheduling, based on time. He showed the humane face of management and listed the conditions that have a favourable psychological effect on the worker.

By the end of the nineteenth century, the internal combustion engine had been invented; and the first assembly line manufacture of cars was started by Henry Ford in Detroit, USA.

1.2.3 The Era of Human Relations

The impact of the behaviour of workmen on their performance was increasingly recognized and some experiments were carried out at Hawthorne Works in Chicago, USA. These tests called Hawthorne studies, form the basis of several behavioural and motivation theories. Other important contributors of this era were A. Maslow, F.Hertzberg, and Douglas Mc Grefor.

1.2.4 The Era of Quantitative Techniques

These techniques originated during World War II. Operations Research teams were formed to deal with strategic and technical problems faced by the military. These were later used for non-military applications. George Dantzig discovered the simplex method of solved linear programming problems in 1947. Many developments followed and computers have enabled people to solve a large variety of industrial problems. The technology explosion continues and today digital manufacturing has enabled companies to rapidly build to order, maintain non-stop production, and integrate their supply chains.

1.2.5 The Era of Quality

Toyota first caught the world's attention in the 1980s when the Company manufactured automobiles with unbelievable consistency in processes and products. Success came from their astounding quality reputation.

In-built quality became the necessity. This was followed by TQM or total quality management and the focus shifted from quality control to quality assurance.

The ISO 9000 series for quality management systems, ISO 14000 environment management standards are followed across the world. Companies are now aiming for six sigma.

1.3 DEFINITIONS OF PRODUCTION AND OPERATIONS MANAGEMENT

The Association of Operations Management (APICS) defines Operations Management as, '*The field of study that focusses on the effective planning, scheduling, use and control of manufacturing or service organizations through the study of concepts from design engineering, industrial engineering, MIS, quality management, production management, industrial management and other functions as they affect the organization.*'

According to Sherin and Joel G. Siegel, Production and Operations Management ***is the management of all activities directly related to the production of goods and services.*** It may be remembered that goods are produced and services are rendered.

In the early days, **production** involved the processes followed in mass production and it produced tangible goods. As the complexities of business grew, management of the systems responsible for production became essential. Then services also began to be 'produced' or rendered. These were intangible. So, some principles were needed which could encompass the entire system that produced a good or delivered a service. It was found that the same principles could be effectively applied in the management of processes that were involved in the making of 'goods' as well as 'services'. This is what is meant by Production and Operations Management.

POM (as it is called), uses the decision-making tools of Operations Research and the principles of industrial engineering, quantitative techniques, shop-floor control, organizational behaviour, safety management, maintenance management, etc.

Thus, we can say that POM deals with the concepts and principles employed by organizations to make them efficient and effective.

1.4 THE PRODUCTION PROCESS

The production and operations of goods and services involve the conversion of input into output through a transformation process. (see Figure 1.1).

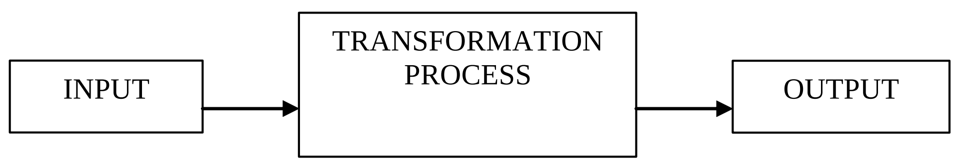

Fig. 1.1 *Conversion of Input into Output*

(a) **Input**: This includes the 6Ms, i.e., man, machine, materials, money, method and now management.

(b) **Transformation Process**: This is the process by which the inputs are converted into output. It is a value-addition process which modifies or adds value to the input and converts it into a form that is more useful and sold to a customer. This value addition can be done in any of the following ways:

- **Alteration:** This includes all the activities such as change in the physical state of input, changing dimensions, adding chemicals, heating, rolling, galvanizing, etc. The methods of transformation are numerous and there is one distinct method for every available product in the market.
- **Transportation**: This refers to the physical movement of goods from one place to another. Some firms such as traders specialize in buying goods from one place (usually the place of manufacture) and transporting them to a location where they can be sold.
- **Storage**: This refers to preserving the goods in a protected environment so that they can be made available at a later date, for example, food grains. This is also a kind of transformation process.

Value addition can also be done by inspection or transportation companies, book publishers, etc. There are as many processes as there are products. The process for every product is unique.

In short, any process that adds value to a product is part of the transformation process.

(c) **Output:** It can be a good/product or a service. The major differences between goods and services are listed below as shown in Table 1.1.

Table 1.1 *Major Differences between Goods and Services*

	Goods	Services
1.	Goods are tangible; they have physical parameters.	Services are intangible. They are just ideas, concepts or information.
2.	Goods can be produced, stored and transported according to demand since the value is stored in the product.	Services cannot be produced beforehand, stored or transported. Value is conveyed as used.
3.	They are produced in a factory environment, usually away from the customer.	Services are produced in a market environment in collaboration with the customer.
4.	Often, the goods are standardized.	Often customized.
5.	Quality is inherent in the product.	Quality is inherent in the process since it is a function of people.

As the complexities of organization grew, it was found that merely converting input to output was not enough. Feedback from the output stage was necessary to adjust the changes required in input or the transformation process. So, production control was done to take care of fluctuation in inputs, if any. The quality of the produced output was now constantly compared to the quality of the desired output and feedback mechanisms were put in place to monitor performance of transformation process.

Then, some random disturbances were found to be hampering the transformation process. These random disturbances are unexpected and sometimes unplanned; they occur due to external environment and can be in the form of strikes, government interference, recession, etc. In effect, the cycle of production and operations management looks like this as shown in Figure 1.2.

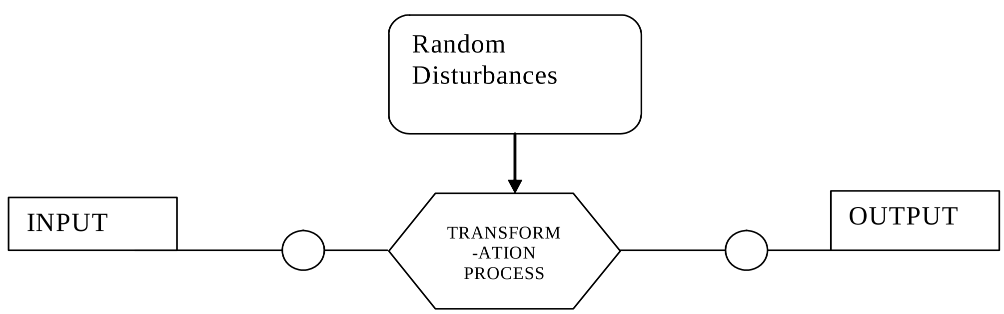

Fig. 1.2 *The Cycle of Production and Operations Management*

1.5 PRODUCTION: THE HEART OF AN ORGANIZATION

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Production is the primary business of an organization. All other divisions or activities of an organization exist only if production exists. Without production or anything to sell, there is no organization at all.

An organization usually has several departments and each department is assigned a specialized function, as shown in Figure 1.3.

- Marketing establishes the demand for the goods and sells what is produced.
- Finance provides the capital for equipment and resources.
- Human resource management provides the manpower and takes care of employees.
- Purchasing is concerned with procurement of materials needed to run the organization.
- Materials management takes care of inventories.
- Law department safeguards the organization on legal issues.
- Public relations department builds the image of the organization.
- R&D is responsible for research and development.

However, it is production which produces the goods and services. It plays a vital role in achieving a firm's strategic goals.

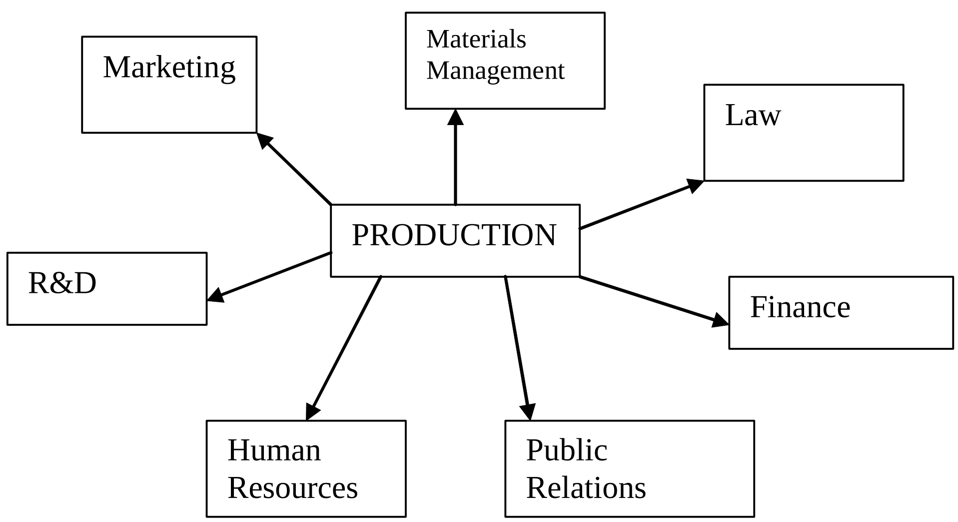

Fig. 1.3 *Departments of an Organization*

Production includes the bulk of a company's employees and is responsible for a large portion of company's assets. It also has a major impact on the quality of goods produced and their cost and is thus the visible face of the company.

Hence, we say that production is the heart of an organization.

1.6 OBJECTIVES OF PRODUCTION AND OPERATIONS MANAGEMENT

Every organization starts with a goal and mission and then chalks out the activities to achieve these goals. All the activities, primarily those for converting inputs into required outputs are planned accordingly. The common objectives of any kind of organization are:-

(a) Customer satisfaction

Customer satisfaction is vital to the survival of an organization. The organization researches the expectations of the customer or service to be rendered and decides on the product. An organization can survive only if its products satisfy the customers on the basis of the following criteria:-

- Quality of the product as per acceptable standards
- Easy maintenance and reliability of the product
- Functionality of the product as offered by the seller

(b) Profitability

The pricing of the product should be competitive to achieve sales. For this, the market price of products should be competitive and commensurate with the features offered in the product. A good organization produces the right quality that meets all product specifications, at optimal cost. The organization should focus on minimizing costs and maximizing revenue for increasing profitability.

(c) Timeliness

The product produced or service rendered may be qualitative and cost- competitive but if it does not reach the consumers when they require it, the organization loses. The consumer does not wait for a good or service; he acquires it from a competitor. Therefore, Production and Operation Management plays a vital role in providing the product or service on time by effectively maintaining production schedules.

To summarize, we can say that an effective POM needs to produce goods or render services of the right quality in right quantities at the right time and at minimal costs. It should also ensure that there is no wastage in the system because this results in cost escalations and severe delays.

If the above mentioned factors are not kept in mind then it could lead to failure of the management in achieving its objectives and targets.

1.7 SCOPE OF PRODUCTION AND OPERATIONS MANAGEMENT

The scope of production and operations management encompasses all the activities involved in producing a good or service. Listed below is the scope of production and operations management:-

1. **Product selection and development –** This deals with the study of how a product is selected and developed for commercial production.
2. **Process selection –** It deals with how the process required to produce a product is selected for commercial production.

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3. **Facilities location –** It deals with the parameters that are to be considered for locating a factory premise.
4. **Layout planning –** It deals with the study of how the factory / plant is to be laid out for optimum production.
5. **Material handling –** It deals with the study of significance of material flow in an organization, the different methods of material handling, etc.
6. **Manufacturing system –** It deals with the study of the different types of manufacturing systems and their applicability.
7. **Production planning and production control –** It deals with the methods followed in different kinds of manufacturing systems. This includes methods followed for job loading, scheduling, dispatching, PERT /CPM, Linear programming, etc.
8. **Work studies –** It deals with method study and work measurement.
9. **Materials management –** It deals with methods to control inventory, inventory analysis, etc.
10. **Quality –** It deals with standards and techniques, TQM, Six Sigma, etc.
11. **Safety management –** It deals with principles, methods, etc.

1.8 IMPORTANCE OF TECHNOLOGY IN PRODUCTION

The importance of automation and advanced technology in manufacturing and service organizations is due to several factors.

1. The high level of competition and problem of survival has increased the need for productivity improvement.
2. A shift from the mass production of standardized products to custom produced products requires production systems with a high degree of flexibility.
3. Marketing pressures that demand shorter life cycles for products require production systems that are fast, accurate, standardized and yet responsive to change.
4. The increasing complexity of products with increasing technology has made the problems associated with production more difficult. This calls for even more advanced technology to control them.

To accommodate such factors in the manufacturing environment requires production systems that are both responsive and flexible. In the subsequent units, you will learn about some of the important concepts of automation and advanced technologies that influence operations management decisions. In order to better understand the role of technology, we will first study the relative roles that humans and machines play in production.

1.8.1 The Human–Machine Interface

Rapid changes in technology in the last few decades have resulted in creating machines that are capable of performing tasks that have traditionally been done by people. Robots, for example, have relieved workers of menial and dangerous tasks such as welding or lifting heavy objects. In offices, word processors have broadened the scope of secretaries'

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jobs. On the one hand, technological developments have enhanced the role of the worker in production systems. On the other hand, increased automation has resulted in a threat to job security; for instance, totally automated factories are a reality in countries such as Germany and Japan. This presents a dilemma for operations managers: What should be the proper balance between human work and machine work?

Automation has significantly changed the nature of the workforce. It has decreased the need for low skilled, direct factory workers but has increased the demand for highly trained specialists. There are now a large number of technical, professional, and managerial workers who are performing complex, long -cycle activities. A worker's time is mostly devoted to mental processes, with much less time being spent on physical work. The degree of human and machine work varies from industry to industry. Human involvement is generally more in the primary sector and less as we go into the secondary and tertiary sectors.

The level of automation and use of human labour in an industry should be selected so as to provide the lowest unit manufacturing cost at highest productivity. The relative roles that human beings and machines have played in production have changed during the course of history. Prior to the Industrial Revolution, manufacturing tasks were performed primarily by people. Activities such as weaving cloth, forging and bending metal, etc. were labour intensive. As the Industrial Revolution progressed, machines provided more power for manufacturing, but workers retained much of the control of the process. For example, lathes and drill machines required a large amount of operator assistance. Today, numerically controlled machines and robots permit less human involvement in the production process. In service organizations, we also see evidence of this evolution in ATMs of banks, railway bookings, etc.

The focus has now shifted from issues of human production to human–machine interface. In order to make effective decisions regarding the introduction of new technology, managers need to understand the fundamental differences between machines and people.

Advantages of humans over machines

- They can think creatively and adapt to new and unexpected situations much better than machines.
- They can take subjective decisions and have reasoning abilities. But humans tire after some time; their productivity is not uniform over time; due to boredom, frustration, fatigue, etc., they are not capable of performing heavy- duty jobs and their memory is short and limited.

Advantage of machines over humans

- They are better suited for complex or repetitive tasks requiring precision and speed.
- They are accurate, fast and precise and can perform heavy duty tasks which are beyond the human capabilities.
- They can store and process large amounts of data.
- They are more reliable and consistent than humans.
- They do not cause Industrial relation problems like strikes, lockouts, etc.

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- State-of-the-art automated plants increase the market value of the firm and improve client base in international markets. But their capability is limited to their programmed instructions. They are less flexible than humans and cause unemployment/ retrenchment of work force.

The goal of the operations manager is therefore to provide the best synthesis of technology and people so that the objectives of the organization are met.
Technological changes have occurred in every industry and can be categorized into two groups - hardware and software.

Hardware technologies have resulted in greater automation of processes. They perform labour - intensive tasks that were originally performed by humans. Examples of these major types of hardware technologies are numerically controlled machine tools, machining centres, industrial robots, automated materials handling systems, and flexible manufacturing systems. These are all computer - controlled devices that can be used in the manufacturing of products.

Software-based technologies aid in the design of manufactured products and in the analysis and planning of manufacturing activities. These technologies include computer-aided design and automated manufacturing planning and control systems. Each of these technologies is described in greater detail in Unit 3.

1.9 PRODUCTIVITY

In this section we will focus on measuring how effectively and efficiently the inputs are being converted into outputs, and whether the transformation process is working properly or not. This is done objectively by calculating a factor called **Productivity.**

Productivity is a measure of the quantity of output per unit of input. Productivity can be expressed as a factor or percentage

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{\text{Goods or Services Procued}}{\text{All factors or Production}} \times 100$$

In the early days, productivity meant 'labour productivity'. This was because machines were not many, and they were not very complicated. They could be understood and could be made to run faster or slower, as planned. But there was a lot of unpredictability in labour and the performance of humans varied greatly, depending on many factors. So to establish some standards against which the performance of humans could be measured, the concept of labour productivity was started.

The productivity figure of an organization immediately gives a reader the idea of how an organization is being run. It indicates how efficiently the organization is working in converting the input into output. Productivity can be an indicator in any of the following circumstances:

1. It indicates the level of utilization of man, machines and materials.
2. It indicates the level of efficiency in the method of working.

3. It indicates whether there is motion economy in the organization – i.e., effectiveness of layout/plan.
4. Material handling efficiency.
5. Appropriation of technology/production process.
6. Maintenance policy and its adequacy.
7. Working condition of employees.
8. It also helps in fixing wages/proper compensation/incentive schemes.
9. Level of quality control/quality assurance.

Before we proceed further on productivity, let us understand the meanings of the terms **Efficiency** and **Effectiveness.**

Efficiency means doing something at the lowest possible cost.

Effectiveness means doing the right thing to create the most value for the company.

An efficient organization need not be effective. Employees may appear to be very busy throughout the day as they write notes, file, mark them up, down, to other departments, etc. attend meetings, fly for conferences etc. The Manager may be extremely busy, hard working and efficient, but is he effective? He may have held up the bill of a supplier for three months simply because he has not had the time to put it in a file and send it to the Finance Department. Such a busy manager will always be 'fire fighting' and will never have the time for 'conceptual thinking'. He is efficient but not effective.

The difference between efficiency and effectiveness is shown in Table 1.2.

Table 1.2 *Difference between Efficiency and Effectiveness*

Efficiency	Effectiveness
To produce in quantity and quality for the customer.	To enhance the value for the customer.
Decision on HOW to perform a task.	Decision on WHY to perform a task and WHAT to perform.
Common question is – Is everything running well?	Question is – Are we aiming correctly?
Aim is to improve the process and the product.	Aim is to determine the right direction of the organization.

Example 1

For the year 2006-07, Company A recorded the following:

Net sales = Rs 200 cr

Accounts receivables = Rs 100 cr

Inventory = Rs 40 cr

Find the Inventory Turnover ratio and Accounts Receivables ratio.

Solution:

$$\text{Inventory Turnover ratio} = \frac{\text{Sales}}{\text{Inventory}} = \frac{200}{40} = 5$$

$$\text{Accounts Receivables ratio} = \frac{\text{Sales}}{\text{Accounts Receivables}} = \frac{200}{100} = 2$$

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Check Your Progress

1. Show the transformation process of your management institute.
2. What are the main objectives of production and operations management?
3. List the major areas of work of a production manager or operations manager.
4. What does value addition mean, in the context of production and operations management?

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Example 2

Company B produces 500 pieces of a product in a month at a cost of 270 per piece. If the labour cost was Rs 90, material cost Rs 130 and overheads Rs 30, find the total productivity of CompanyB.

Solution:

$$\text{Productivity} = \frac{\text{Total cost of production}}{\text{Labour + material + overheads}} = \frac{270}{90+130+30} = 1.08$$

A productivity measure represents or reflects the overall capability of a company. Sometimes the Management focuses on one of the aspects, such as labour or materials or capital or assets. It helps them to find out how effectively that factor is performing. It can then find out the productivity of factors such as labour productivity, materials productivity, energy productivity, etc. This is called 'Multi factor Productivity.'

Example 3

Study the table given below for Company C:

All figures in Rs lakh

Output		**Input**	
Finished Units	10,000	Human	3,000
WIP	2,500	Material	5,530
Dividend	1,000	Capital	4,923
		Energy	540
		Other Expenses	1,200
Total	13,500	**Total**	15,193

Find the Total Productivity, Labour, Materials and Energy Productivity.

Solution:

$$\text{Total Productivity} = \frac{13,500}{15,193} = 0.89$$

$$\text{Labour Productivity} = \frac{13,500}{3,000} = 4.5$$

$$\text{Materials Productivity} = \frac{13,500}{5,530} = 2.44$$

$$\text{Energy Productivity} = \frac{13,500}{540} = 25$$

1.10 SUMMARY

In this unit, you have learned what is production and operations management, how it all began, and the different eras of development of this branch of management. This unit also explained the difference between production and operations management, the fundamental production process comprising input, transformation process and output. You have further learned about the differences between goods and services. The unit explained why production is called the heart of an organization and explained the objectives and scope of production and operations management.

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1.11 KEY TERMS

- **Production and operations management:** Production and operations management is concerned with the production of goods and services and is responsible for ensuring that these operations are efficient and effective.
- **Input:** It includes the 6 Ms, i.e., man, machine, materials, money, method and now management.
- **Transformation process:** This is the process by which the inputs are converted into output. It is a value addition process that modifies or adds value to the input and converts it into a form that is more useful and can be sold to a customer.
- **Output:** It can be a good/product or a service.
- **Customer satisfaction:** Customer satisfaction is vital to the survival of an organization. The organization researches the expectations of the customer or service to be rendered and decides on the product.
- **Profitability:** The pricing of the product should be competitive to achieve sales. For this, the market price of products should be competitive and commensurate with the features offered in the product.
- **Product selection and development:** This deals with the study of how a product is selected and developed for commercial production.
- **Process selection:** It deals with how the process required to produce a product is selected for commercial production.
- **Facilities location:** It deals with the parameters that are to be considered for locating a factory premise.
- **Layout planning:** It deals with the study of how the factory/plant is to be laid out for the most optimum production.
- **Material handling:** It deals with the study of significance of material flow in an organization, the different methods of material handling, etc.
- **Manufacturing system:** It deals with the study of the different types of manufacturing systems and their applicability.
- **Production planning and production contro**l: It deals with the methods followed in different kinds of manufacturing systems. This includes methods followed for job loading, scheduling, dispatching, PERT/CPM, linear programming, etc.
- **Work studies:** It deals with method study and work measurement.
- **Materials management**: It deals with methods to control inventory, inventory analysis, etc.
- **Quality:** It deals with standards and techniques, TQM, six sigma, etc.
- **Safety managemen**t: It deals with principles, methods, etc.
- **Productivity:** It is a measure of the quantity of output per unit of input.

- **Efficiency:** It means doing something at the lowest possible cost.
- **Effectiveness:** It means doing the right thing to create the most value for the company.

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1.12 ANSWERS TO 'CHECK YOUR PROGRESS'

1. For any educational institute, it will be as follows:

   INPUT: OHP, books, computers, etc.

   PROCESS: Lectures, seminars, project work, assignment, educational tours.

   OUTPUT: Graduates, students with good inter-personal skills, leadership qualities, good management skills.

   FEEDBACK: Tests / exam, alumni association, placement.

   RANDOM DISTURBANCES: Strikes, government notification, sealing of premises, resignation of faculty.

2. The main objectives are:
   a. **Customer satisfaction:** The organization researches the expectations of the customer from the product or service to be rendered and decides on the product. An organization can survive only if its products satisfy the customer on the following criteria:
      - Quality of the product as per the acceptable standards
      - Easy maintenance and reliability of the product
      - Functionality of the product as offered by the seller

   b. **Profitability:** A good organization produces the right quality that meets all product specifications, at optimal cost. The organization should focus on minimizing costs and maximizing revenue for good profitability. The product should be competitive in the market place, to achieve sales.

   c. **Timeliness:** The product produced or service rendered must reach the consumers when they require it. The consumer does not wait for a good or service: he acquires it from a competitor. Therefore, Production and Operation Management plays a vital role in providing the product or service on time by effectively maintaining production schedules.

   Besides producing the product/service of the right quality in right quantities at the right time and at minimal costs, the organization should also ensure that there is no wastage in the system whatsoever because these wastes result in cost escalations and severe delays.

3. The major areas of work of a production manager are:
   - Product selection and development – This deals with the study of how a product is selected and developed for commercial production.
   - Process selection – It deals with how the process required to make a product is selected for commercial production.
   - Facilities location – What parameters are to be considered for locating a factory premise.
   - Layout planning – It deals with the study of how the factory/plant is to be laid out for the most optimum production.

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- Material handling – It deals with the study of significance of material flow in an organization, the different methods of material handling, etc.
- Manufacturing system – Study of the different types of manufacturing systems and their applicability.
- Production planning and production control – Study of the different methods followed in different manufacturing systems. This includes methods followed for job loading, scheduling, dispatching, PERT /CPM, Linear programming, etc.
- Work studies – Method study and work measurement.
- Materials management
- Quality – Standards and techniques, TQM, six sigma, etc.
- Safety management – Principles, methods, etc.

4. In a production process, the inputs are converted into output. It is a value addition process which modifies or adds value to the input and converts it into a form that is more useful and sold to a customer. This is called value addition and can happen by the following:
   - Alteration: This includes all the activities such as change in the physical state of input, changing dimensions, adding chemicals, heating, rolling, galvanizing, etc. The methods of transformation are numerous and there is one distinct method for every available product in the market.
   - Transportation: This refers to the physical movement of goods from one place to another. Some firms, especially traders specialize in buying goods from one place (usually the place of manufacture) and transporting them to a location where they can be sold.
   - Storage: This refers to preserving the goods in a protected environment so that they can be made available at a later date. for example food grains. This is also a kind of transformation process.

Value addition can also happen by inspection, by transportation companies, book publishers, etc.

Every product has a unique method of value addition.

1.13 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is the difference between goods and services?
2. How has technology helped in establishing production?
3. What is production?
4. Why are services considered a part of production and operations management?

Long-Answer Questions

1. What do you understand by the statement ‘production is the heart of an organization’?
2. What do you understand by production and operations management? Explain.
3. What is the relevance of technology in a production environment? Explain.

1.14 FURTHER READING

NOTES

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Evans, J.R., D.R. Anderson, D.J. Sweeney and T.A. Williams. 1984. *Applied Production and Operation Management.* St. Paul MN, US: West Publishing Co.

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UNIT 2 MANUFACTURING SYSTEMS

NOTES

Structure

2.0 INTRODUCTION

We all know that the taste of food depends not only on the ingredients, i.e. the raw materials, but also on the way it is cooked, i.e. the process. So, what is a process? A process is a sequence of steps that transforms input into output, adds value to it, and converts it into a form that sells in the market. It merges input from the market environment and the organization's own technological base into an economically efficient productive activity.

Every process has its own set of objectives, which involves a workflow cutting across departmental boundaries and requires resources and information from several agencies, such as marketing, R&D, operations, etc. It also requires coordination among many agencies in order to churn out the products of the organization.

2.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand the need for process design and process selection
- Know the classification of processes
- Describe the parameters of process design and process selection
- Explain competitive priorities
- Understand manufacturing systems
- Discuss the product-process matrix

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2.2 NEED FOR PROCESS DESIGN AND PROCESS SELECTION

We know that a process involves the use of organization's resources to provide something of value to the customer. No product can be made nor can a service be provided without a process, and vice versa i.e. no process can exist without at least one service or product.

An organization is as effective as its processes. Every process is designed with a focus on the 'customer'. Some customers are external, i.e., they are the buyers or end users of the firm's finished products and services. Other customers are 'internal' i.e., they are employees or processes which rely on the output of the present process. Every process has an internal and external supplier. External suppliers are businesses or individuals outside the firm, who provide the necessary inputs for the firm's needs. Internal suppliers are within the firm, who also provide the inputs for a particular process's needs.

So far we have learnt that a process decides how the input will be converted into output. We have also learnt that it is a cross functional effort and that the success of the firm depends on the performance of its core and supporting processes.

2.3 CLASSIFICATION OF PROCESSES

In this section you will learn about the various ways in which processes can be categorized.

2.3.1 On the Basis of Number of Steps

In their simplest form, processes can be categorized on the basis of the number of steps that they follow.

(a) *Single Stage Process*

A simple stage process is one in which the input goes through a single stage. This system is too simplistic and is not found in the industrial scenario. (Figure 2.1)

Fig. 2.1 *Single Stage Process*

(b) *Multi-Stage Process*

A multi-stage process has several steps or stages and the raw material flows through these steps in a particular sequence to give the final product. (Figure 2.2)

Fig. 2.2 *Multi-stage Process*

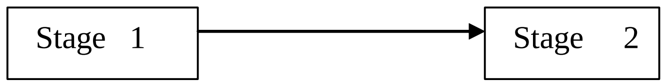
Before we study further, let us understand some commonly used terms in this topic.

(i) **Buffering:** This refers to the storage activity between two successive stages. When the output at one stage is stored for sometime before it passes over as input to the next stage, it is called buffering. It helps two consecutive stages to be decoupled or delinked so that if one stage breaks down, for sometime at least the successive stage can continue working using the buffer stock.

(ii) **Blocking:** When the buffer becomes so high that there is no more place to stock, the production of this stage has to stop. Besides lack of space, management can decide to block production of a stage for some other reasons.

(iii) **Starving:** If activities of a stage have to stop because there is no output of the previous stage available, it is called starving.

(iv) **Bottleneck:** Consider a process of two stages:



Let the output of Stage1 be 8 units per hour and the input for Stage 2 be 6 units per hour. What will happen? Every hour, 2 units will be added to the buffer stock. This will continue till a stage is reached when it is decided to stop production of Stage 1.

On the other hand, if the input capacity of Stage 2 is 10 units per hour. Then what will happen? Every hour, Stage 2 will remain idle or starve for some time since it receives only 8 units per hour, against its requirement of 10 units per hour.

Both these situations are called **bottlenecks** because they limit the capacity of the system. The capacity in such processes becomes the capacity of the slowest stage in the process.

(v) **Simultaneous Activities:** Often a process contains several stages that act simultaneously. They are represented as shown in Figure 2.3.

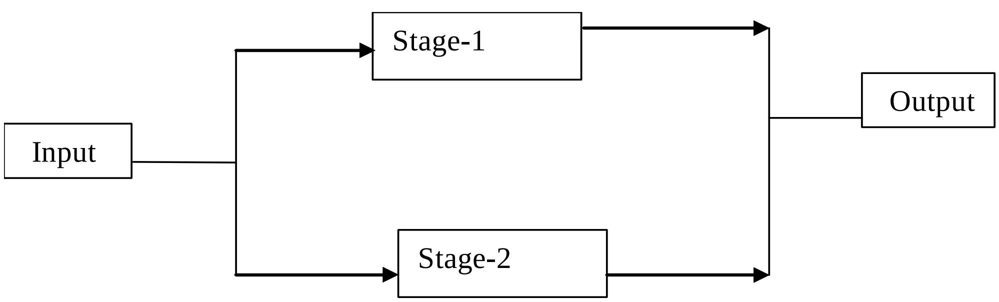


Fig. 2.3(a) *Simultaneous Activity*

This is one kind of simultaneous activity. Another kind of simultaneous activity is where different products are produced.

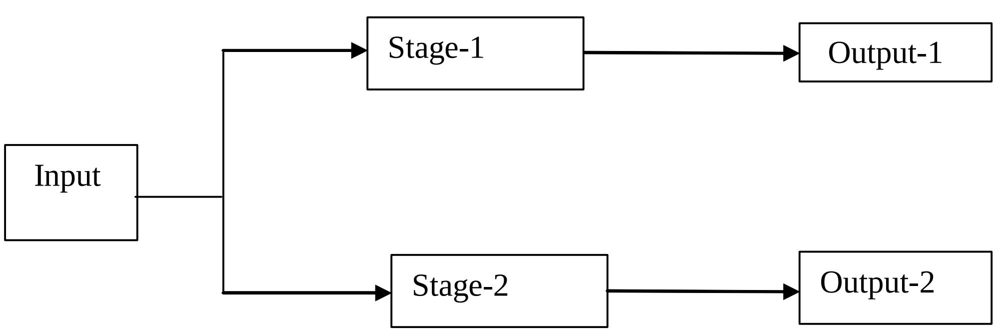


Fig. 2.3(b) *Simultaneous Activity*

2.3.2 On the Basis of 'Made to Stock' or 'Made to Order'

Another way of classifying processes is to say whether the processes are 'Made to Stock' or 'Made to Order'.

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(a) In a **'Made to Order'** process, production starts only when an order is received. The company produces the goods as and when the order is received. Typical examples are making of an aeroplane, activities in a fast food restaurant, etc.

(b) But in a '**Made to Stock'** scenario, the manufacturer makes the goods and pushes them into the market in anticipation of sale. The consumer durable goods industry works predominantly in this method.

However, nowadays, most of the activities are **'hybrid',** i.e., the processes are part 'Made to Order' and part 'Made to Stock'. A generic product is made and stocked at some point. This is the work in progress. This is 'Made to Stock'. As and when an order is received, these generic units are finished in a final process and it then becomes a 'Made to Order' product. We see this typically in any restaurant. The ingredients (chutneys, gravy, rice, dough, etc.) are prepared and kept ready. As and when the customer order is received, the ingredients are mixed appropriately, heated and served to the customer. Similarly, an automobiles manufacturer makes the cars. As per the customer's requirements, the fittings such as wheel caps, mirrors, seat covers, etc. are fitted and delivered to the customer.

2.4 PARAMETERS OF PROCESS DESIGN AND PROCESS SELECTION

Process selection depends on a variety of economic, quantitative and qualitative factors. The most suitable production process is the one which meets the following criteria:

1. All specifications for the product are met while maintaining a desirable quality standard.
2. The cost of production is feasible to produce the product.
3. The process is sustainable, i.e., it is dependable to produce for the estimated duration.
4. All environmental and government regulations are followed.

2.5 COMPETITIVE PRIORITIES

Every process must possess certain critical dimensions, which will help to satisfy its internal and external customers, now and in the future. These critical dimensions are called Competitive Priorities**.** The four major competitive priorities of any firm are:

(a) Cost

(b) Time

(c) Quality

(d) Flexibility

Let us understand each of these in detail.

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(a) **Cost**

Lowering costs will increase demand and sales while increasing cost will improve profits but will eat into sales. So the organization needs to arrive at a process wherein the cost is the most optimum. This is arrived at by several methods such as process redesign, scrap or rework, workforce optimization, automation, etc. Firms should aim to achieve 'Low cost operations', i.e., produce goods and services at the lowest possible cost to the satisfaction of the firms' internal and external customers.

The efficiency of a production process is determined by its ability to produce the required quality and quantity at the minimal costs. This is best achieved when the products are produced in large volumes. But again the decision on volumes to be produced is based on the demand for that product in the market and sales estimation from the marketing department. Depending on the volume, the management must select the process that is most feasible for producing the required volume of the required quality at the least cost.

(b) **Time**

Time is money. The more a company delays in giving out its deliverables, more does it lose in terms of customers, goodwill, demurrages, etc. Processes should be so designed that the product reaches the market at the quickest possible time. This is possible only if the managers carefully define the steps and the time needed to deliver a product or service, and then analyse each step to determine whether or not they can save time without reducing quality. Process time is vital in the following situations –

- **Deliveries –** The time taken to deliver and order from the moment the order is placed is called delivery lead time. Companies try to reduce lead time as much as possible by improving processes, reducing delays in the process, removing buffers, etc. The consumer demand and expectation from a product in the current market scenario changes quickly. If there is a delay in the product reaching the market, consumers may shift to other brands or purchase a competitor's products that are available in the market. The demand for the product will then fall. So it is critical that the right production process is chosen so that the product can reach the market within the stipulated time frame. On-time deliveries (i.e., meeting delivery time promises) has become an important parameter for judging the effectiveness of services such as airlines, railways, etc. Dominos, the pizza chain is constantly improving processes so that it can deliver within 30 minutes of placement of order!
- **Product Development –** In this rapidly changing business environment, getting a product to the market first, ahead of the competitors' has many advantages for a firm. Time taken between idea generation and product development should be as little as possible. Processes selected should be such that the process of product development is fast, accurate and efficient.

(c) **Quality**

Quality means conformance to customer's requirements. Consistent quality means the ability of a firm to produce the same set of goods consistently, meeting the prescribed specifications every time. Process selected should be such that it produces the goods and services of the same specifications every time, under identical conditions. We will read more about quality in the succeeding units.

NOTES

Volume and variety of the products to be produced is significant. If the variety is more but the volumes are less than the variety, management must try to reduce fixed costs even though the variable costs will rise on account of more variety. If the required volume for the product to be produced is high and the variety is less, fixed cost can rise but variable costs will not be very high.

(d) **Flexibility**

Flexibility means the ability of a firm to react to the customers' changing needs quickly and efficiently. Flexibility can be in terms of changing volumes, changing varieties or customization.

- **Volume flexibility** is most common and involves accelerating or decelerating the rate of production to take care of fluctuations in demand. It often supports other competitive priorities such as delivery speed or development speed. Processes must be so selected that they can handle variation in volumes quickly.
- **Variety flexibility** means the ability to handle an assortment of products efficiently. Processes with variety flexibility should be able to focus on the needs of the customers and efficiently shift their focus across a variety of products and services.
- **Customization** is slightly different from variety flexibility in the sense that customization refers to the unique needs of a specific customer. Such products are usually 'tailor made', i.e., they cannot be sold elsewhere in the market; they are more expensive and generally have longer lead times. A process that has customization priority should be able to work closely with its customers and satisfy their unique needs.

We can say that there is nothing like a best production process that should be followed. We should arrive at the best production process by considering various options and adopting the most suitable ones, under the given circumstances. The right choice would be to choose a process that meets the maximum specifications and constraints within the cost permissible, keeping competition into consideration.

2.6 ADOPTION OF APPROPRIATE TECHNOLOGY AS PER MARKET REQUIREMENTS

When an entrepreneur decides to manufacture a product or deliver a service, he first needs to select an appropriate technology for the same. A consideration of the competitive priorities is a useful strategy to translate the goals of the company to the level of the processes that actually do the work. We have already learnt that in a business transaction, competitive priorities reflect what external customer considers important. This is essential, because a firm has to not only retain its current business but win future business. Appropriate competitive priorities must be assigned to the firm's core and supporting processes that not only reflect the needs of external customers but of internal customers as well, and at the same time help it to sustain in the market.

To get a better understanding of how competitive priorities are used, let us study the services of an airline. We will consider two market segments: (i) first class passengers and (ii) economy class passengers. The core services for both these market segments are the same: ticketing and seat selection, baggage handling and transportation to the customer's destination. However, the peripheral services for these two categories are quite different.

A first class passenger gets (i) a higher baggage allowance; (ii) separate airport lounges; (iii) preferred treatment during check-in, boarding, and deplaning; (iv) more comfortable seats; (v) better meals and beverages; (vi) a higher level of personal attention (by cabin attendants who address them by name) and courtesy; (vii) frequently attended to – at a higher price, of course. All these add to the feeling of being special.

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Economy class passengers, on the other hand, are satisfied with standardized services, courteous flight attendants, and low prices.

Both market segments, however, expect the airline to keep to its schedules and perform on-time every time. Therefore, we can say that the competitive priorities for the first class segment is top quality and on-time delivery, whereas the competitive priorities for the economy class market segment are low cost operations, consistent quality, and on-time delivery.

The airline knows its market segments as well as its requirements. The job is now to correlate its capabilities with customer requirements. The airline cannot adopt the same parameters for both segments. Serving a three-course meal to an economy class traveller is not going to please him since he is looking for low cost travel. Similarly, a first class traveller will not like to wait in queue to board the aircraft.

This situation is the same for any other manufacturing organization. Every organization, whether a manufacturer or a service provider, needs to first analyse its core processes. The commonly considered core processes are customer relationship, new service/product development, order fulfilment, and supplier relationship.

Every core generally process has many nested processes within it; for example, customer relationship would mean top quality/consistent quality, timeliness, variety, etc. New service/product development would include customization, speedy development, and so on. Order fulfilment would include low-cost operations, on-time deliveries, etc., and supplier relationship would include quality, delivery, variety and low cost.

Competitive priorities are assigned to each core process in order to achieve the service levels required to ensure complete customer satisfaction.

We can say that there is nothing like a best production process that should be followed: we should arrive at the best production process by considering all the options and then adopting the most suitable one, under the given circumstances. The right choice would be to select a process that meets the maximum specifications and constraints within the permissible cost, and keeping competition in consideration.

2.7 PROCESS DESIGN AND SELECTION

Planning for manufacturing begins with an idea and proceeds through product development. A common way of defining a product is by drawing it. In an **assembly drawing**, the individual components of a product and their relationships to one another are shown. Detailed engineering drawings provide the necessary technical specifications for in-house manufacturing personnel, as well as for purchasing agents who are authorized to procure the item from a vendor. Such drawings are also useful for inspecting finished parts to determine if they confirm to specifications.

A **parts list** is then made. This provides detailed technical information that is not found in an assembly drawing. A parts list includes such information as part numbers, names, whether the part is manufactured or bought, and a detailed engineering drawing number. Parts list also contains parts dimensions, material specifications, and other manufacturing information.

NOTES

Drawings and parts lists together determine what materials and machines are required. As consumers, we often find assembly drawings packed along with assembly instructions for a product which needs to be assembled by the consumer.

2.7.1 Process Design

The next step is **Process Design.** *It refers to the selection of inputs, resources, workflows and methods needed to transform inputs to outputs.* Process design decision also deals with the mix of human skills and machines and which processes are to be performed by whom. Decision about processes must be consistent with the competitive priorities of the firm and the firm's ability to obtain the resources necessary to support them. Besides these parameters, process design decisions also take into account other choices such as quality, capacity, layout and inventory.

The objective of process design is to determine how the physical resources of a firm can be best organized; for example, one way of describing a factory is in terms of units called **work centres**. A work centre can be a single machine or group of machines in one location, a group of workers who perform a similar task or closely related set of tasks (such as on an assembly line), or a set of different machines that function together to perform a set of operations on one or more products.

Product design also affects the flexibility of a firm to adapt to changes in product mix or volume, the amount of control required in planning and scheduling and a variety of work force related management issues.

The next stage is **Process technology.** It refers to the process of determining the methods and equipment needed to manufacture the product. It is an essential component of the organization's manufacturing strategy.

2.7.2 Process Selection

Process Design and Process Technology determine **Process Selection**. *The latter is the way by which processes must be selected such that it meets the competitive priorities of the firm, viz. Cost, Time, Quality and Flexibility and is also able to meet the financial and other constraints of the firm.*

The issues involved in process selection can be classified under two headings-

(a) Technical

(b) Managerial

Technical issues in process selection

They include the following:

(i) The volume and variety of the products required

(ii) Specification of equipment for converting inputs to outputs

(iii) The physical transformation of materials— i.e., how the process works

(iv) Rate of output required and the rate of output that the process can achieve

(v) Short term and long term economics of the process

(vi) Ability of the process to meet design specifications and achieve consistent quality

(vii) Reliability of the process

Managerial issues in process selection

They include the following:

(i) Anticipating and Mistake proofing – making a list of things that can go wrong

(ii) Estimating manpower requirement

(iii) Training manpower

(iv) Work studies

(v) Maintenance requirements

(vi) Simulation – to study how the process reacts to change

(vii) Assessment – Can the process meet strategic goals and objectives and also give the firm a competitive edge?

(viii) Compatibility – Is it unique or compatible with other existing products in the market?

Both technical and managerial issues need to be considered in making process decisions. A narrow technical perspective can often lead to operating problems. When Apple Macintosh introduced the personal computer, it was acknowledged that the 32-bit processor and high-resolution graphics capability was superior to that of the existing products of the time. But its major drawback was that it was not compatible with the existing applications software. Hence, it could not succeed. On the other hand, having good managerial abilities but a technically weak product to sell can also result in failure of the organization. For an organization to be successful, Process-selection decisions must incorporate both technical and managerial viewpoints..

2.8 MANUFACTURING SYSTEMS OR PRODUCTION SYSTEMS

Production systems or manufacturing systems convert inputs into goods that have a physical form. This value addition can happen in any of the ways as stated in Unit 1. Depending on the kind of manufacturing process adopted for converting the input into output, we can classify them into certain major groups, as shown in Figure 2.4.

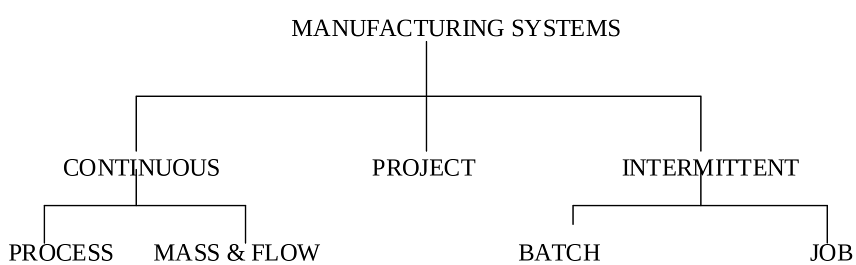

Fig. 2.4 *Classification of Manufacturing Systems*

Let us now learn about each of these systems.

2.8.1 Continuous Production System

It involves a continuous or almost continuous physical flow of material. It makes use of special purpose machines and produces standardized items in large quantities. The processes usually operate round-the-clock to maximize utilizations and to avoid expensive and time consuming shutdowns and start-ups.

NOTES

Characteristics of continuous production system

1. Standard products are manufactured, which have large demand throughout the year. Production is usually 'Made to stock'.
2. Standardized inputs and standardized sequence of operations, machine tools and equipment are used.
3. Division of labour is efficient and less supervision is required since the same or similar products are always produced.
4. Inventories are low and Material handling can be streamlined. It will be lower than intermittent manufacturing system.
5. There is a balanced flow of work. This will result in small work in progress.

Advantages of continuous production system

1. Reduced labour cost because highly skilled workers are not generally required. Also, division of labour and job rotation is possible.
2. Once systems are set, strict supervision is not required since system takes care of itself.
3. High volumes of production, so cost is low.
4. Low inventories and reduced material handling.
5. Minimum wastage seen as products are standardized.
6. Possible to use all the techniques of Production control, material control/inventory, maintenance systems, etc.

Disadvantages of continuous production system

1. Strict maintenance is necessary to avoid production hold-ups.
2. Adjusting to fluctuating demand is difficult as it takes time and capital investment.
3. Huge capital investment.
4. Cannot make sudden or frequent changes in the Production schedules since system is not flexible.

The two types of continuous production system are:

(a) Process Production, and
(b) Mass or Flow Production.

(a) **Process Production**: Its name is derived from the way materials move through the process. This system is used for manufacturing items for which the demand is continuous or high. Here, a single raw material can be transformed into different kinds of products at different stages of the production process. Examples include petroleum refining – different fractions, viz. kerosene, gasoline, etc., are recovered during the process of fractional distillation and steel making (e.g., Integrated steel plants of SAIL).

(b) **Mass or Flow Production**: Few types of products are manufactured in large quantities. The volumes are high and products are standardized which allows resources to be organized around particular products. Standardization of products, processes, materials, machines and uninterrupted flow of materials are the main characteristics of this system. It lies between Process production and batch production. Examples include automobiles, appliances, computers, etc.

2.8.2 Intermittent Production System

In this system, the goods are generally manufactured to fulfill customers' orders rather than producing against stock. The flow of materials is intermittent. The production facilities are flexible enough to handle a wide variety of products and sizes. Considerable storage between operations is seen.– Individual operations are usually carried out independent of the preceding and succeeding operations.

NOTES

Characteristics of intermittent production system

1. Products are manufactured in small quantities.
2. Variety of products is high.
3. Highly skilled workers are required.
4. Large work in progress.
5. System has high flexibility since variety and volume of products keep changing.
6. Unbalanced workloads, since workload depends on the work in hand.

Advantages of intermittent production system

1. Can adjust to new situations and specifications and fluctuation in demand can easily be taken care of.
2. Initial investment is not very high compared to continuous production.

Disadvantages of intermittent production system

1. As production is in small quantities, the cost of production per unit is high. This makes the product costly.
2. Skilled people are required for each operation. So labour cost is high.
3. More inventory, high work in progress and large storage space are required.

The two types of intermittent production systems are (a) Job production, and (b) Batch production.

(a) **Job production**: Job Production is the production of a wide variety of products in relatively low quantities; customization is high, there is considerable complexity and divergence in the steps performed in production, thereby creating a jumbled flow rather than a line flow. The system requires versatile and highly skilled labour with high capital investment.

Examples – machining a metal casting, producing customized shelves and cabinets.

(b) **Batch production**: Here, items are processed in lots or batches and a new batch is undertaken for production only when the production on all items of a batch is complete.

In fact, batch type production can be considered as an extension of job type system. An example is the chemical industry where different medicines are manufactured in batches. Other examples include production of machine tools, printing press, etc.

2.8.3 Differences between Continuous and Intermittent Production Systems

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Continuous Production	Intermittent Production
1. There is continuous flow of raw material. 2. It is 'Made to Stock'. 3. It is not flexible – change in the process takes time and involves huge investment. 4. Cost of labour is low. 5. Has low work in progress. 6. High division of labour, lesser supervision required. 7. Lesser inventories and lesser material handling. 8. Huge capital investment required.	1. The flow of raw material is in batches or lots. 2. It is 'Made to Order'. 3. It is highly flexible. 4. Cost of labour is very high. 5. Has high work in progress. 6. High supervision and high skill set are required. 7. High inventories and plenty of material handling are required. 8. Capital investment is relatively low.

2.8.4 Project Process

A project process is one in which there is a very high degree of customization and the job is undertaken to meet specific requirements. Each project is unique. For each project the sequence of steps or process flows is defined. Project processes are valued more on the basis of their capabilities to do certain kinds of jobs, rather than to produce specific products at low cost. They tend to take a long time and involve several interrelated tasks that must be completed. This requires close coordination. Resources needed for a project are brought together at the beginning of the project and are disbanded once the project is over.

Examples: Construction of bridges, aeroplanes, etc.

2.9 PRODUCT-PROCESS MATRIX

There is no one method for selecting a production process. The production method selected should be such that it blends the marketing and manufacturing strategies.

Every method has its own pros and cons but the technology or method selected should be able to fulfil the following objectives –

- Minimize cost
- Maximize output
- Provide consistent quality

A **Product-Process Matrix** determines how the appropriate technology or manufacturing process must be selected. The matrix has three parameters (see Figure 2.5)

- Volume
- Product design
- Process

Check Your Progress

1. What is a 'process?'
2. What do you understand by the competitive proirities of an organization?
3. Tabulate the main differences between continuous and intermittent manufacturing systems.

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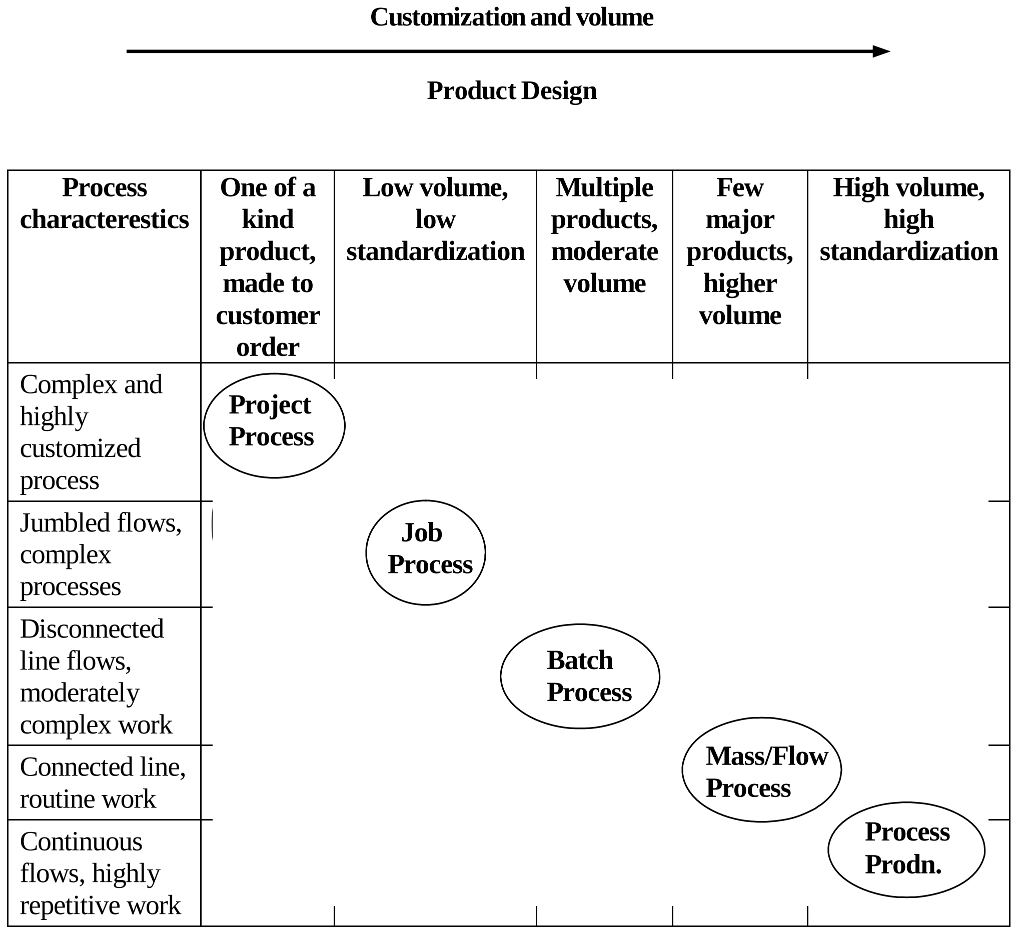

Fig. 2.5 *Product-Process Matrix*

The above matrix shows that there are several process choices for a product. This matrix can be applied either to the entire manufacturing process or to one specific sub-process within the manufacturing process.

From the above matrix, we can see that the number of varieties required to be produced and the volume of each variety influences the choice of production method. High product variety requires highly skilled labour, well-equipped and adaptable machines and good amount of planning and controlling. So Job or Batch process is suitable. Low product variety and high volumes requires low skilled labour, high automation and somewhat lesser planning and controlling. So Mass or Process Production system must be selected.

It is also possible for a company to choose another position on the matrix. For example, suppose Honda Motor Company announces a redesign of its assembly lines so that any model can be produced. This redesign will mean that with more flexible lines, it will not be able to produce at the high volumes produced earlier. This situation of lower volume with higher variety of products corresponds to a horizontal move from Line Process to Batch Process.

2.10 SUMMARY

In this unit, you have learned about the need for process design and process selection. The latter involves the use of an organization's resources to provide something of value

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to the customer. You have also learned about the various ways in which processes can be categorized. Process selection depends on a variety of economic, qualitative and quantitative factors. You have also learned that every process must assess the critical dimensions that help to satisfy its internal and external customers, now and in the future. In this unit, you have also studied about process design and selection process, as well as manufacturing systems. Finally, you have learned about the product-process matrix. The latter determines how an appropriate technology or manufacturing process must be selected.

2.11 KEY TERMS

- **Single stage process:** A simple stage process is one in which the input goes through a single stage.
- **Multi-stage process:** A multi-stage process has several steps or stages and the raw material flows through these steps in a particular sequence to give the final product.
- **Buffering:** This refers to the storage activity between two successive stages. When the output at one stage is stored for sometime before it passes over as input to the next stage, it is called buffering.
- **Blocking:** When the buffer becomes so high that there is no more place to stock, the production of this stage has to stop. Besides lack of space, management can decide to block production of a stage for some other reasons.
- **Starving:** If activities of a stage have to stop because there is no output of the previous stage available, it is called starving.
- **Made to order:** In a ‘Made to Order’ process, production starts only when an order is received. The company produces the goods as and when the order is received.
- **Made to stock:** In a ‘Made to Stock’ scenario, the manufacturer makes the goods and pushes them into the market in anticipation of sale. The consumer durable goods industry works predominantly in this method.
- **Competitive priorities:** Every process must possess certain critical dimensions, which will help to satisfy its internal and external customers, now and in the future. These critical dimensions are called competitive priorities.
- **Volume flexibility:** This involves accelerating or decelerating the rate of production to take care of fluctuations in demand. It often supports other competitive priorities such as delivery speed or development speed.
- **Variety flexibility:** This means the ability to handle an assortment of products efficiently.
- **Assembly drawing:** In an assembly drawing, the individual components of a product and their relationships to one another are shown.
- **Parts list:** A parts list provides detailed technical information that is not found in an assembly drawing.
- **Process design:** This refers to selection of inputs, resources, workflows and methods needed to transform inputs into outputs.
- **Process technology**: This refers to the process of determining the methods and equipment needed to manufacture the product.

- **Continuous production system:** It involves a continuous or almost continuous physical flow of material.
- **Process production:** Its name is derived from the way materials move through the process. This system is used for manufacturing items for which the demand is continuous or high.
- **Mass or flow production**: In this few types of products are manufactured in large quantities.
- **Job production:** Job production is the production of a wide variety of products in relatively low quantities; customization is high, there is considerable complexity and divergence in the steps performed in production, thereby creating a jumbled flow rather than a line flow.
- **Batch production:** Here, items are processed in lots or batches and a new batch is undertaken for production only when the production on all items of a batch is complete.
- **Project process:** A project process is one in which there is a very high degree of customization and the job is undertaken to meet specific requirements.
- **Product-process matrix:** A product-process matrix determines how the appropriate technology or manufacturing process must be selected.

2.12 ANSWERS TO 'CHECK YOUR PROGRESS'

1. A process is any sequence of steps that transforms inputs into outputs, adds value to it and makes it in a form that sells in the market. It merges input from the market environment and the organization's own technological base into an economically efficient productive activity. Every process has its own set of objectives, involves workflow cutting across departmental boundaries and requires resources from several agencies. A process involves the use of organizations' resources to provide something of value to the customer. No product can be made nor can any service be provided without a process, and vice versa, i.e., no process can exist without at least one service or product.
2. Every process must possess certain critical dimensions, which will help to satisfy its internal and external customers, now and in the future. These critical dimensions are called competitive priorities. The four major competitive priorities of any firm are –
   (a) Cost: We need to arrive at that process wherein the cost is the most optimum. Firms should aim to achieve 'Low cost operations', i.e., produce goods and services at the lowest possible cost to the satisfaction of the firms' internal and external customers.
   (b) Time: Processes should be so designed that the product reaches the market in the quickest possible time. Companies try to reduce lead time as much as possible by improving processes, reducing delays in the process, removing buffers, etc. In this rapidly changing business environment, getting a product to the market first, ahead of the competitors has many advantages for a firm,
   (c) Quality: Process selected should be such that it produces the goods and services of the same specifications every time, under identical conditions. Volume and variety of the products to be produced is very significant.

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(d) Flexibility: Flexibility means the ability of a firm to react to the customers' changing needs quickly and efficiently. Flexibility can be in terms of changing volumes, changing varieties or customization.

3.

Continuous Production	Intermittent Production
1. There is continuous flow of raw material. 2. It is 'Made to Stock'. 3. It is not flexible – change in the process takes time and involves huge investment. 4. Cost of labour is low. 5. Has low work in progress. 6. High division of labour, lesser supervision required. 7. Lesser inventories and lesser material handling. 8. Huge capital investment required.	1. The flow of raw material is in batches or lots. 2. It is 'Made to Order'. 3. It is highly flexible. 4. Cost of labour is very high. 5. Has high work in progress. 6. High supervision and high skill set are required. 7. High inventories and plenty of material handling are required. 8. Capital investment is relatively low.

2.13 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is the difference between 'Made to Stock' and 'Made to Order'?
2. What are the main parameters to be considered during process selection?
3. Write short notes on:
   (a) Mass and flow type of production systems
   (b) Batch processing
   (c) Product-process matrix
   (d) Process design
   (e) Importance of selecting appropriate production process

Long-Answer Questions

1. What is the product-process matrix? Why is it used?
2. What is the relevance of process selection to the profitability of an organization?
3. What are the competitive priorities that a firm needs to have in order to survive in the market?
4. What is the relevance of 'flexibility' in process selection?

2.14 FURTHER READING

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UNIT 3 PRODUCTION PLANNING AND CONTROL

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Structure

3.0 INTRODUCTION

In the previous unit, you learnt about manufacturing systems. In this unit, you will learn about production planning and control. You will learn how raw materials are converted into finished goods through a process of value addition. You will also learn that these activities are not sporadic. It requires a lot of planning and coordination to ensure that these activities are carried out in a systematic manner so that just the right amount of raw materials are purchased, the right number and type of people are employed, the right kind of operations are done on the right kind of machines, and so on.

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The activities of production need to be controlled at every step so that there is no deviation from the plan.

Production can be divided into two types of activities:

- Production planning
- Production control

You will study each of these in detail, in this unit, including elements of automation, assembly line balancing and production scheduling.

3.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Know what is production planning
- Understand the strategy of production planning
- Describe the main functions of production planning and control
- Explain production control
- Understand the elements of automation
- Discuss the concept of assembly line balancing
- Understand what comprises production scheduling

3.2 WHAT IS PRODUCTION PLANNING?

3.2.1 Types of Plans

In the previous units you have learned about the 5 Ms of a business that form the input – man, machine, materials, money and method. Planning their inputs over a specified period of time so as to get the planned output is the job of 'Production Planning'. Depending on the timeframe of planning, it can be

- **Long-term or strategic planning** – focuses on a horizon greater than one year.
- **Medium-term or intermediate range** – usually covers a period of six to eighteen months. If done annually, it is called aggregate planning.
- **Short term** – routine planning may be daily, weekly or monthly.

3.2.2 Elements of Production Planning

Production planning is a complex activity, encompassing the following: Figure 3.1 show the elements of production planning.

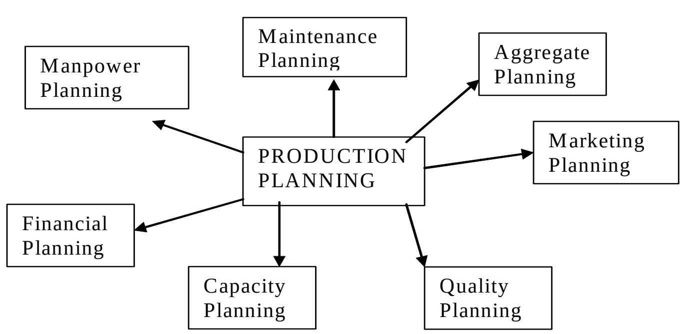

Fig. 3.1 *Elements of Production Planning*

You will learn about manpower planning, capacity planning, maintenance planning, aggregate planning and quality planning.

3.3 STRATEGY OF PRODUCTION PLANNING

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3.3.1 Manpower Planning

There are three parameters that affect the nature of production planning. These are:

- The number of workers
- Utilization of workers
- Size of inventory

Following are the three basic production planning strategies that are based on the above variables. In each of these strategies, one variable is varied and the other two are kept constant.

(a) Level output rate plan

The inventory size is varied keeping the workforce size and utilization of workers constant throughout the time period under consideration. During months of low demand, the excess units produced over demand are accumulated as inventory. This is utilized during periods of high demand. The advantage of this plan is that the cost of hiring and training new workers is zero. Also, the cost of laying off workers is zero, as the workforce size is kept constant. The employee morale is high due to a sense of job security. The disadvantage of this method is that during periods of low demand, there is a high inventory cost due to its large size.

(b) Chase plan

The workforce size is varied according to demand, keeping the utilization of workers and inventory size constant. During periods of low demand, the workforce size is decreased and the extra workers are laid off. Similarly, during periods of high demand, more workers are hired. The hiring and laying off costs are substantial in this plan. Since production is in tune with demand, inventory is almost negligible. During the period of heavy demand, overtime may be required on the part of workers, for which the company incurs overtime cost. The workers' morale could be low due to a sense of insecurity.

(c) Varying utilization plan

The utilization of workers is varied keeping the workforce size and inventory size constant. The number of workers is kept constant in this plan. When demand is low, the workers produce less and have a lot of idle time. On the other hand, when demand is high, the excess units are produced by workers who work overtime. The idle time on the part of workers during months of low demand is a loss to the company, which pays full wages to its employees. On the other hand, the company incurs overtime costs during periods of high demand. Overtime is usually expensive compared to the regular wages given to workers. In addition, excess overtime leads to less efficiency on the part of workers and more accidents due to lack of concentration. Nonetheless , the company saves on inventory costs, which are also negligible, in this plan.

In reality, a combination of these strategies is used in preparing the aggregate production plan. Let us understand how to use a combination of these strategies in the following example.

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Example 1

M/s Cooperative Textiles is a cooperative society that makes bed sheets. A worker makes 100 bed sheets /month. In the month of October, there are 25 workers on the roll. The salary per worker is Rs 4,000/month. The cost of hiring a worker is Rs 500 and a worker who is laid off has to be paid 20 percent of a month's salary. If the forecast for November and December is 2000 and 3000 blankets respectively, prepare a Production Plan. Take the Inventory carrying cost to be Re 1/blanket/month.

Solution:

Case 1: *Chase Plan*

November:

No. of workers required = 2000/100 = 20

Total salary to be paid = Rs 4,000 × 20 = Rs 80,000.

Since there are 25 workers on the roll in October, 5 workers need to be laid off.

Therefore, laying off cost = 20 per cent × 4000 × 5 = Rs 4000/-

Obviously, no worker is hired.

December:

No. of workers required = 3,000/100 = 30

Total salary = 4,000 × 30 = Rs 1,20,000

Since there are 20 workers on the roll in November, 10 more workers need to be hired.

Hiring cost = 500 × 10 = Rs 5000

Lay-off cost = 0

Total Additional Expenditure = Rs 4,000 + 5,000 + 80,000 + 1,20,000= Rs 2,09,000.

Case 2: *Level Output Rate Plan*

If 25 workers are employed in November,

Number of blankets produced = 25 ×100 = 2,500 blankets

Since demand is 2,000, the number of blankets left in inventory = 500

Inventory carrying cost = 10 × 1 × 500 = Rs 5,000

This will be consumed in December as 2,500 blankets will be produced and demand is for 3,000.

Salary in November and December = 4,000 × 25 × 2 = Rs 200,000.

Therefore grand total cost = 2,00,000 + 5,000 = Rs 2,05,000.

Of the two plans, the Level Output Rate Plan costs less, so this method should be used.

Example 2

M/s Advani Castings employs 20 workers at a salary of Rs 2,000/ month per worker. It takes four hours to produce one casting. The cost of hiring a worker is Rs 1,500 and the cost of laying-off a worker is Rs 1,000. (Assume eight working hours per day).Find the total cost.

Month	Apr	May	Jun	Jul	Aug	September
Demand	1000	2340	864	1674	1408	1512
No. of Working days	25	26	24	27	22	18

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Solution:

Case 1

Calculate the number of workers required every month.

E.g. April –

Number of castings produced in April by one worker = 25 × 8/4 = 50

Number of workers required = 1,000/50 = 20

Salary paid = 20 × 2,000 = Rs 40,000

No hiring or laying-off cost.

Similarly calculate for the other months.

Month	Demand	Working days	Men required	Salary	Hiring Cost	Lay-offcost
Apr	1000	25	20	40,000	0	0
May	2340	26	45	90,000	37,500	0
Jun	864	24	18	36,000	0	2000
Jul	1674	27	31	62,000	16,500	0
August	1408	22	32	64,000	18,000	0
Sept	1512	18	42	84,000	33,000	0

Case 2

If in the above example, the number of workers employed should remain constant at 30 and the Inventory Carrying cost is Rs 6/casting/month and Shortage cost is Rs 100/ casting/month then calculate the total cost. Compare the two and suggest which the better method is.

Solution:

Calculate the quantity of castings produced every month.

E.g., April= 30 × 25 × 8/4 = 1,500

The Inventory column is to be filled like this.–

E.g., for May, Inventory from previous month April is 500.

Production in May is 1,560 and Demand for May is 2340

So, 2340 – (1560 + 500) = –280. So, there is a shortage of 280 units.

Month	No. of workers	Qty produced	Demand	Inventory	Inventory Carrying Cost	Shortage cost	Salary
Apr	30	1500	1000	500	3000	0	60,000
May	30	1560	2340	-280	0	28,000	60,000
Jun	30	1440	864	296	1576	0	60,000
Jul	30	1520	1674	242	1452	0	60,000
August	30	1320	1408	154	924	0	60,000
Sept	30	1080	1512	-278	0	27,800	60,000

Total Cost = Salary + Inventory Carrying Cost + Shortage cost = Rs 4,22,752.

The second method is better since the total cost is lesser.

3.3.2 Aggregate Planning

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Aggregate Plan is the total or aggregate plan of a company for producing a product over a certain period of time, say in the next 12 months. Formulation of an **Aggregate Plan** is the starting point for any manufacturing planning and is based on orders expected during the planning period. Various forecasting techniques are used to determine the approximate aggregate demand for the product family. The plan must be firmed up for a reasonable period of time because overall production volume cannot be changed abruptly without incurring significant unplanned costs.

Every production volume utilizes a given mix of labour, materials and equipment. When the output volume is changed, a new optimal mix must be achieved by readjusting the usage of the various resources. Even though it is possible to change in the long run, in the short run, it is difficult to do it efficiently.

A **Master Production Schedule** *is the disaggregating of an aggregate plan. This means it gives information about the number of various models and sub – models of a product planned to be produced in a given duration.* The master production schedule shows the quantity and timing of each specific product for a time horizon.

A master production schedule (MPS) gives details about the quantities and timing of the planned production of every product of an organization. The MPS provides the sales personnel with information about how many units of a product they can commit to customers in a given time period.

Table 3.1 illustrates the difference between Aggregate Plan and Master Production Schedule for a toy manufacturing company.

Table 3.1 *Differences between Aggregate Plan and Master Production Schedule*

Aggregate Plan *Figures in 000*

Apr	***May***	***Jun***	***July***	***August***	***Sept***
300	400	350	375	350	290

Master Production Schedule

Apr	***May***	***Jun***	***July***	***August***	***Sept***
Model A 100	120	110	130	125	90
Model B 100	80	125	125	110	100
Model C 100	100	115	120	115	100

The sum total of the Master Production Schedule will be the Aggregate Plan.

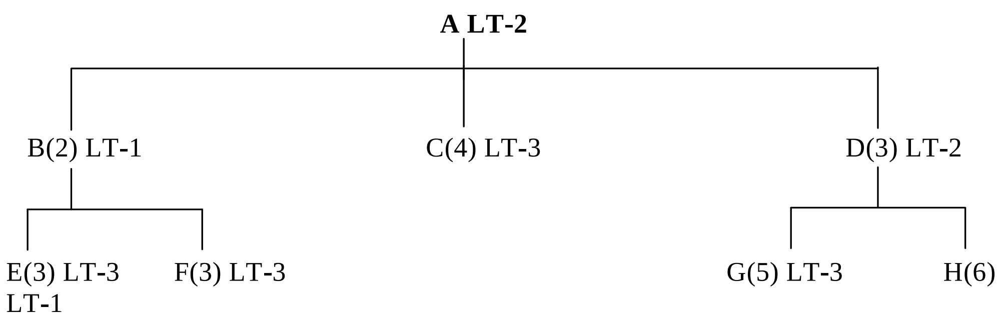
The time interval used in MPS varies from firm to firm. It depends on the type of products used, the volume of production, and the lead times of the materials used. This span of time that the MPS covers is called the **Planning Horizon.** Typically, within the framework of a twelve-month Aggregate Plan, the MPS is updated weekly to reflect changing sales demand and also internal problems which require scheduling.

In Manufacturing, the planning process can be stated as follows:

The production control group inputs existing or forecast orders into an Aggregate Plan. From this, the MPS is derived. The MPS generates the quantities and dates of specific items required for each order. Rough–cut capacity planning then confirms that production and warehouse facilities, equipment, and labour are available and that key vendors have allocated sufficient capacity to provide materials when needed. Then the Material Requirements Plan (MRP) is made. This plan specifies when the products need to be made, what the raw materials are, when and how many are required and when the order should be placed with the vendors. The final planning activity is daily or weekly order scheduling of jobs to specific machines, production lines, or work centres.

Example 3

Study the Product Structure Tree given below. If 100 units of A are to be supplied in eight weeks, prepare the **Bill of Materials** and **Planned Order Releases.**



Solution:

If A is to be ready in 8 weeks, B, C, and D should be ready by the sixth week because it takes 2 weeks to make A.

Similarly, if B has to be ready by the sixth week, E and F should be ready by the fifth week (6 – 1).

G and H should be ready by the fourth week (6 – 2).

Therefore, the order should be placed in 2 weeks (E = 5 – 3)

Now, B has to be ready by the sixth week and it takes one week to make it ready or to buy it. So order for B should be placed in the fifth week.

For 1 unit of A, 2 units of B are required. So for 100 units of A, 200 units of B will be required.

For 1 unit of B, 3 units of E are required. So for 2 units of B, 6 units (2x3) of E will be required.

Calculating for all the items and tabulating them, we get,

Item	*No. reqd.*	*For 100 units of A*	*Lead time*	*To be ready in in week#*	*To be ordered in week#*
A	1	100	2	8	6
B	2	200	1	6	5
C	4	400	3	6	3
D	3	300	2	6	4
E	6	600	3	5	2
F	6	600	3	5	2
G	15	1500	3	4	1
H	18	1800	1	4	3

3.4 MAIN FUNCTIONS OF PRODUCTION PLANNING AND CONTROL

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The main activities encompassing Production Planning and Control (PPC) are as follows-

(a) **Order preparation:** The work of PPC begins once an order is received from the sales department. This order is then converted into a 'work order' or 'shop order' and sent to various departments concerned, for planning action at their end.

(b) **Materials planning:** Once the order is received, the PPC decides on the raw materials required for manufacture, taking into account the capacity of various production shops, the Bill of Materials, inventory on hand, and lead time for procurement.

(c) **Routing (or process olanning):** *Routing means determination of the sequence of operations for manufacturing a product or service.* This path is determined in advance and forms the basis for most of the scheduling and dispatching functions. According to Kimball and Kimball:

'Routing is the selection of path or route over which each piece is to travel in being transformed from raw material into finished product.'

Routing includes the following activities:

- Deciding the volume of production.
- Selecting the men, machines, and materials to be used in its production.
- Deciding the type, number, and sequence of production operations.
- Deciding the place where production is to be carried out.

When routing or process planning is being done, a **Route Sheet** is prepared. This is done in the following manner:

1. The product is analysed w.r.t. its constituent parts. A decision is then taken as what parts are to be manufactured and which are to be purchased.
2. The specifications, grade, quality and quantity of materials to be used in production are determined.
3. The number of manufacturing operations and their sequence is determined and listed on the Route Sheet.
4. The process time for each operation and the type and number of machines necessary to produce are determined.
5. The lot size for production is determined keeping in mind the customers' orders and rejections and spoilage anticipated during the course of manufacturing.

(d) **Estimating**: This involves establishing the operation times for every process; this also leads to fixation of performance standards for both men and machines.

(e) **Scheduling:** According to Spriegal and Lanburgh, '*Scheduling involves establishing the amount of work to be done and the time when each element of work will start or order of the work.*

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Thus, scheduling includes the following activities:

- Determination of quality and rate of output of the plant or department
- Allocation of time for each operation

Scheduling indicates when the work will be released to the plant in a prescribed order and in proper sequence. It fixes the time of start and completion of the operation.

The scheduling function begins when the following information is furnished:

(a) Date of delivery specified by the customer's order

(b) Time required for assembly and sub-assembly process

(c) Time to be taken in the production of component parts

(d) Time required to make purchases

(e) Time required for moving the materials from one station to the other, inspection, etc.

(f) Priority of orders

Necessary provisions for unforeseen contingencies such as power breakdown, strike, and lockout, absence of workers or rush of orders of extreme importance, etc. are usually made when the schedule is prepared.

(f) Loading: This involves allocating jobs to machines as per the capacity of machines and priority of jobs to be done, so that the machinery is utilized to the maximum possible extent. It includes the following activities -

- Preparation of machine loads.
- Fixing of actual dates of various operations/sequence of operations to be performed on the jobs.
- Coordination with the Sales Department to confirm delivery dates and keeping them informed about the status of the schedules.

(g) Dispatching: Dispatching means preparation and distribution of work orders and manufacturing instructions to the concerned departments in accordance with the details worked out under routing and scheduling functions. The work order received by the various departments is an authority for them to start the work according to that schedule.

According to Spriegal and Lansburgh, *'Dispatching involves the meeting of schedules by proper utilization of machines work – places, materials and workers, as designed by the routing. The dispatching unit of the planning department thus includes persons whose duty it is to see that orders are issued to the shop, that materials are at the work place, that tools are provided, that job cards are issued, and, in general all necessary steps are taken to ensure that the schedules will be properly carried out.'*

(h) Progressing: This involves controlling the process of production, collection of data from various manufacturing shops, recording the progress of work and comparing progress against the plan.

(i) Expediting and follow-up: Follow-up means to see whether the work is being carried out according to the planning and orders and instructions issued. It ascertains that the materials, tools and equipment are supplied at

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the job at the right time and to the right person or job. Follow-up is the means by which the progress and execution of the plan is evaluated from time to time and divergence from the plan is noted. The reasons for such divergence are then found out and efforts are made to eliminate them from the plan.

(j) **Inspection:** Inspection means comparing the actual with the written or expected specifications and assessing whether they have been met. Inspection can be process inspection or Product inspection, in which the process or the product is inspected respectively.

(k) **Cost control:** PPC is responsible for cost control and cost reduction by reducing or eliminating wastes, value analysis, etc.

(l) **Miscellaneous functions**: In addition to the above stated functions of PPC, there are certain miscellaneous functions such as building cost estimates for products, fixing standards with the help of Industrial Engineering Department, capacity planning, making or buying decisions, making specifications of raw materials, process improvement, etc. that have to be performed. Another function is taking corrective measures. If the production manager feels that routing is defective or scheduling is rigid and unrealistic, he can rectify the route and lay down realistic and flexible schedules. Workload, machines and men should be determined scientifically, and an effective and optimum utilization of the plant's capacity should be the objective.

Sometimes abnormal situations like strikes and power or machinery breakdown can upset the work schedules. In such situations the production manager should adjust the schedules and make up for delays. The production manager is also responsible for appraising the performance of personnel working in the Production department.

3.4.1 Benefits of Production Planning and Control

By learning about the functions of Production Planning and Control, you would have realized that it is the nerve centre of any production organization. An effective production planning and control system gives many benefits to an organization. These benefits are-

(a) Better quality of products

(b) Better utilization of resources

(c) Reduction in inventories

(d) Reduction in manufacturing cycle time

(e) Better customer services due to adherence in delivery dates

(f) Lower production costs so profits will increase

(g) Improved market share due to goodwill which is caused by better products at lower costs

(h) It gives a competitive advantage to the firm when compared to competitors' with poorer PPC system

(i) Dependability on the firm results in earning goodwill in the market

3.5 PRODUCTION CONTROL

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So far, we have learnt what Production Planning and Control is, what its main functions are, its advantages and what Production Planning is. Now we will learn about Production Control.

3.5.1 Input/Output Control

One aspect of Production Control is Input-Output Control. The concept is that the planned work input to a work centre should never exceed the planned work output. When the input exceeds the output, backlogs build up at the work centre, congestion occurs, processing becomes inefficient, and the flow of work to downstream work centres becomes sporadic. The control process would entail finding the cause of upstream problems and adjusting capacity and inputs accordingly.

3.5.2 Shop-Floor Control

Shop-floor control is also called production activity control. It is the heart of any manufacturing organization. The APICS dictionary defines shop floor control system as, '*A system for utilizing data from the shop floor as well as data processing files to maintain and communicate status information on shop orders and work centres.*'

The major functions of shop floor control are:

(a) Assigning priority of each shop order
(b) Maintaining work-in-process information
(c) Maintaining shop-order status information
(d) Providing actual output data for capacity control purposes
(e) Providing information for inventory and accounting purposes
(f) Measuring efficiency, utilization, and productivity of manpower and machines

3.6 ELEMENTS OF AUTOMATION

Automation means replacing human labour with machines.

In Unit 1, you have learned about the advantages and disadvantages of machines versus humans. So, depending upon the need, the extent of automation can range from partial to total.

Automation and advanced technology began in the 1950s with the development of numerically controlled (N/C) machine tools. N/C machining enabled the machinist's skills to be duplicated by a computer program that was stored on a computer medium such as punched paper tape. The computer program controlled the movements of a tool when making complex shapes. Over time, N/C computer hardware has become smaller and cheaper, computer – controlled software has become more sophisticated, and machine tools have become more complex. This has led to the development of industrial robots and flexible manufacturing systems (FMS). Advances in computer software and communications systems have led to improvements in manufacturing equipment and vice versa. Similarly, the knowledge base on which production planning and control decisions are made has significantly improved. By combining knowledge bases with physical process control, computer assisted manufacturing (CAM) was born.

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The union of CAD (Computer aided design), CAM, and FMS represents the latest development in manufacturing, which is referred to as computer integrated manufacturing (CIM).

N/C was probably the first true CAM system. Early N/C systems had manufacturing instructions on punched paper tapes. These instructions controlled the operations of a machine tool – for example, movement, drilling, and cutting – and tool changes.

Computers are also used to create N/C tapes automatically. An interesting system has been developed by Structural Dynamics Research Corporation (SDRC), which specializes in computer-aided engineering. The SDRC HI – PRO system is an integrated N/C tape-preparation system for punching, shearing, and other sheet metal operations. Typically, a supplier receives orders for sheet metal parts of different sizes – for instance, 100 pieces of 1.5" x 8", 300 pieces of 6" x 10", and so on. These parts are cut from larger sizes of sheet metal on N/C shearing machines. The different parts must be laid out in a manner that will minimize the waste from the larger sheets. Computer programs are used to generate optimal cutting patterns, to plot graphically the patterns for visual verification, and to create automatically an N/C tape for manufacturing. The user needs to enter only the various stock sizes, part dimensions, and requirements. The cutting patterns and manufacturing is computer- controlled.

We will learn in brief the various technologies of automation.

3.6.1 Computer-Aided Design (CAD)

Early CAD systems were basically computer-controlled plotting systems; today's systems revolve around graphics terminals. CAD allows engineers and designers to work in two and three dimensions and utilize colour to simplify complex designs. Designers can carry out geometric transformations at high speeds and can obtain the top, side and front views of design, rotations about any axis and cross sections. In addition, CAD systems allow the storage and retrieval of designs for easy updating and automatic creation of Bills of Materials and process information for production planning and scheduling systems.

3.6.2 Computer-Aided Manufacturing (CAM)

CAM involves computer control of the manufacturing process, such as determining tool movements and cutting speeds. N/C machines is an old form of CAM, robotics is a modern example. CAM offers advantages over conventional manufacturing methods. It can be used when several different parts with variable or cyclic demands are produced, when frequent design changes are made, when the manufacturing process is complex, when there are multiple machining operations on one part, or when expert operator skills and close control are required. Each machine in a CAM system has the ability to select and manipulate a number of tools according to programmed instructions. Thus CAM provides a high degree of flexibility in performing and controlling manufacturing processes.

Caterpillar Corporation, for instance, uses CAM to make components for tractor engine drive assemblies. A transfer device shuttles parts among the work stations on both sides of a track, where some 30 to 40 machining operations are performed. Operators at entry and exit points clamp the parts on and off the transfer mechanism; the rest of the process is computer-driven.

When a CAD system and a CAM system share a common data base, the term CAD/CAM is used. The integration of CAD and CAM allows for important coordination between design and manufacturing; through such integration the lead time for process planning can be reduced, quality assurance is improved and cost savings in tool design and other capital investments can be realized.

3.6.3 Flexible Manufacturing System (FMS)

NOTES

A flexible manufacturing system (FMS) is a logical extension of CAM. An FMS consists of two or more computer-controlled machines linked by handling devices such as robots and transport systems. Computers direct the overall sequence of operations and route the work piece to the appropriate machine, select and load the proper tools, and control the operations performed by the machine. More than one different work piece may be machined simultaneously, and many different parts can be processed in random order.

General Electric modernized its locomotive plant in Pennsylvania using an FMS. The machining time for engine-frame parts was reduced from 16 days to 16 hours; overall productivity was increased by 240 per cent; capacity was increased by 38 per cent; and design flexibility was increased as well.

The advantages of FMS

- It reduces work-in-process inventory.
- It provides increased capacity due to reduction in setup times.
- It provides better predictability and control of operations and scheduling.
- It offers reduction in material-handling costs.
- It provides greater sensitivity to market requirements.

All these advantages increase profitability and competitive position of the company.

3.6.4 Computer-Integrated Manufacturing System (CIMS)

The complete integration of CAD, CAM and FMS has led to systems called **computer–integrated manufacturing systems** or **CIMS.** This system represents the union of hardware, software, database management and communications, to plan and control production activities from planning and design to manufacturing and distribution. CIMS allows for much smaller and economically viable batch production capabilities. A firm can then match its production efforts to a much wider range of demand and create a competitive advantage through rapid response to market changes and new products. CIMS also provides all the advantages discussed for CAD, CAM, and FMS.

The cost of developing and implementing a fully operational CIM system is exorbitant and requires a high degree of management commitment and effort. Many companies are beginning to reap the rewards of carefully planned systems. The development of CIMSs will be a focus of manufacturing throughout this century.

3.6.5 Robotics

A robot is a programmable machine designed to handle materials or tools in the performance of a variety of tasks. Industrial robots were first introduced in 1954 when George Devol filed a design with the U.S. Patent Office for a simple pick and place robot. Unimation, founded in 1962, was the first industrial robot manufacturing company. In 1986, approximately 16,000 industrial robots were in use in the United States and Japan had approximately 60,000 in use. Robots have been relatively slow to be used in the United States because of management resistance to change, the fact that the United

States has a plentiful labour supply, human fears associated with being replaced by robots, and lack of technical knowledge about their uses.

NOTES

By using computer control, the robot can be 'taught' a large number of sequences of motions and operations and can even make logical decisions. A principal advantage of a robot is that it can be reprogrammed and transported from one application to another. Some of the typical applications of industrial robots include spot welding of automobiles, spray painting, machining operations such as drilling and assembly, inspection and material handling. Robots are especially useful for working with hazardous materials or heavy objects, labour, improvement in quality, increased capacity, and more flexibility of low – volume production equipment. In addition, they never complain!

3.6.6 Vision Systems

Vision systems consist of a camera and video analyser, a microcomputer, and a display screen. Computer vision systems can read symbols, identify objects, measure dimensions, and inspect parts for flaws. Thus, they are beginning to find extensive use in quality control.

In automotive applications, vision systems are used in conjunction with robots to weld body seams of varying widths, tighten imprecisely located bolts, mark identification numbers on engines and transmissions using lasers, and arrange car hoods on racks that have unevenly spaced slots. At a General Motors plant in Lansing, Michigan, for example, a vision-equipped robot system finds the exact location of a dozen lower– suspension rail bolts and then uses a pneumatic nut runner attachment to tighten the bolts to precise torque specifications. The system has resulted in more accurate bolt torquing and in less manual rework required downstream on the assembly line.

3.6.7 Automatic Identification Systems

At the operational level of manufacturing, a large amount of data from the shop floor is required in order to provide the information necessary for effective production control. The conventional method of capturing data involves manual recording by supervisors in a register. This data is then keyed into a computer system for processing. This method is slow and subject to errors. An alternative approach to the conventional method of capturing data involves the use of **automatic identification systems**. These systems read source data and convert it into a form readable by computers for controlling equipment and generating reports. Error rates for automatic identification systems are as low as 1 in 3 million, and speeds are hundreds of times faster than conventional methods. Automatic identification systems reduce paperwork, improve accuracy, and provide more timely and useful information than previous methods of data collection.

Examples of automatic identification systems are barcode scanners and voice – recognition systems. Barcode scanners read symbols by measuring the width of the bars and spaces and differentiating between symbols by the amount of light reflected. Bar code scanners are probably the most popular method of automatic identification, and are the fastest and most accurate. Voice recognition systems are useful in operations that require a worker to use both eyes and hands for accomplishing a task for instance, in a receiving and inspection application, in which handling, sorting and recording of data must all be done simultaneously.

3.6.8 Automation in Materials Handling

NOTES

Automation plays an important role in materials handling applications. Two major applications here are automated sorting and automated storage and retrieval. Automated sorting equipment is often found in such places as post offices, air cargo terminals, mail order distribution centres, airline baggage handling, truck terminals, and publishing houses.

Automated storage and retrieval systems (AS/RS) are designed to provide high material flow rates through warehouses, particularly for high volume, unit load storage. Incoming pallets arrive via a conveyor and are transferred to a loader at one of the storage aisles. The storage/retrieval (S/R) vehicle then moves both horizontally and vertically to deposit the load in an empty storage location. On the way back, S/R vehicles usually retrieve a required item to be sent to shipping. S/R vehicles may be manually controlled or fully automated. Computer control is needed to maintain an up -to-date list of storage locations for efficient retrieval. Capital investment in AS/RS is high, although the increased productivity and reduction of direct labour are the primary benefits.

3.7 ASSEMBLY LINE BALANCING

In the previous units, we have learned that for high volume continuous production, a line layout is preferred. This is also called an assembly line.

The production planning problem in an assembly line is about-

- Establish production rates of the final product, from the line
- Obtain this production rate with optimal workforce level

This is done so that the costs are reduced and there is smooth and regulated flow of material through a sequence of operations at a uniform rate. The process through which this is accomplished is called 'assembly line balancing.

Suppose, in a line, one operation takes 10 minutes and the next operation takes 2 minutes only. Then, the rate of production in this line will be one unit in 10 minutes, i.e., the rate of production in a line will always be the rate of the slowest operation in the line.

The operator of the 2nd operation will be idle for 10 - 2 = 8 minutes, every 10 minutes This is a huge wastage of time.

Assembly line balancing tries to reduce this idle time between operations so that the operations take place at the lowest possible time. This is done by equalizing the output rates of groups of operations, by 'balancing' them, hence the term assembly line balancing.

However, before we proceed further, we should know what 'work centres' are. In Unit 2, we learnt that *a work centre is an area in a business in which productive resources are organized and work is completed. The work centre may be a single machine, a group of machines, or an area where a particular type of work is done. These work centres are organized according to function in a job-shop configuration; or by product in a flow, assembly line, or group technology (GT) cell configuration.*

Let us learn assembly line balancing through this example.

M/s Caterpillar Inc., a manufacturer of garden equipment, has designed an assembly line for manufacturing belt-driven lawn mowers. Using the information given below, let us construct the precedence diagram.

NOTES

Work element nomenclature	*Description of work element*	*Immediate predecessor of work element*	*Time taken (in seconds)*
A	Bolt leg frame to front wheel	Nil	40
B	Drilling for fixing rear wheels	Nil	40
C	Weld rear wheels	B	30
D	Attach shears	A, C	20
E	Mount the motor	D	20
F	Mount rubber belts	D	30
G	Mount filters	E, F	50
H	Mount tyres	E, F	80
I	Install rubber mountings	G, H	10
J	Mount nameplate	I	10
			Total Time - 330 seconds

First and foremost we have to draw the **precedence diagram**. (See Figure 3.2, it helps us to visualize the predecessor relationships better).

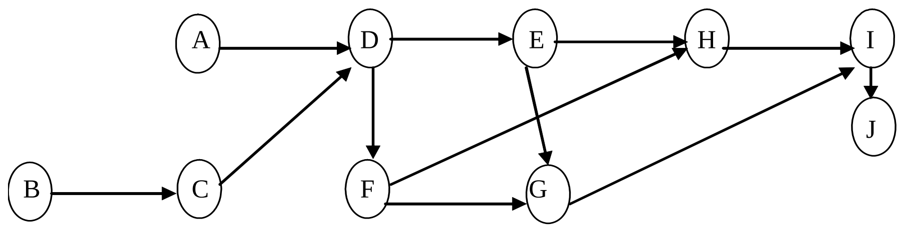


Fig. 3.2 *Precedence Diagram*

The next step is to group the work elements into work centres. We have to group those jobs that are independent of each other, but without violating precedence requirement.

Jobs A and B are independent of each other. So they can become one work centre. Job C cannot be a part of the same work centre as job B because to begin job C, job B should be completed. Jobs A and B together will take a time of 40 + 40 = 80 seconds.

Next, can jobs C, D and E be clubbed together? Precedence wise, they could be joined. The time taken is, 30 + 20 + 20 = 70 seconds.

Next, job F cannot be clubbed with job G or H, since it will violate the precedence requirement.

Next, job H would be a separate work centre taking 80 seconds.

Jobs G, I and J could be another work centre.

So summarizing,

Work Centre 1: Jobs A and B = 80 seconds

Work Centre 2: Jobs C, D and E = 70 seconds

Work Centre 3: Job F = 30 seconds

Work Centre 4: Job H = 80 seconds

Work Centre 5: Jobs G, I and J = 70 seconds

Cycle time: This is the time required to produce one unit of the finished product or the time available at each work centre.

In this problem, the cycle time is 80 seconds.

Total time of all the elemental tasks = 330 seconds

(If we reduce the number of work centres, we can minimize idle time, maximize efficiency and minimize balance delay. Also, if a worker mans each centre, reducing the number of work centres means maximizing worker productivity.

Idle time is the total unproductive time for all stations in the assembly of each unit of the product. In this problem, it is 80 x 5 - 330 = 70 seconds

Efficiency is the ratio of productive time to total time. In this problem, it is

$$\frac{330}{400} \times 100 = 82.5\%$$

Balance delay: It is the amount by which efficiency falls short of 100 per cent, 100 – 82.5 = 17.5 per cent.

The above example is not the only way to group the work centres. They can be grouped in any manner as long as the technological and other sequential requirements are not violated.

However, this visual method is too simplistic for complex problems involving a large number of elemental tasks, so the heuristic methods are generally used in assembly line balancing.

3.8 PRODUCTION SCHEDULING

In the previous section you have learnt about Assembly Line Balancing for continuous production systems. Next, you will learn how to do production planning for job or batch processes, where different products are produced on the same set of machines.

You have learnt that a schedule is a timetable for performing activities, utilizing resources or allocating facilities. It schedules, dispatches, tracks, monitors, and controls production on the factory floor.

In the case of the job shop, jobs need to be routed through a sequence of work centres to complete the work.

Scheduling systems can use either **infinite or finite loading**.

Infinite loading occurs when work is assigned to a work centre simply based on what is needed to be done, without consideration of capacity or resources required to complete the work or the sequence of the work to be done. Infinite loading is beyond the scope of our study.

In finite loading, the work is assigned to a work centre only after a careful consideration is done of each resource such as capacity of machine, materials available, manpower available, etc. If an operation is delayed due to a material shortage, the order will wait for the part to become available from a preceding operation. Theoretically, all schedules are feasible when finite loading is used.

Scheduling systems can also be based on whether the schedule is generated **forward or backward in time. Forward scheduling** refers to the situation where the system takes an order and then schedules each operation that must be completed forward in time. The system will then project the earliest date that an order can be completed.

Backward scheduling starts from some date in the future (generally the due date) and schedules the required operations in reverse sequence. The backward schedule tells when an order must be started in order to be done by a specific date which has been demanded by the customer.

NOTES

3.8.1 Objectives of Scheduling

Why is scheduling so important in Production Planning and Control? This is because it enables the organization to:

- Meet due dates
- Minimize lead time
- Minimize setup time and set up cost
- Minimize work-in process inventory
- Maximize machine and labour utilization

There are several methods that are used in industry for work centre scheduling, or simply called job scheduling. We will study the most important ones here.

3.8.2 Job Sequencing (or Scheduling)

The process of determining which job to start first, and in what order other jobs should be processed on the machine or in a work centre, is known as Job Sequencing or priority sequencing. Priority rules are the rules used in obtaining a job sequence. Jobs are generally sequenced according to processing time, due date or order of arrival. This method can be used for both finite loading as well as infinite loading and forward as well as backward sequencing.

The following are the common bases on which sequencing is done:

1. Meeting due dates of customers or downstream operations
2. Minimizing the flow time (the time a job spends in the process)
3. Minimizing work-in-process inventory
4. Minimizing idle time of machines and workers

There can be several situations, there may be number of jobs and one machine, or there may be 'n' jobs and n machines. For each situation, there are methods for sequencing. We will learn the important ones here.

3.8.3 Scheduling when there are Several Jobs and one Machine

In the first case, jobs may be sequenced according to any of the following rules:

1. **Minimum process time method (MINPRT) –** This is also known as Shortest Operation Time Method (SOT). Under this rule, job with the shortest process time is first scheduled, followed by next lowest process time and so on.
2. **Due date method (DD Method) –**In this method, the job with earliest due date is done first.
3. **First come first served method (FCFS) –** In this method, jobs are scheduled in the order in which they are received by the company.
4. **Longest process time method (LPT) –** This method is just the reverse of MINPRT method as the job with longest processing time is attended first.
5. **Dynamic slack/Remaining operation (DS/RO) or minimum slack per operation (MINSOP) method –** In this method, first Dynamic Slack (DS) is computed. (This is the difference between due time and processing time). This is divided by Remaining Operation (RO) time. RO unless specified will be assumed as one. Final scheduling of the job under this method is done as per the ranking.

NOTES

Job with lowest DS/RO value is assigned Rank 1 and attended first. The next higher value gets Rank 2 and so on.

Which particular rule is more appropriate for a given situation will depend on the average job lateness and average number of jobs in the system The lesser the job lateness, the better it is as it will ensure customer satisfaction, optimum utilization of machine, reduced slack time, etc.

We will understand all the above methods by means of the following example.

Example 4: Four jobs W, X, Y and Z need to be done on the same work centre. Their process times and due dates are as given below. Sequence the jobs by different methods.

Job	*Process Time (no. of days)*	*Due Date (days from today)*
W	5	12
X	6	18
Y	7	21
Z	10	14

Solution:

1. Minimum process time method (MINPRT)

W is done first since it has the least process time.

Next X is done (By now, total days required = 5 + 6 = 11, It is less than 18)

Next do Y, Total days required = 11 + 7 = 18 It is below 21. Thus, there is no delay.

Next do Z. Total days 5+6+7 + 10 = 28.

It is beyond by 14 days. So delay is 14 days.

Job Z gets delayed by 14 days.

2. Due date method (DD Method)

	Process time	*Flow time (Cumulative Process time)*	*Due dates*	*Job lateness*
W	5	5	12	0
Z	10	15	14	1
X	6	21	18	3
Y	7	28	21	7

First the jobs are rearranged in the increasing order of due dates, i.e., W,Z,X Y

Calculate Total completion time = 5+10+6+7 = 28 days.

Next, calculate Flow Time.

For W=5

Then Z is completed after 5+10=15 days.

X=15+6 = 21, Y=21+7 = 28 days.

Cumulative or Total = 5+15+21+28 = 69 days.

Average Completion time = 69/4 = 17.25 days.

Average Job lateness = (0+1+3+7)/4 = 11/4 = 2.75

NOTES

3. First come first served method (FCFS)

Irrespective of the process times or due dates, the job received first is done first.

4. Longest process time method (LPT)

	Process time	*Flow time (Cumulative Process time)*	*Due dates*	*Job lateness*
Z	10	10	14	0
Y	7	17	21	0
X	6	23	18	5
W	5	28	12	16
	28	78		21

In this case, the jobs are rearranged in the decreasing order of Process Times, i.e., Z, Y, X, W

Total completion time =28 days.

Average Completion time = 78/4 = 9.5

Av. Job lateness = 21/4 =5.25

5. Dynamic slack/Remaining operation (DS/RO) or minimum slack per operation (MINSOP) method –

Assume that the number of operations for each job are W = 2, X = 3, Y = 2, Z = 4. (Number of operations means the number of activities which need to be done to make W).

$$\text{DS/RD ratio} = \frac{\text{Delivery Date} - \text{Process time}}{\text{No. of operation}}$$

DS/RD ratios are = W = (12-5)/2 = 7/2 = 3.5

Similarly, X = 4, Y = 7, Z = 1.

Rank them with Z being the lowest at 1. W = 2, X = 3, Y = 4

Rearranging them in the increasing order of their rank, we get

	Process time	*Flow time (Cumulative Process time)*	*Due dates*	*Job lateness*
Z	10	10	14	0
W	5	15	12	3
X	6	21	18	3
Y	7	28	21	7
				13

Total completion time = 28 days

Average Completion time = 74/4 = 18.5

Average Job lateness = 13/4 = 3.25 days

Tabulating all the results:

Sequencing Rule	*Total completion time*	*Av. Completion time*	*Av. Job lateness*
MINPRT	28	15.5	4.25
FCFS	28	15.5	2.21
LPT	28	19.5	5.25
DD	28	17.25	2.75
DS/RD	28	18.5	3.25

We can select the rule depending on our requirements.

NOTES

3.8.4 Sequencing when there are Several Jobs and Several Machines

This method was developed by S.M. Johnson, to minimize idle time by prudent job allocation.

As with the earlier method, we will learn this one through an example.

Example 5

In a job shop, jobs A,B,C,D,E,F and G have to be performed on two machines M1 & M2 in the same sequence i.e M1 first and followed by M2. The time taken by each job on each machine is given below. Determine the sequence of the jobs.

JOB	*M1*	*M2*
A	9	2
B	5	4
C	8	10
D	3	5
E	4	6
F	1	11
G	7	6

Solution:

(a) Lowest time taken on M1 is job F. So F is first.

(b) Next '2' is taken by job A on M2. So A will be last.

(c) Next '3' is job D on M_1. So D is second job.

(d) Next '4' is job E on M_1 . So E is third.

(e) Also '4' is job B on M_2. So B is before A.

(f) Next '5' is job D on M_2. But D is already scheduled. So ignore.

(g) Next '6' is Job E on M_2. Ignore since E is already scheduled.

(h) '6' is also job G on M_2. So G is before B

(i) C is left over. So place it after E.

So the sequence decided is F,D,E,C,G,B,A.

The situation becomes difficult when we have to assign several jobs to several machines. The index method and assignment methods are used for this purpose. The examples below illustrate both these methods.

3.8.5 Index Method

This is a method of finite job loading and backward scheduling. The least time or cost required by a particular job - machine combination is considered as the base and the indices for the other combinations are made based on the base index. While allocating, the capacity of the respective machines and the time available are considered, which under no circumstances should be exceeded. Let us learn this method through this example.

Example 6

In a job shop, five products, A, B, C, D and E, need to be produced on four machines 1, 2, 3 and 4. The number of days it will take if A is made on Machine 1 is 10; if A is made on 2 is 9 days; and so on. Allocate the five jobs to the four machines so that all the jobs are completed within the total time available of 20 days.

NOTES

WORK CENTRE (NO. OF DAYS)

JOB	*1*	*2*	*3*	*4*
A	10	9	8	12
B	3	4	5	2
C	25	20	14	16
D	7	9	10	9
E	18	14	16	25
No. of days Available	20	20	20	20

Solution:

Assign an index number first. For every job, assign the number 1 to the job-machine combination having the lowest number of days. In this example, for job A, 8 is assigned index 1, for B, 2 is assigned 1, for C, 14 is assigned 1, for D 7 is assigned 1 and for E 14 is assigned 1.

Then calculate the ratios for the other numbers and tabulate as below.

WORK CENTRE

JOB	*1*	*Index*	*2*	*Index*	*3*	*Index*	*4*	*Index*
A	10	1.25	9	1.13	8	1.0	4	1.5
B	3	1.5	4	2.0	5	2.5	2	1.0
C	25	1.78	20	1.42	14	1.0	16	1.14
D	7	1.0	9	1.28	10	1.47	9	1.28
E	18	1.28	14	1.0	16	1.14	25	1.78
Days available	20		20		20		20	
Days assigned	7	14	8	2 + 16 = 18				

In the table, A has the lowest index for Work Centre 3. So A is allocated Work Centre 3.

Similarly, D is assigned line 1.

E = line 2

B = line 4

For C, the lowest index is at Work Centre 3. But if it is allotted, it will take 8 + 14 = 22 days, which will exceed the available 20 days. So if C goes to 1.14 index, that is line 4. Then line 4 will be booked for 2 + 16 = 18 days.

3.8.6 Assignment or Job Loading

In most job shops, there may be more than one work station available to perform a job. It then becomes necessary to choose between alternatives and jobs are allocated to the most time and cost effective job - machine combination. Assignment or job loading technique is a quantitative method which optimizes our decision on job scheduling.

The Hungarian Method is a combinatorial optimization algorithm that helps in solving the assignment problem. This method was first invented by Harold Kuhn in 1955 and then modified by James Munkres in 1957. The study of this method is beyond the scope of this course.

3.8.7 Gantt or Bar Charts

This method was introduced by Henry Gantt in 1917 for use in production planning, scheduling and control. It is a type of bar chart that plots tasks against time. It is used for project planning as well as for coordinating a number of scheduled activities. In a Gantt chart, the time frame, which may be in terms of hours, days, weeks or months, is on the 'X' axis. The activities are plotted on the vertical or 'Y' axis.

Gantt Charts are used as –

- Scheduling or progress charts, to show the sequence of job progress;
- Load charts, to illustrate the work assigned to work group or allocated to machines;
- Record charts, to keep a track of the actual time spent and delays, if any.

Gantt charts require updating at regular intervals, like when starting of work is delayed, when work continues beyond the time schedule, or when progress of work is not in accordance with actual plan. For unforeseen eventualities, it may be essential to initiate corrective action, which will require corresponding changes in Gantt charts.

Advantages of Gantt charts

1. They are simple and inexpensive and can be developed even by a supervisory staff with some amount of training.
2. The decided time and work schedules for every job can be clearly shown.
3. Updating and changes can be made quickly and with less cost involvement.
5. These types of chart boards are available in standard sizes in the market, which substantially saves the cost of developing customized Gantt chart boards.

Disadvantages of Gantt charts

1. Interrelationships and interdependencies between jobs cannot be shown.
2. Cost aspect of jobs cannot be indicated.
3. Alternatives for project completion cannot be shown.

Depending on the nature of requirement, the shape and form of Gantt charts may be different.

Smaller job shops and individual departments of large ones employ the Gantt chart to help plan and track jobs. We will learn how to draw and interpret a Gantt chart through the following example.

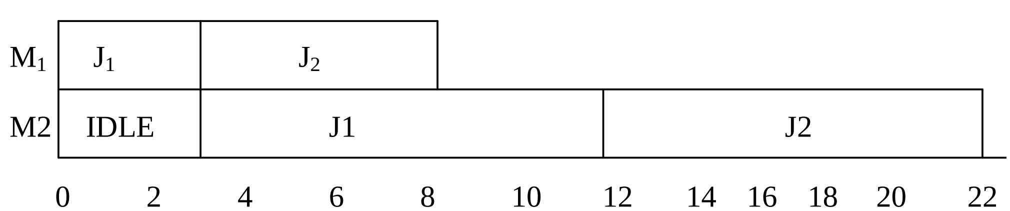
Example 7

Two jobs, J1 and J2, need to be performed on two machines in that sequence, that is M1 first and then M2. The time taken by each job on each machine is given below. Draw a Gantt chart and use it to allocate the jobs to the machines.

	M_1	M_2
J_1	3	9
J_2	5	11

Solution:

Suppose we follow sequence J_1, J_2.



NOTES

Check Your Progress

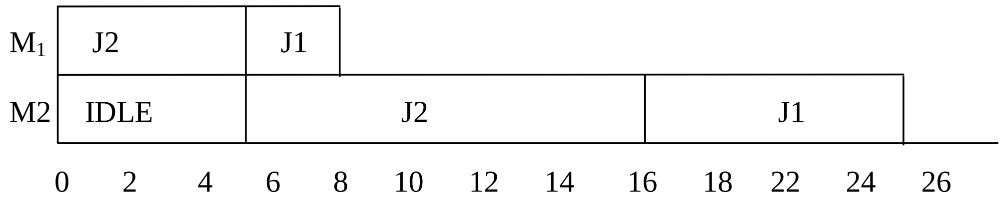
1. What is routing?
2. How does production control benefit an organization?
3. What is scheduling?
4. What is dispatching?
5. Write a short note on follow-up or expediting.

When J1 is on M_1, M_2 is idle. After 3 hours, when J_1 goes to M_2, J_2 starts on M_1.

Total time required in this sequence = 3+9+11 = 23 hours.

Suppose we follow the sequence J2, J1.

NOTES



When J_2 is on M_1, M_2 is idle. After five hours, when J_2 goes to M_2, J_1 starts in M_1.

Total time required in this sequence = 5+9+11 = 25 hours.

So, J_1, J_2 is a better sequence since time taken in lesser.

3.9 SUMMARY

In this unit, you have learned about the two fundamental or core activities of production management—production planning and production control. You have learned that production planning deals with how to plan for capacities, materials, machine and labour utilization. In scheduling, you have learned how to solve sequencing and assignment problems. All these activities are aimed at achieving the basic objectives of an organization, i.e., produce the required volumes at pre determined quality levels and at the budgeted costs.

One point that needs to be mentioned here is that shop-floor control systems in most modern plants are now computerized, with job status information entered directly into a computer as the job enters and leaves a work centre. Many plants have incorporated barcoding and optical scanners in order to speed up the reporting process and to cut down on data entry errors. The key issue in these situations is, therefore, data integrity. Data integrity requires a sound data gathering system to be in place, which is not always easy. Despite best efforts, inaccuracies can still creep into a system.

3.10 KEY TERMS

- **Aggregate plan:** This is the total or aggregate plan of a company for producing a product over a certain period of time, say in the next 12 months.
- **Master production schedule**: This is the disaggregating of an aggregate plan. This means it gives information about the number of various models and sub-models of a product planned to be produced in a given duration.
- **Planning horizon:** The time interval used in MPS varies from firm to firm. It depends on the type of products used, the volume of production, and the lead times of the materials used. This span of time that the MPS covers is called the planning horizon.
- **Material requirements plan (MRP)**: This plan specifies when the products need to be made, what the raw materials are, when and how many are required and when the order should be placed with the vendors.

NOTES

- **Order preparation:** This work begins once an order is received from the sales department. This order is then converted into a 'work order' or 'shop order' and sent to various departments concerned, for planning action at their end.
- **Materials planning:** Once the order is received, the PPC decides on the raw materials required to manufacture, taking into account the capacity of various production shops, the Bill of Materials, inventory on hand, and lead time for procurement.
- **Routing (or process planning)**: Routing means determination of the sequence of operations for manufacturing a product or service. This path is determined in advance and forms the basis for most of the scheduling and dispatching functions.
- **Loading:** This involves allocating jobs to machines as per the capacity of machines and priority of jobs to be done, so that the machinery is utilized to the maximum possible extent.
- **Dispatching:** Dispatching means preparation and distribution of work orders and manufacturing instructions to the concerned departments in accordance with the details worked out under routing and scheduling functions.
- **Progressing:** This involves controlling the process of production, collection of data from various manufacturing shops, recording the progress of work and comparing progress against the plan.
- **Expediting and follow-up:** Follow-up means to see whether the work is being carried out according to the planning and orders and instructions issued. It ascertains that the materials, tools and equipment are supplied at the job at the right time and to the right person or job. Follow-up is the means by which the progress and execution of the plan is evaluated from time to time and divergence from the plan is noted. The reasons for such divergence are then found out and efforts are made to eliminate them from the plan.
- **Inspection:** Inspection means comparing the actual with the written or expected specifications and assessing whether they have been met. Inspection can be process inspection or product inspection, in which the process or the product is inspected respectively.
- **Cost control:** PPC is responsible for cost control and cost reduction by reducing or eliminating wastes, value analysis, etc.
- **Shop floor control system**: The dictionary defines shop floor control system as a system for utilizing data from the shop floor as well as data processing files to maintain and communicate status information on shop orders and work centres.
- **CAD:** Early CAD systems were basically computer-controlled plotting systems; today's systems revolve around graphics terminals. CAD allows engineers and designers to work in two and three dimensions and utilize colour to simplify complex designs.
- **CAM:** CAM involves computer control of the manufacturing process, such as determining tool movements and cutting speeds.
- **FMS:** A flexible manufacturing system is a logical extension of CAM. A FMS consists of two or more computer-controlled machines linked by handling devices such as robots and transport systems. Computers direct the overall sequence of operations and route the work piece to the appropriate machine, select and load the proper tools, and control the operations performed by the machine.

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- **CIMS:** The complete integration of CAD, CAM and FMS has led to systems called or CIMS. CIMS represents the union of hardware, software, database management and communications, to plan and control production activities from planning and design to manufacturing and distribution.
- **Robotics:** A robot is a programmable machine designed to handle materials or tools in the performance of a variety of tasks
- **Work centre:** A work centre is an area in a business in which productive resources are organized and work is completed. The work centre may be a single machine, a group of machines, or an area where a particular type of work is done. These work centres can be organized according to function in a job – shop configuration; or by product in a flow, assembly line, or group technology cell (GT cell) configuration.
- **Infinite loading:** It occurs when work is assigned to a work centre simply based on what is needed to be done, without consideration of capacity or resources required to complete the work or the sequence of the work to be done
- **Finite loading:** Here, the work is assigned to a work centre only after a careful consideration is done of each resource such as capacity of machine, materials available, manpower available, etc
- **Forward scheduling:** This refers to the situation where the system takes an order and then schedules each operation that must be completed forward in time
- **Backward scheduling**: This starts from some date in the future (generally the due date) and schedules the required operations in reverse sequence. The backward schedule tells when an order must be started in order to be done by a specific date which has been demanded by the customer.
- **Gantt or Bar charts:** This method was introduced by Henry Gantt in 1917 for use in production planning, scheduling and control. It is a type of bar chart that plots tasks against time. It is used for project planning as well as for coordinating a number of scheduled activities. In a Gantt chart, the time frame, which may be in terms of hours, days, weeks or months, is on the 'X' axis. The activities are plotted on the vertical or 'Y' axis.

3.11 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Routing means determination of the sequence of operations for manufacturing a product or service. This path is determined in advance and forms the basis for most of the scheduling and dispatching functions. According to Kimball and Kimball:

   'Routing is the selection of path or route over which each piece is to travel in being transformed from raw material into finished product.'
2. Production control offers the following benefits to an organization:
   (a) As production control aims to make the right quality and quantity of products accessible to the customers at the right time at minimum cost, the management can align the production activities with its sales programme.
   (b) Investment in inventories and finished stock can be kept to the minimum.
   (c) The firm can capture and increase its market share by producing the goods at the lowest cost
   (d) Profits will improve as increased sales will increase profit.

(e) Production control function guides the management to direct the production along the lines planned. It evaluates the actual performance consistently and locates deviations. It also suggests corrective measures to eliminate the deficiency in planning and operations.

3. Scheduling: According to Spriegal and Lanburgh, '*Scheduling involves establishing the amount of work to be done and the time when each element of work will start or order of the work.*'

   Thus scheduling includes the following activities:

   - Determination of quality and rate of output of the plant or department.
   - Allocation of time for each operation.

   Scheduling indicates when the work will be released to the plant in a prescribed order and in proper sequence. It fixes the time of start and completion of the operation.

   The scheduling function begins when the following information is furnished:

   (a) Date of delivery specified by the customer's order
   (b) Time required for assembly and sub assembly process
   (c) Time to be taken in the production of component parts
   (d) Time required to make purchases
   (e) Time required for moving the materials from one station to another, inspection, etc.
   (f) Priority of orders

   Necessary provisions for unforeseen contingencies such as power breakdown, strike, and lockout, absence of workers or rush of orders of extreme importance, etc are usually made when the schedule is prepared.

4. Dispatching means preparation and distribution of work orders and manufacturing instructions to the concerned departments in accordance with the details worked out under routing and scheduling functions. The work orders received by the various departments serve as an authority for them to start the work according to that schedule.

   According to Spriegal and Lansburgh:

   '*Dispatching involves the meeting of schedules by proper utilization of machines work – places, materials and workers, as designed by the routing. The dispatching unit of the planning department thus includes persons whose duty it is to see that orders are issued to the shop, that materials are at the work place, that tools are provided, that job cards are issued, and, in general all necessary steps are taken to ensure that the schedules will be properly carried out.*'

5. Follow-up means to see whether the work is being carried on according to the planning and orders and instructions issued. It ascertains that the materials, tools and equipment are supplied at the job at the right time and to the right person or job. Follow up is the means by which the progress and execution of the plan is evaluated from time to time and divergence from the plan is noted. The reasons for such divergence are then found out and efforts are made to eliminate them from the plan.

3.12 QUESTIONS AND EXERCISES

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Short-Answer Questions

1. What is FMS?
2. What are the advantages and disadvantages of automation?
3. What are the main functions of PPC of an organization?
4. Write short notes on:

   Automation in material handling

   Finite and infinite loading

   Gantt charts

   Prioritization

   Hungarian Method

Long-Answer Questions

1. A good production planning and control system adds to the profit of an organization. Explain.
2. What are aggregate plan and master production schedule? Explain their relevance.
3. What are the different methods of manpower planning?
4. What do you understand by production planning? Explain the classification of plan w.r.t time.

3.13 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

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UNIT 4 PRODUCT DESIGN AND FORECASTING

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Structure

4.0 INTRODUCTION

When the Tata group decided to launch the 'people's' car in India, how do you think they designed the car? What factors did they consider and what features did they want their car to have? In this unit, you will study the steps that are involved in designing a product for production and sale in the market.

Typically, every product begins with an idea. The management of any organization must develop this idea such that it can meet customers' needs, by using the available resources and technological capabilities of the organization. Product development is the combined effort of all the units of the organization. However exciting the potential opportunity of a new product might be, making it happen is full of challenges.

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4.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand the meaning of product selection
- Define product design and development
- Describe the need for product design and development
- Explain the characteristics of a good design
- Discuss the concepts of a good design

4.2 PRODUCT SELECTION

4.2.1 Product Selection Process

All activities of an organization must start with 'product selection'. It simply means the process of selecting the right product, which the organization will produce.

An organization can sustain itself only if the right product is selected and produced. Valuable resources will be wasted if the wrong product is selected and in the end, the company may have to close down.

When a product is to be selected, a company usually defines a product evaluation and selection process. A list of relevant selection criteria is compiled and this list is used to identify products that are expected to meet the customers' requirements. This is not as easy as it sounds, since the number of innovative products is overwhelming.

Warren Avis in his book *Take a Chance to Be First* has said, '*... Our best business missions are based on those ideas that often emerge out of our deepest personal motivations and interests*'. This means every business starts with an idea. The predominant cause for setting up a manufacturing unit /service is 'opportunity', i.e., a prospect to give a service or a product that can create adequate surplus.

At the same time, merely having an idea is not enough. Every idea cannot be converted into a commercial product. Once the idea has emerged, several questions need to be asked, the most important among them being:

1. Will it match the expected needs of the clientele, for which the product is aimed?
   - This needs to be confirmed through basic market research and if possible, tested in the market place. Experts may be consulted in this regard. The company needs to assess itscompetition in the field.
2. Will it be a sunrise industry?
3. Is it a workable business plan in the locality?
4. Does the company have or can it arrange the necessary funds to implement the idea?

If the company decides to go ahead with the idea, then the following issues need to be considered. –

(a) Generic issues

- Physical dimensions of the product such as height, width, weight, density, viscosity, etc.

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- Packaging
- Branding and positioning
- Distribution
- Warranties and after sales service

(b) Technology issues

- The easiness at which raw material is available
- Process Technology: Type of manufacturing system, production planning and control required, maintenance necessities, etc.
- Accessibility to suppliers and customers
- Incentive and support from government

(c) Market issues

- Presence of other players in the market with similar products
- Stages in the life cycle of the product
- The complex job of marketing
- Internal supply capability
- The total amount of capital needed to enter the market

(d) Export issues

- What ought to comprise export-product portfolio, if the product is meant for export?
- If the product is to be exported, what are the packaging specifications?
- What product adaptations are needed for exporting a product to a specific country?
- Are any WTO stipulation involved, e.g., 'child labour free', ISO 9000 certified, etc.
- External demand conditions

The Export Import Bank of India has a model for conducting export-product portfolio analysis based on the following three factors.

- Domestic environment
- Supply capability in product group
- Export market attractiveness

Packaging issues are equally relevant when we are thinking of exports. Wooden packaging is not permissible when exporting to Australia. Some products need to be adapted for country specific needs, e.g., some countries adhere to a voltage supply of 220V while some to 110V. In some countries automobiles have left-hand drive, while others have right-hand drive, etc.

4.3 DEFINITIONS OF PRODUCT DESIGN AND DEVELOPMENT

I. **Product design** is a term that refers to transforming an idea of how a product should be and the specifications, which are required for producing that product. These specifications are created keeping in mind the constraints of the production process, feasibility to produce, and meeting the customer expectations without sacrificing the quality. Product design involves activities like creating drawings

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and specifications pertaining to sizes and tolerances and deciding on the type of materials to be used, etc.

II. **Product development** refers to the process of creating new products or modifying the existing ones in a predefined time frame, and at the targeted cost price while achieving the preset quality requirements. The needs or requirements of consumers keep on changing over the period of time. Therefore, to meet these needs successfully, organizations either introduce new products in the market or modify the existing ones to match the new needs. The objective of both these activities is to achieve customer satisfaction and improve the feasibility in production. This provides the organization both growth and profitability.

4.4 NEED FOR PRODUCT DESIGN AND DEVELOPMENT

Product design and product development are required to achieve certain objectives for any organization. We will analyse them separately for new products and for modified products.

4.4.1 Objectives of an Organization

To develop and introduce new products in the market, we need to keep in mind the following objectives of an organization:

(a) To overcome decline in the growth rate of organization
(b) To replace short-lived products
(c) To optimally utilize surplus capacity, such as available physical facilities, managerial expertise and workmen skills
(d) To redeploy surplus manpower, arising out of technological changes
(e) To utilize surplus funds and increased borrowing power of the organization
(f) To increase market visibility with introduction of new products
(g) To meet new requirements of the customers
(h) To seek growth in the market share by adding more variety and new designs to the product range
(i) To fill in the missing products in the product range in order to provide consumers with all the possible options within the same brand, thereby keeping brand loyalty intact with the consumers

4.4.2 Modifying the Existing Products

Sometimes instead of introducing new products, the company modifies the existing products. These modifications are made for reasons such as:

(a) To develop brand loyalty
(b) To improve the life cycle of the product in the market by providing it with a new look or adding to its functionality, thereby increasing the profitability by bringing the product back to the growth base.
(c) To save finances as expenses pertaining to developing new products are generally much higher than for modification.

(d) To save time as time required to modify an existing product is lesser than the time required to launch a new product.

(e) To maintain the advantage of an already established product in the market by improving it from time to time, by offering benefits such as functionality, multiple ability, etc. immediately.

(f) To utilize the production resources effectively, since the same lines for production can be more or less utilized in the case of modification in the existing product.

(g) To increase the market share with economical pricing, by passing on the advantage of reduced cost of production, achieved by amortising capital cost over increased number of units produced.

To summarize, we can say that introducing a new product adds to the profitability for an organization by an increase in sales. Modification of the existing product provides sustainability in the market and cost reduction and helps to maintain the profitability for an organization.

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4.5 CHARACTERISTICS OF GOOD DESIGN

The design of the product has an enormous effect on the factors responsible for the success or failure of the product in the market. While designing a product, various factors are considered such as product performance in the prevalent market conditions, feasible productivity of the product, and the features that would satisfy the consumer needs. Even a small omission in interpreting the market requirement into a design for the product can prove to be disastrous for the company. The characteristics of well-designed product are explained as under.

4.5.1 Functionality

While designing, the most important consideration is the function that the product is expected to perform. Products are designed with a core objective, and for meeting a specific customer need. If the product is unable to meet that need, the whole purpose of introducing new or modifying an existing product is defeated. For example, the basic function of a mobile phone is to verbally communicate. If the camera in the mobile phone or picture clarity on the screen is very good, but there is no voice clarity in the phone, then that model of the phone is not performing its basic function and is likely to fail in the market.

4.5.2 Reliability

Reliability means dependability on the performance of a product for a designated period of time, without deterioration in the quality of performance of that product. While designing a product, the life of the product for which it should last is an important consideration. A consumer has an expectation from a product with regards to its life span in terms of duration or number of cycles it is going to last. When we buy an electric bulb, we expect it to burn for a specified number of hours, giving a certain level of illumination.

4.5.3 Productivity

Productivity for a product can be defined as the possibility of producing the product in the required quantity at a feasible cost. A well-designed product in terms of functionality and appearance that cannot be produced in the required quantity and at an estimated

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cost will not be successful in the market. The factors that should be considered while designing in relation to productivity are, number of operations that form the manufacturing process, availability of the necessary materials, technology requirements, etc.

To improve the productivity of the product, designers consider certain options like reducing the number of operations or replacing the ones that take more time or cost more than the budgeted cost with other technology options. Today, most computers are attached to printer-cum-fax machine-cum-scanner-cum anything else. Instead of using separate machines for each operation, multiple machines are being used, thereby reducing the number of machines. Productivity of the machine has now increased manifold, at a fraction of the cost. Alternate materials can also be used to achieve this objective. For example, steel plants use zinc of 99 per cent purity for galvanizing. If they used zinc of 95 per cent purity, the cost would come down by almost 20 per cent without any change in the product quality, since the impurities do not harm the galvanized sheet produced.. This would greatly reduce the cost of production.

4.5.4 Quality

Quality means conformance to specifications. A good design ensures the required quality in a product. The process to be followed should be capable of producing the desired quantity with consistent quality. Inspection only informs us about the deviations from specifications.

The materials and their specifications ascertained while designing, play an important role in making the product durable and reliable. Tolerances in the dimensions of individual parts affect the final quality of the assembled product. In certain cases where the product is an assembly of more than one part, the tolerances of the individual parts used, when combined together should not be beyond the tolerance specified for the assembly. This is especially to be taken care of in assembly parts, where the tolerance of the individual components when put together, tends to exceed the tolerance of the assembly as a whole.

4.5.5 Standardization and Simplification

Standardization is a tool that is employed to promote the use of minimum number of parts to serve the maximum number of purposes, in order to achieve economy in manufacture, minimize whole life cost, and maintain quality and reliability necessary to ensure operational efficiency and effectiveness.
Simplification is the process of making the design simple. Complicating things which can be made simple is only going to add to costs.

A design which has standard parts will always have an edge over designs which have custom made parts. For example, all computers and typewriters have the same arrangement of keys on the keyboard because it has become a standard that consumers are used to. Although many other designs of keyboard keys are available, no company is willing to take the risk of deviating from this standard.

Lack of standardization creates problems. Standardization has benefits such as lower design cost due to use of existing components/parts and easy availability of components for replacement if any defects arise. Also, the inventory management of few standard parts is simpler when compared to having a large number of different components in a non-standard design.

4.5.6 Maintainability

Products are designed to perform reliably for a designated period of time, but still some amount of maintenance is required. This maintenance could be preventive i.e. to prevent deterioration of the product or could be corrective i.e.to correct any defect that may occur in the product. The product design should be such that maintaining it is simple and cost effective, in terms of repair or replacement of the defective part. You would have noticed that we see this desire for easy maintainability everywhere around us. For instance, we often buy clothes which are easy to maintain, do not require starching, ironing, etc. Other examples include new age water purifiers that do not require frequent cleaning, and new automobile tyres which are tubeless.

4.5.7 Cost Effectiveness

The cost of production for a product is influenced at the designing stage and plays an important role in economical manufacturing of that product. At the designing stage, effective measures like standardization of parts and manufacturing processes and choice of input materials influence the cost of product. Being cost competitive is an essential requirement for a product to be successful.

This unit explains how products are designed and developed.. Marketing suggests ideas for new products and provides specifications for existing product lines. Product development provides the technical concept for the products to be manufactured.

The product development activity links customer needs and expectations with the activities required to manufacture the product.

4.6 CONCEPTS OF PRODUCT DESIGN

Let us begin by understanding the various concepts involved in designing a product. Figure 4.1 shows concept of product design.

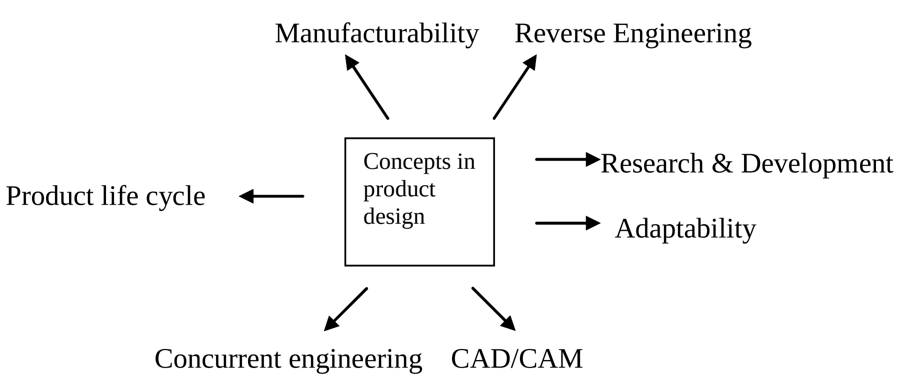

Fig. 4.1 *Concepts of Product Design*

4.6.1 Research and Development

We know that research is a conscious investigation to find new knowledge. Basic research is a search for new knowledge without regard to any specific use and may not be immediately converted into commercial applications. For example, when Newton found the law of gravity, it was a fundamental research, which did not have immediate applications. In the course of time, many commercial applications of the law came into existence.

Applied research has the objective of developing commercial applications and is investigative or experimental, for specific problems, products and processes. Development is the process of converting the results of applied research into useful commercial applications. Research usually has a good deal of uncertainty about the technological or commercial successes. Most organizations have a Research & Development wing.

4.6.2 Reverse Engineering

Reverse engineering is the process of carefully dismantling an existing product (usually of a competitor) step by step in order to understand its unique underlying concepts. It helps in designing new products, which are better than those of the competitors. Sony Corporation is the market leader in electronic items such as walkman, handy cam, digital cameras, etc. Many other companies are said to have followed the reverse engineering approach in order to produce similar products in the shortest possible time.

4.6.3 Computer-Aided Design/Computer-Aided Manufacturing

CAD and CAM carry out product design and manufacturing activities with material and capacity planning, scheduling, materials handling, and inventory control. These techniques depend on the use of computers and an accurate database. In the database each item has a unique code and stores the relevant characteristics of the item (e.g. dimensions, composition, number in stock, list of suppliers, drawings, etc). This data is available to many functional users such as engineering and marketing department personnel.

Computer-aided design (CAD) refers to the use of computerized work stations to rapidly develop and analyse a product's design. Once the designer inputs his specifications, the system creates a three-dimensional geometric model of the product which can be rotated on the screen to display the product's characteristics in their entirety even before it is manufactured. In addition, designers can obtain and test such factors as stress, tolerances, product reliability, serviceability and costs.

Computer-aided manufacturing (CAM) follows CAD. It is the extensive use of computers to accomplish and control production operations. Some major examples are numerically controlled (NC) machines, process controllers, systems that are linked by group technology, automatic assembly operations, and computer-aided inspection and testing.

4.6.4 Concurrent Engineering

Concurrent engineering (CE) is a product design approach which is radically different from the classical serial product design approach in which the design process takes place in stages, moving from one department to the other. Concurrent engineering saves time and effort since it emphasizes cross functional mixing and parallel development of goods and its processes.

Cross functional teams form the backbone of the CE process. Several types of teams exist, such as (i) technical team, program management team, etc. If a project is complex, teams are added to solidify the efforts of the various teams involved in it. Some special task forces are also formed to solve any particular problems, such as investigating an emerging technology.

The main benefit of the CE approach is the reduced time to complete a project. This happens when all major activities happen in parallel, e.g., developing marketing ideas simultaneously, the process of manufacturing, product support structures, etc. The time overlap might help in saving and also from reduction in errors. Frequent information sharing is important to CE success. Hewlett-Packard uses technology-focused teams operating in parallel as part of its strategy. Each team works on a key technology essential to the development of its products.

4.6.5 Life Cycle of a Product

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Every product has a certain marketable life. The duration that the product exists in the market can be broken down into several stages. Depending on the product, the life span varies. Also, the relative life span of each stage varies. An analysis of the life span helps understand the pattern of demand during the life of the product.

(a) Introduction phase

This represents the launching phase of the product. The product has to find a market and prove its worth. There is low demand and the company does not make a profit with this product. When products are introduced into the market, frequent design changes occur. Hence, innovation flexibility, and responsiveness to customer needs are most important. Productivity is not critical.

(b) Growth phase

As the product finds acceptability in the market, its sales climb. . The company streamlines its manufacturing and distribution systems and makes profit with the product. As the growth stage develops, manufacturing must have the ability to meet these growing demands. Capacity growth and utilization become critical performance measures. Manufacturing tries to maximize productivity and minimize costs. Productivity becomes a useful performance measure at this stage, and this is likely to continue during the decline stage.

(c) Saturation phase

The demand/ sales of the product are stable. Competitors may begin to introduce new and similar products; hence the growth rate of this product will not show any increase.

(d) Decline phase

At this stage, the demand/sales of the product begin to decline. Unless new features are added and fresh lease of life is given to the product, it may eventually be withdrawn. In this phase, the product begins to lose its appeal as substitute products are introduced and they become more popular. At this point the product is either discontinued or replaced by a new or modified product.

The life cycle is shown in Figure 4.2.

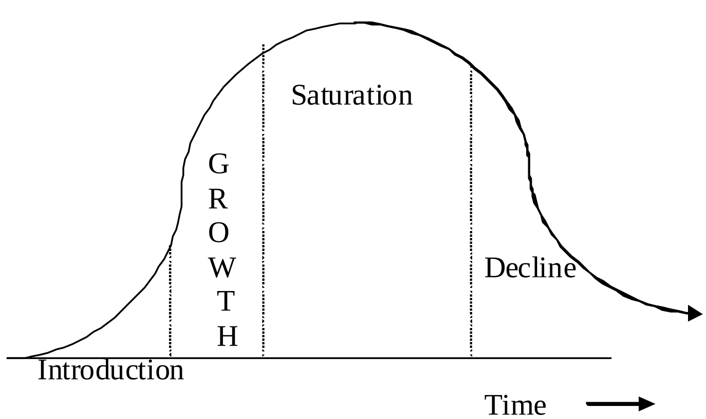

***Fig. 4.2** The Life Cycle of a Product*

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4.6.6 Manufacturability

Manufacturability implies designing a product in such a way that the manufacturing / assembling can be done easily. While designing a new product, the manufacturing capabilities (such as existing machines, equipment, skills of workers, etc.) of the organization have to be kept in mind. It is also to be kept in mind whether the product can be produced in bulk, economically or not.

4.6.7 Adaptability

A product should be operational in varying environmental conditions. It is always easier to create a product with robust design rather than make changes in the environment to suit the product. You would recall that some years ago, computers needed to be kept in air conditioned surroundings, free from dust. But today's computers are more robust and can work efficiently at room temperatures.

4.7 SUMMARY

In this unit, you have learned about the relevance and importance of product selection to the viability of an organization. You have also seen how forecasting is essential to help an organization anticipate changes and be prepared for the same. It helps the production manager to plan by correlating the forces of demand and supply. You have also learned about the characteristics of a good design, concepts of product design.

4.8 KEY TERMS

- **Product selection**: Product Selection is the process of selecting the right product, which the organization will produce.
- **Product design**: Product design is a term that refers to transforming an idea of how a product should be and the specifications, which are required for producing that product.
- **Product development:** Product development refers to the process of creating new products or modifying the existing ones in a predefined time frame, and at the targeted cost price while achieving the preset quality requirements.
- **Reliability:** Reliability means the dependability on the performance of a product for a designated period of time, without deterioration in the quality of performance of that product.
- **Quality:** Quality means conformance to specifications.
- **Standardization:** Standardization is a tool that is employed to promote the use of minimum number of parts to serve the maximum number of purposes, in order to achieve economy in manufacture, minimize whole life cost, and maintain quality and reliability necessary to ensure operational efficiency and effectiveness.
- **Simplification:** Simplification is the process of making the design simple. Complicating things which can be made simple is only going to add to costs.
- **Manufacturability:** Manufacturability implies designing a product in such a way that the manufacturing/assembling can be done easily.

Check Your Progress

1. What do you mean by product selection?
2. What is the role of concurrent engineering in the product designing process?
3. What are the characteristics of a good design?

- **Adaptability:** Adaptability means that a product should be operational in varying environmental conditions.

4.9 ANSWERS TO 'CHECK YOUR PROGRESS'

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1. Product selection means the process of selecting the right product, which the organization will produce. Any organization can sustain only if the right product is selected and produced. Valuable resources will be wasted if the wrong product is selected and in the end, the company may have to close down.
2. Concurrent engineering is a product design approach which emphasizes on cross functional integration and concurrent development of a product and its processes.

   Cross functional teams forms the backbone of the CE process. Several types of teams exist: technical team, programme management team, and numerous design-building teams. Based on the project's complexity, teams may even be required to consolidate the efforts of the various design-build teams. Further, task forces may be formed to attend to specific problems, such as investigating an emerging new technology.

   The main benefit of the CE approach is the reduced time to complete a project. This happens when all major activities happen in parallel, for example, simultaneous development market concepts, of manufacturing processes, product support structure and product design. The saving can come from not only the time overlap but also the reduction in mistakes that might occur in one phase but not discovered until a later phase. Frequent information sharing is important to CE success. Hewlett-Packard uses technology-focused teams operating in parallel as part of its strategy. Each team works on a key technology essential to the development of its products.
3. The characteristics of a good design are as follows:
   (a) Functionality or the function that the product is expected to perform.
   (b) Reliability or the dependability on the performance of a product for a designated period of time, without deterioration in the quality of performance of that product.
   (c) Productivity or the possibility of producing the product in the required quantity at a feasible cost. Several factors should be considered while designing the product such as number of operations that form the manufacturing process, availability of the necessary materials, technology requirements etc.
   (d) Quality or conformance to specifications. The process to be followed should be capable of producing the desired quantity with consistent quality.
   (e) Standardization and simplification – to promote the use of minimum number of parts to serve the maximum number of purposes, in order to achieve economy in manufacture, minimize whole life cost and maintain quality and reliability necessary to ensure operational efficiency and effectiveness.
   (f) Maintainability or ability to perform reliably for the designated period of time
   (g) Cost effective – being cost competitive is an essential requirement for a product to be successful.

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4.10 QUESTIONS AND EXERCISES

Short-Answer Questions

1. How do we ascertain that an idea is capable of commercial production?
2. What is meant by the life cycle of a product?
3. What is the relevance of product design in case of an existing product as well as a new product?
4. What do you mean by concurrent engineering in the concept of creating a product design?

Long-Answer Questions

1. What is product selection? What is its relevance in the profitability of a company?
2. What do you understand by the term 'value'? Explain value engineering and value analysis.
3. Differentiate between product design and product development.

4.11 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

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Evans, J.R., D.R. Anderson, D.J. Sweeney and T.A. Williams. 1984. *Applied Production and Operation Management.* St. Paul MN, US: West Publishing Co.

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MODULE - 2

UNIT 5 PROJECT ANALYSIS – PERT/CPM

NOTES

Structure

5.0 INTRODUCTION

In the previous units, you have learnt about the repetitive activities in organizations. However, what about activities in an organization that are one-time in nature? The Metro Rail Corporation of Delhi constructs metro lines at one place and then moves on to the next. Gammon India constructs bridges and dams. A software consultant implements a database management project; a scientist in the research and development department of an organization is given a research project to do; and for an entrepreneur, starting a new business or manufacturing unit is a project. These are all one-time activities. The methods we learnt in previous units cannot be applied here.

In any manufacturing facility, besides production, there are a number of other activities such as minor and major repair work, maintenance work, etc. Each of these has a well-defined objective, a sequence of activities, a defined beginning and end, utilization of resources, such as man, machine, materials, money and method. However, the uniqueness of these activities is that they are all one-time. It is not a routine production. All such activities are called projects.

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Due to their uniqueness, a different methodology is adopted to manage them. This unit is about understanding a project and network analysis in managing projects.

5.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Define the characteristics of a project
- Understand the life cycle of a project
- Describe the different types of projects
- Assess the scope of project management
- Discuss the project planning process
- Understand PERT and CPM
- Explain the principles of network construction
- Understand the time aspect of projects
- Analyse the limitations of PERT and CPM

5.2 DEFINITIONS OF PROJECT AND PROJECT MANAGEMENT

We can define a project as a series of related jobs usually directed towards some major output and requiring a significant period of time to perform.

There are several definitions of a **project**. Munns and Bjermi define a project as, '*The achievement of a specific objective which involves a series of activities and tasks that consume resources, and project management as the process of controlling the achievement of project objectives.*'

The British Standard for Project Management BS 6079 defines **project management** as '*The planning, monitoring and control of all aspects of a project and the motivation of all those involved in it to achieve the project objectives on time and to the specified cost, quality and performance.*'

5.3 CHARACTERISTICS OF A PROJECT

The main characteristics of a project are:

(a) Every project has a unique set of objectives.

(b) Every project has a life span.

(c) Every project has defined starting and ending points.

(d) Change is a feature of a project. The character of the project may change mid-way.

(e) Projects are made-to-order or customized. So they are unique.

(f) They use a wide variety of resources and skills and involve cost and time.

(g) They involve coordination across functional units of an organization and across organizations.

5.4 LIFE CYCLE OF A PROJECT

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As every project has defined starting and ending points, it also has a life cycle. You have learnt about a product life cycle in Unit 4. Now you will learn about the life cycle of a project.

The life cycle of a project can be classified into four stages –

(a) Conception and definition phase
(b) Planning and organizing phase
(c) Implementation phase
(d) Project close

5.4.1 Conception and Definition Phase

This phase begins with the idea of the project. The idea is explored by listing out the following:

– Raw materials required
– Location selection and plant layout
– Technology/process selection
– Machinery/equipment needed
– Utilities – fuel/ power, water, sanitation, etc.
– Manpower and organization pattern
– Resources needed

5.4.2 Planning and Organizing Phase

This is a very important phase. In this phase –

(a) Necessary approvals are taken to go ahead with the project.
(b) Finances are arranged.
(c) Project infrastructure is planned – land is obtained, machinery is put in place.
(d) Manpower recruitment and organization structure are finalized. Project leaders are appointed.
(e) Schedules and budgets are finalized.
(f) Licenses and government clearances are obtained.
(g) Contracts are prepared and executed.
(h) Site preparation is done.
(i) Construction resources and materials are put in place.
(j) Work packaging is done. This means the entire project is split into activities and work packages and roles are assigned.

5.4.3 Implementation Phase

This is the actual implementation phase where the work is carried out.

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5.4.4 Project Close

It is also called project clean-up. Once the project has been implemented, all the drawings, documents, operation manuals, maintenance procedures/ manuals, etc. are handed over to the customer. Usually a small portion of the payment is held up till this phase. The final installment of payment is released after the customer is satisfied with the guarantee test runs.

Figure 5.1 shows the life cycle of a project.

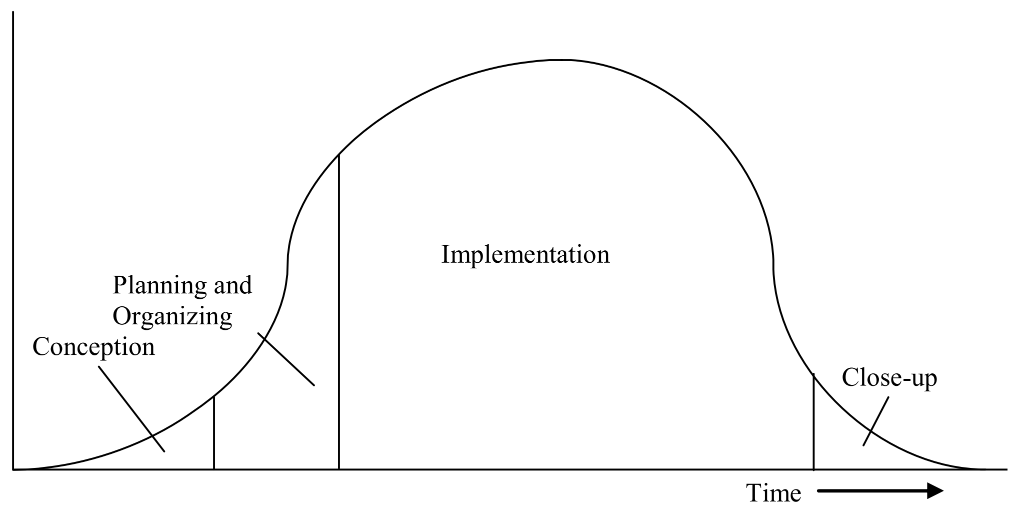

Fig. 5.1 *Life Cycle of a Project*

5.5 TYPES OF PROJECTS

A project requires the coordinated functioning of several units of an organization such as – financial, HRD, information system, etc. Typically, for every project, a separate team is formed which consists of project managers and a project leader. In a project, besides the technical activities involved, the management aspects are equally important. Success in projects is a group activity. Also, after a project has been completed, the team is supposed to be disbanded. For another project, a new team is formed.

Although projects are one time occurrences, many projects can be repeated or transferred to other settings or products. But the result will always be considered as another output.

5.5.1 On the Basis of Composition

Projects can be classified on the basis of composition into mainly three types:

(a) Pure project

(b) Functional project

(c) Matrix project

5.5.1.1 Pure project

Pure project is one in which a self-contained team works full time on the project. A team typically consists of a Project Leader and Team members reporting to him and only him.

Advantages of a pure project

- The project manager has full authority over the project.
- Team members report to one boss. They do not have to worry about dividing loyalty with a functional area manager.
- Lines of communication are shortened. Decisions are made quickly.
- Team pride, motivation, and commitment are high.

Disadvantages of a pure project

- Duplication of resources takes place since equipment and people are not shared across projects.
- Organizational goals and policies are ignored, as team members are often both physically and psychologically removed from headquarters.
- Because team members have no functional area home, they worry about life - after -the project, and project close-up is often delayed.

5.5.1.2 Functional project

At the other end is the functional project. Several projects could be running simultaneously for example, several research projects in the R&D department of an organization.

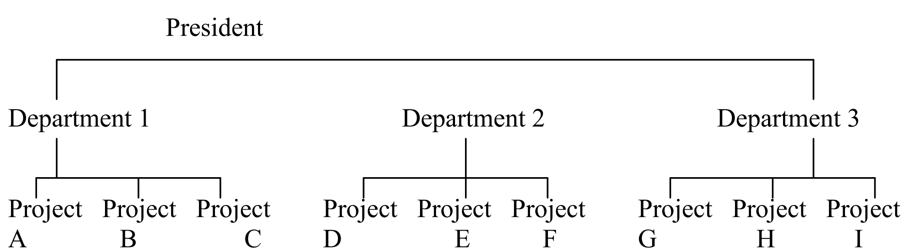

Fig. 5.2 *A Functional Project*

Advantages of a functional project

- A team member can work on several projects.
- Technical expertise is maintained within the functional area even if individuals leave the project or organization.
- The functional area is a home after the project is completed.
- There is synergy within the department since the team members keep moving from one project to another.

Disadvantages of a functional project

- Aspects of the project that are not directly related to the functional area get short-charged.
- Motivation of team members is often weak.
- Needs of the client are secondary and are responded to slowly.

5.5.1.3 Matrix project

The matrix project is an amalgamation of functional and pure project structures. Each project utilizes people from different functional areas. The project manager (PM) decides the tasks and when they will be performed, but the functional managers control which people and technologies are to be used.

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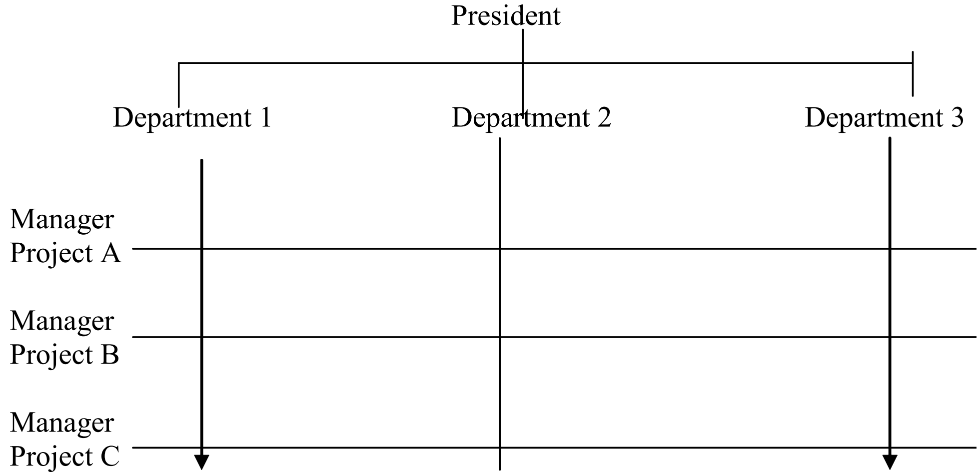

Fig. 5.3 *The Matrix Project*

Advantages of a matrix project

- Inter departmental communication is better than in other projects.
- Duplication of resources is minimized.
- Team members have a functional 'home', after project completion, so they are less worried about life- after- project than if they were a pure project organization.
- Policies of the parent organization are followed. This increases support for the project.

Disadvantages of a matrix project

- There are two bosses. Often the functional manager will be listened to before the project manager.
- It is doomed to failure unless the project manager has strong negotiating skills.

5.5.2 On the Basis of Size

Projects can also be classified on the basis of size.

(a) **Major** – Major projects are those whose value is equal to the capital of parent organization.

(b) **Large** – Large projects are those whose value is equal to one-tenth the capital of parent organization.

(c) **Medium** – In a medium project, the value is equal to one-tenth the value of a large project

(d) **Small** – In a small project, the value is equal to one-tenth the value of a medium project.

5.6 THE SCOPE OF PROJECT MANAGEMENT

There are three factors that predominantly influence a project. These are:

– Time
– Resources, such as people and equipment
– Cost

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Time – In most projects, some activities are critical and must be completed exactly on schedule or the entire project will be delayed. For rest of the activities, there is some freedom in scheduling. It is important for the project manager to determine which are these critical activities as these will determine how long a project will take and when specific activities should be started for controlling the progress of the project.

Resources – Project managers must also determine the resources, such as people and equipment that are available for the project and how they should be allocated among the various activities. Improper management of resources can significantly delay a project.

Cost – The cost of the project must be controlled. Managers seek ways in which cost can be minimized in order to meet a deadline. Cost is closely related to the allocation of resources throughout the project.

Most organizations often have specific people designated as project managers. Project managers are the Leaders of a project. They lead the project activities, plans and track progress of the work and provide direction to project personnel.

Two of the more useful tools that have been developed to assist project managers in their scheduling efforts are project evaluation and review technique or PERT and critical path method or CPM. These are explained in Section 5.9.

5.7 THE PROJECT PLANNING PROCESS

Planning is the process of determining the set of activities that need to be performed and when they should be completed in order to meet an organization's goals. There are a number of basic questions that must be addressed in order to develop a useful plan. – These include, 'What results do we want and by when?', 'Why do we want them?', 'How should we go about getting them?', 'Who should be involved?', 'Where should the work be done?' and 'When should the activities be completed?'

These questions can be logically structured into a step-by-step planning framework that provides the basis for project management. This methodology can be described as follows:

1. **Project definition:** This is the starting stage. In this stage, the individual activities that must be performed and the sequence required to perform them are listed out.
2. **Resource planning**: For each activity that is identified, the resources that are needed are determined: personnel, time, money, equipment, materials, and so on. It is also determined whether any training is needed or not and ensured that the personnel are properly trained.
3. **Project scheduling:** All the timelines are decided and the time schedules for each activity are laid out.
4. **Project control:** Controls are established in order to determine the progress of the project. Alternative plans are developed in case the original plan meets roadblocks that cannot be overcome.

Projects are often delayed because of failure to properly perform the above stated four tasks.

The first step in the project planning process is to define the individual activities that must be performed and the sequence in which they must be performed. This is by far the most difficult task in project management and requires a good deal of experience and knowledge of the project, as well as good communication with all parts of organization that may be involved.

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Projects are generally defined in terms of both activities and events. Activities are tasks that consume time; events are points in time that represent the start or completion of a set of activities. Events are milestones by which to measure the progress of a project. Hence, events are often specified and then the activities necessary to accomplish them are defined.

The immediate predecessor information is also important in identifying the sequence in which the activities must be performed.

Once the project has been planned, the next step is to determine the resources needed to accomplish the task. The network diagrams are drawn which indicate the resources needed for each activity, the timelines, etc. The timelines inform of the targets or milestones to be achieved for each activity or set of activities. Project control involves monitoring to see that each of the milestones is being met and that the project is running as per schedule.

The plan for the project specifies the end product that is desired, and in some cases it may contain considerable details about the components that make up the end product. Such information provides the basis for constructing work packages and specifying their contents. In many cases, however, the nature of the work packages cannot be determined simply from the specifications of the end product, and engineers must develop a concrete plan, often working backward from the end product to its components, and then to the activities that are required to obtain such components. In a complicated project, it is often difficult to describe work packages in terms that are definite enough to enable the manager to know exactly when the project can be completed.

For research projects, the nature of work may not be foreseeable, and hence the designing of work packages with written descriptions of every step may be difficult or impossible. The absence of a written plan greatly complicates the control problem.

Detailed project report

The detailed project report (DPR) prepared at the beginning of a project includes the time schedule, equipment requisition plan, cost schedule and the detailed engineering and erection plans. It is a complete blue print for the execution of the project and is an implementation guide for the project team. It describes the functions, authority and activities with regard to time, cost and technical parameters. The DPR sets the standards for time, cost and work against which the actual performance can be later compared as the work progresses. In the case of multi-level scheduling, the DPR is prepared in many sections, each one for a separate work package and function.

5.8 CONSTRUCTING NETWORKS

A network depicts the framework of a project. It is a pictorial representation of the set of activities that are to be performed; their sequence, timelines, resources needed, Networking shows what is to be done in the proper sequence and thus, (a) provides visibility to all the concerned agencies their inter-relationships, and (b) computes the time, cost and resource requirements for the project.

The different types of networks are:

(a) Programme Evaluation and Review Technique (PERT) network

(b) Critical Path Method (CPM) network

(c) Decision network

(d) Graphical Evaluation and Review Technique (GERT) network

NOTES

Before we learn how to draw networks, let us learn the meanings of some of the commonly used terms, with respect to a project.

A project starts out as a **statement of work (SOW).** The SOW may be a written description of the objectives to be achieved, with a brief statement of the work to be done, and a proposed schedule specifying the start and completion dates. It could also contain performance measures in terms of budget and completion steps ((milestones) and written reports to be supplied.

A **task** is a further subdivision of a project. It is usually not longer than several months in duration and is performed by one group or organization. Several tasks make a project.

A **sub task** is a part of a task and may be used if needed to further subdivide the project into more meaningful pieces. Several sub tasks make a task.

A **work package** is a group of activities combined to be assignable to a single organizational unit. The package provides a description of what is to be done, when it is to be started and completed, the budget, measures of performance and specific events to be reached at specific points in time.

Project milestones are specific events in a project, which need to be met so that the project runs on schedule. Typical milestones might be the completion of the design, the production of a prototype, the completed testing of the prototype, and the approval of a pilot run.

Completion of one or more work packages results in the completion of a subtask; completion of one or more subtasks results in the completion of a task; and completion of all tasks is required to complete the project.

Activity is the smallest sub-division of the work or job. As the work in a project gets further sub-divided into smaller and smaller work packages, there comes a point where further sub-divisions are not economically feasible. Activities are tasks that consume time.

Events are points in time that represent the start or completion of a set of activities. Every activity has a start event or node and an end event or node.

Sequencing relationships between activities

After a list of activities has been made, the next task would be to find the interrelationships between these different activities. The interrelationships are generally technological in nature and indicate the following:

- Jobs that can be done only when one or more other jobs are completed,
- jobs that can be done independently, which means one job does not have to wait for the completion of another job, and
- jobs that can be done simultaneously.

The **work breakdown structure (WBS)** defines the hierarchy of project tasks, sub tasks and work packages. The WBS is important in organizing a project because it

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breaks down the project into manageable pieces. The number of levels of breaking down will depend on the project. How much detail or how many levels to use will depend on the following:

- The level at which a single individual or organization can be assigned responsibility and accountability for accomplishing the work package.
- The level at which budget and cost data can be collected during the execution of the project.

There is not a single correct WBS for any project, and two different project teams might develop different WBSs for the same project. Some experts have referred to project management as an art rather than a science, because there are so many different ways that a project can be approached. Finding the correct way to organize a project depends on experience with the particular task.

Activities are defined within the context of the WBS and are pieces of work that consume time and resources. But activities do not necessarily require the expenditure or effort by people, although they often do; for example, waiting for paint to dry may be an activity in a project. Activities are identified as part of the WBS. Activities need to be defined in such a way that when they are all completed, the project is done.

The network should be updated according to unavoidable or sudden changes in dimensions. The network application can also help in resource allocation and levelling. Activity time, activity slack, resource requirement for the activities, etc., can be taken into account in resource allocation and levelling.

5.9 PERT AND CPM

The two best known network planning models – CPM and PERT – were developed in the 1950s. While PERT and CPM have the same general purpose and utilize similar methodologies, the techniques were actually developed independently.

PERT or project evaluation and review technique was developed for the US Navy's Polaris missile project in the late 1950s. This was a massive project involving over 3,000 contractors. Because most of the activities had never been done before, PERT was developed to handle uncertain time estimates of the various jobs or activities. Consequently, **PERT** *was developed with the objective of being able to handle uncertainties in activity completion times.*

On the other hand, the Critical Path Method (CPM) was developed for scheduling maintenance shutdown at chemical processing plants owned by Du Pont. Since maintenance projects are performed often in this industry, reasonably accurate time estimates for activities are available. *CPM is based on the assumption that project activity times can be estimated accurately and that they do not vary*. CPM is used to study the option of reducing activity times by adding more workers and/or resources, usually at an increased cost. Thus, a distinguishing feature of CPM is that it enables time and cost trade-offs for the various activities in the project.

PERT is a project evaluation technique. Events and activities must be sequenced in the network under a highly logical set of ground rules, which allow the determination of important critical and non-critical paths for analysis. PERT can be applied where the activities are complex and largely sequential in nature. The application of PERT, however, is limited due to difficulties in estimating the duration of various activities. The probabilistic PERT is not of much use since assigning probabilities to the project activity time is not easy.

NOTES

PERT networking can give an advantage if,

(a) The priority need is to keep the project simple,

(b) The front-end activities are detailed and far-end activities summarized, and

(c) It is divided according to agency or department for better understanding and visibility.

CPM is a deterministic approach using a one time estimate of the activity duration. CPM uses a mathematical procedure for estimating the time-cost trade-offs of a project, reallocation of resources from one activity to another, to achieve the shortest overall project time at the least cost.

Today, the distinction between PERT and CPM as two separate techniques has largely disappeared. Computerized versions of the PERT/CPM approaches often contain options for considering uncertainty in activity times as well as activity time – cost trade-offs. Today, project planning, scheduling and controlling procedures have combined the features of PERT and CPM and the distinction between the two techniques is no longer necessary. Let us now see how PERT/CPM can be used effectively to control a project.

PERT cost: The technique called PERT-Cost attempts to incorporate a cost dimension into the network analysis. This is basically an extension of the planning of the time dimension. This helps in developing a critical path that is optimum considering both time and cost aspects jointly. For the purpose of planning, it is supposed to provide a basis for analysing the actual time and cost jointly. It also helps in determining the cash flow requirement during the course of the project.

Experience shows that PERT-Cost is so complicated that it loses out on practical application. In order to control time, work packages must be quite small, but great difficulty is experienced in estimating the cost of each small work package.

5.9.1 Critical Path Method

In this method of representing a project, a network diagram is drawn which represents the sequence of activities, their starting and ending dates, their predecessor activities and the resources needed. A study of the network diagram will indicate the minimum time required to execute the project from start to finish.

For large projects, such as hydel projects, the number of activities may run into thousands and then the complete CPM charts become quite complicated. Although such a detailed network is necessary and useful, not all the executives in the different hierarchical levels in an organization will be interested in all the jobs indicated in such a network. So what is done is as follows –

– The top level management is interested in only the overall sub- division of work and not in too many detailed activities.

– Functional departmental heads are interested only in activities related to the work of their departments and not in the complete CPM chart for the whole project.

Hence, besides the Master Network, smaller versions of the CPM chart showing only limited portions of the network are drawn. Wherever necessary, the relationship of their components of the jobs in other departments are indicated in the networks meant for them.

First, we need to learn the rules for network construction.

5.10 PRINCIPLES OF NETWORK CONSTRUCTION

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A job or an activity is shown as an arrow between two full circles.

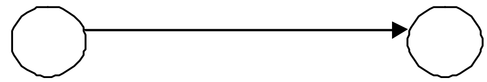

Fig. 5.4 Representation of a Job or Activity

The tail of the arrow represents the start of the activity and the head of the arrow represents the end. The circles at these respective ends, therefore, represent the start and the end of the particular job or activity. These circles are called **events or nodes.** All networks should have one initial and one terminal node. Also, events or nodes are represented by numbers, so duplication of event numbers should never happen. Activities are tasks that consume time; events are points in time that represent the start or end of activities.

Events are often thought of as milestones by which to measure the progress of a project. It is often convenient to specify events and then define the activities necessary to accomplish the events.

It should be remembered that a single activity can never be represented twice in the network.

Before starting a particular activity, all preceding activities should be completed. Two jobs, where one job follows another, are shown below:

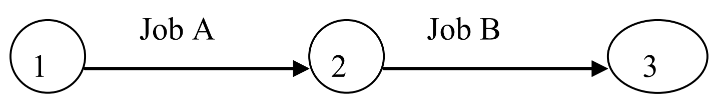

Fig. 5.5 Representation of Job A and Job B

The node or event 2 represents the completion of activity or Job A as well as the beginning of activity or Job B. The nomenclature that is followed is to represent an activity by its start and end events, e.g., Job A as shown above is called job or activity (1,2).

If two jobs or activities can be done simultaneously, they can be shown as follows:

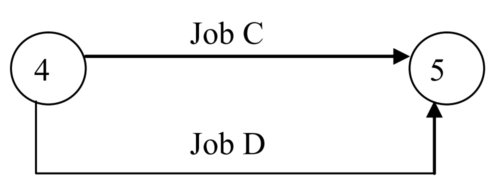

Fig. 5.6 Representation of Two Jobs/Activities that can be done Simultaneously

This representation is similar to what we see in electrical and electronic circuits. Probably that is the reason why CPM and PERT techniques are known as network techniques.

If we were to write the Jobs C and D in the nomenclature defined above, both C as well as D would be called activities (5,6). But every activity should have an independent nomenclature. So we represent them as follows:

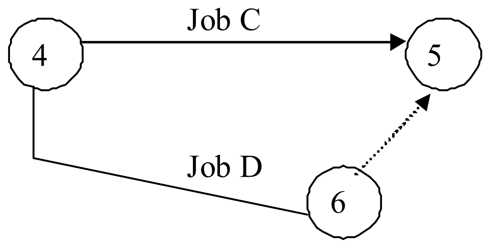

Fig. 5.7 *Every Activity has an Independent Nomenclature*

The dotted arrow included above is called a **Dummy Activity.** This is done so that activities C and D have different nomenclatures, viz C-(4,5) and D-(4, 6). So we introduce a dummy activity when two or more activities have identical predecessor and successor activities. The Dummy activity has been introduced only for facilitating proper nomenclature. It does not exist physically. It consumes neither time, money, material nor any other resources. The duration of a dummy activity is always zero.

It is important to know that a dummy activity cannot be the only activity to emanate from a node; likewise, a dummy activity cannot end at the final node.

Dummy activities are useful in other situations also. Supposing Job C is dependent on the completion of jobs or activities A and B, but activity D is dependent only on the completion of activity B. This can be represented by using a dummy. If a dummy would not have been used, this relationship would not have been properly represented.

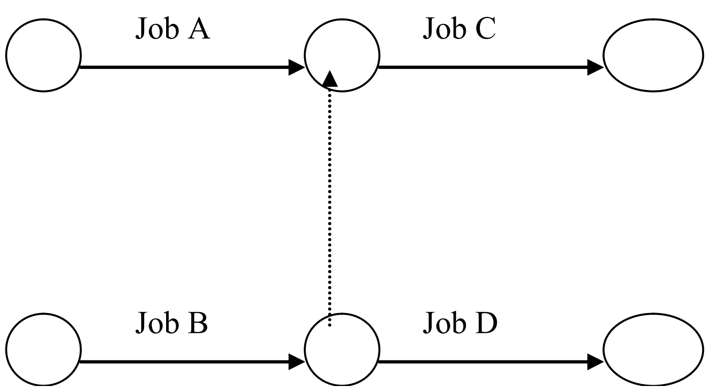

Fig. 5.8 *Example showing the Relevance of using a Dummy*

A **merge event** occurs when there is a situation in which more than one activity needs to be simultaneously completed.

A **burst event** occurs when there is a situation in which more than one activity needs to be simultaneously initiated.

A **dummy event** is an imaginary event which can never happen.

Parallel activities, without having intervening relationships, are prohibited.

Numbering of the events or nodes is an important activity. Different events are numbered in a systematic manner with the numbers increasing from left to right and from top to bottom. Since the flow of certain dummies may be either vertically downwards or vertically upwards, depending upon the flow of the dummies one may number the succeeding events.

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Other Tips for Drawing Networks

For more clarity, while drawing the network one should avoid the crossing of activity arrows. Also, it is better to have as few dummies as possible.

Once the network has been developed, the corresponding time, cost and other resource requirement figures are put in the different activities of the network, for the purpose of analysis of the network. This network analysis provides a plan or guideline for the implementation of the project.

We will understand Network Construction through the example given below.

Example 1

Consider that you have been given a project as part of your BBA programme to arrive at a decision for selecting the best company, in which you can invest. Your Project Guide has suggested that you perform the analysis in the following four activities:

a. Select a company.
b. Obtain the company's annual report and calculate the various ratios.
c. Collect technical stock price data and construct charts.
d. Individually review the data and make a team decision on whether or not to invest in the company.

Your group consists of four people. All the team members should be involved in the project. You will meet at the end of the week to decide what company the group will consider.

Two people will be responsible for Activity B. They will obtain the annual report and do ratio analysis, and the other two will do Activity C. They will collect the technical data and construct the charts. Your group expects that it will take two weeks to get the annual report and perform the ratio analysis, and a week to collect the stock price data and generate the charts. You agree that the two groups can work independently. Finally, you agree to meet as a team to make the purchase decision. Before you meet, you want to allow one week for each team member to review all the data.

Solution:

Following are the steps for executing a project:

1. **Identify each activity to be done in the project, and estimate how long it will take to complete each activity.** This is obtained by studying the information given above. The four activities are – A,B,C and D. Time given to complete A from the start date is one week, for B it is two weeks, for C it is one week and D also takes one week. This is the expected duration of the activities and is written as A (1), B (2), C (1), D (1).
2. **Determine the required sequence of activities, and construct a network reflecting the precedence relationships**. First, identify the immediate predecessors associated with each activity. The immediate predecessors are the activities that need to be completed immediately before an activity. Activity A needs to be completed before activities B and C can start, B and C need to be completed before D can start.
3. Table 5.1 reflects what we know so far:

Table 5.1 ***Table 5.1*** *The Steps for Executing a Project*

Activity	Nomenclature	Immediate Predecessor	Time (weeks)
Select company	A	None	1
Obtain annual report and perform ratio analysis	B	A	2
Collect stock price data and perform technical analysis	C	A	1
Make a decision	D	B and C	1

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Using this information, we draw the **Network Diagram** as follows:–

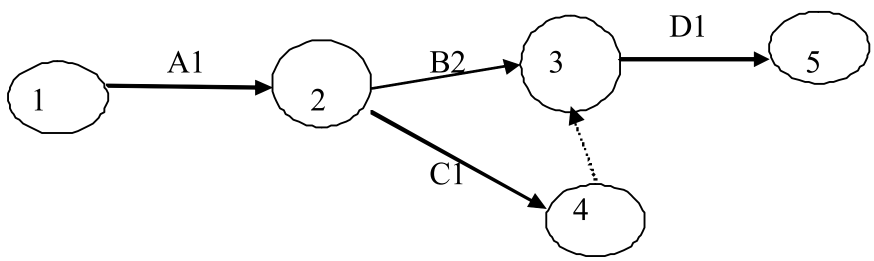

Fig. 5.9 *Network Diagram*

(The number after the alphabets is the time)

4. **Determine the critical path:** Consider each sequence of activities that runs from the beginning to the end of the project. In this project, there are two paths: 1 –2 – 3 – 5 and 1 – 2 – 4 – 3 –5. The critical path is the path where the sum of the activity times is the longest, 1 – 2 – 3 – 5 has a duration of four weeks and 1 – 3 – 4 – 3 –5 a duration of three weeks. The critical path therefore, is 1 – 2 – 3 – 5. If any activity along the critical path is delayed, then the entire project will be delayed.

   Note **-** The critical path of activities in a project is the sequence of activities that form the longest chain in terms of their time to complete. If any one of the activities in the critical path is delayed, then the entire project is delayed. CPM techniques are used to calculate when an activity must start and end and whether the activity is part of the critical path.

   Characteristics of a critical path

   (a) Every network has a critical path. A network may have more than one critical path.

   (b) Number of activities in a critical path may be less than the activities in the non-critical path.

   (c) A critical path may have a dummy activity.

   (d) A critical path determines the project duration time.

   (e) Activities on critical path are called critical activities**.**

   (f) If the project duration time needs to be shortened, then activities on the critical path need to be shortened.

5. **Determine the early start/finish and late start/finish schedule:** To schedule the project, we need to find when each activity needs to start and

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when it needs to finish. For some activities in a project, there may be some leeway when an activity can start and finish. This is called the **slack time in an activity**. It is the maximum delay possible in the occurrence of an event.

For each activity in the project, we can calculate four points in time; the early start, early finish, late start, and late finish. The early start and early finish are the earliest times that the activity can start and be finished. Similarly, the late start and late finish are the latest times that the activities can start and finish. The **difference between the late start time and early start time is called the slack time.**

To calculate numbers, start from the beginning of the network and work to the end, calculating the early start and early finish numbers. Start counting with the current period, designated as period 0. Activity A has an early start of 0 and an early finish of 1 (it takes 1 week). Activity B's early start is A's early finish or 1. Similarly, C's early start is 1. The early finish for B is 3 (third week, and the early finish for C is 2. Now consider activity D. D cannot start until both B and C are done. Because B cannot be done until 3, D cannot start until that time. The early start for D, therefore, is 3, and the early finish is 4.

To calculate the late finish and late start times, start from the end of the network and work toward the front. Consider activity D. The earliest that it can be done is at times 4; and if we do not want to delay completion of the project, the late finish needs to be set to 4. With a duration of 1, the latest that D can start is 3. Now consider activity C. C must be done by time 3 so that D can start, so C's late finish time is 3 and its late start time is 2. Notice the difference between the early and late start and finish times: This activity has 1 week of slack time. Activity B must be by time 3 so that D can start, so its late finish time is 3 and late start time is 1. There is no slack in B. Finally, activity A must be done so that B and C can start. Because B must start earlier than C, and A must get done in time for B to start, the late finish time for A is 1. Finally, the late start time for A is 0. Notice there is no slack in activities A, B and D.

These values are represented in Table 5.2.

Table 5.2 *Calculating the Start and Finish Dates*

Activity	Early start date	Late start date	Early finish date	Late finish date	Slack
A	0	0	1	1	0
B	1	1	3	3	0
C	1	2	2	3	1
D	3	3	4	4	0

Note**: Early start date and early finish dates** of an activity are based on the condition that every activity would be started and finished as early as possible.

Late start date and late finish dates of an activity are based on the condition that every activity would be started and finished as late as possible, but the project will still get completed in the scheduled time.

Example 2

The table below shows the various tasks in a project, their duration and predecessors. Draw the Network diagram.

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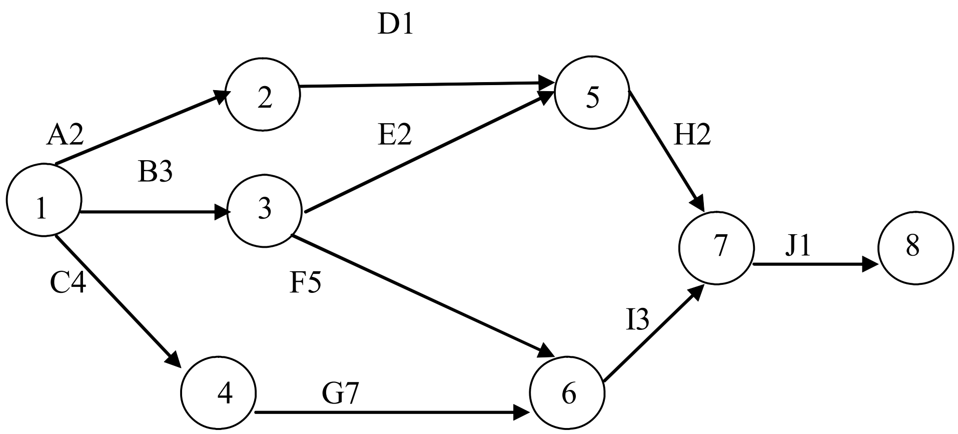
Task	*Time (In weeks)*	*Predecessors*
A	2	-
B	3	-
C	4	-
D	1	A
E	2	B
F	5	B
G	7	C
H	2	D,E
I	3	F,G
J	1	H,I

Solution

(i) Activities A, B and C do not have any predecessors. So this will be the starting point. We can represent these three activities from node-1 and end at nodes 2, 3 and 4 respectively.

(ii) D can start only when A ends. E and F can start only when B ends. G can start when C ends. So D will start from node-2, E and F from node-3 and G from node 4.

(iii) Proceed similarly for activities H, I and J and complete the diagram.



(iv) Find out the critical path. There are several ways to complete the project. It can be ADHJ, BEHJ, BFIJ, CGIJ. Calculate the time duration for each of the paths. It is found that the longest duration is taken by CGIJ = 4+7+3+1 = 15 days. Therefore, this is the critical path for the project.

Critical Path

We learnt above that the Critical path is the longest path, all the activities falling on the critical path are "critical" and have no slack. These critical activities, which are the bottleneck activities, need management's special attention since any delay occurring on any of these activities will delay the project as a whole. The other paths of lesser time duration will have a certain amount of slack which could absorb any delays occurring in the activities on these paths.

In smaller networks it is easy to find visually which is the longest path, and therefore, the 'critical path'. But it is more difficult with networks having a large number of activities.

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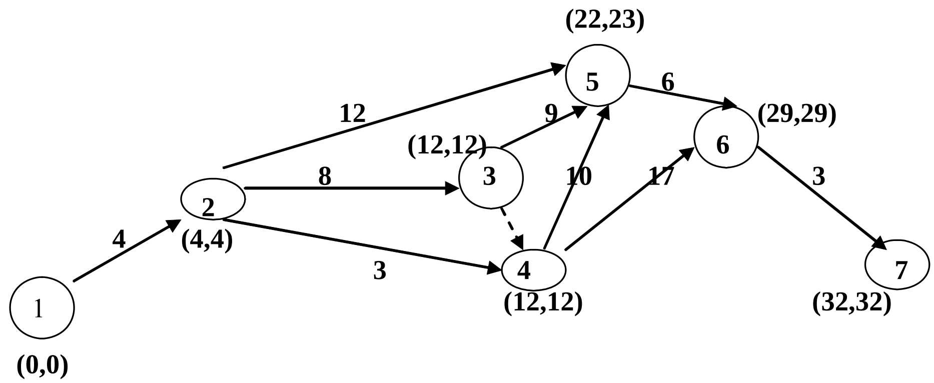
There is a systematic method by which one can find out the critical path and as well the slacks available to different activities on non - critical paths.

Example 3:

Study the network diagram given below.



(a) Calculation of Earliest Start Times

Let us consider the Figure above. Consider only the first numbers within the brackets.

The earliest start time for Activity 1-2 is zero. This takes 4 time periods and will finish by time 4. Therefore, Activities 2-3, 2-4 and 2-5 cannot start before 4 since they are dependant on the completion of 1-2. Activity 2-3 is completed at time period 12 (8+4), 2-4 at 7 and 2-5 at 16.

Activity 3-5 originating from event 3 can start only after Activity 2-3 is completed which is after the end of 12 time periods. The activities starting from event 4 can start only after activities 2-4 and 3-4 are completed. Now 3-4 is a dummy activity consuming no time at all.

Since Activity 2-4 is completed after time period 7 and Activity 2-3 is completed after time period 12, Activities 4-5 and 4-6 have to necessarily wait till the end of 12 time periods. Therefore, Activity 2-4 has a slack. Even if Activity 2-4 is completed earlier than the completion of 12 time periods, we cannot start Activities 4-5 or 4-6. Since the early time of event 3 is 12, early time of event 4 is also 12.

Now come to event 5. Three activities, viz. 2-5, 3-5 and 4-5 arrive at event 5. Activity 5-6 is dependent on the completion of these three activities. So it can start only when the last finishing activity has finished, which is 4-5 with 22 time periods.

Proceed similarly for events 6 and 7. The project can complete at the earliest at the end of 32 times periods.

In this procedure we have proceeded from the left-hand side to the right-hand side in the direction of the arrows. This procedure is called the **'forward pass'.** The forward pass can give us the earliest start times of all the activities in the network.

(b) Calculation of Latest Allowable Completion Times

Assume that the latest allowable time for the completion of the project is the same as the earliest possible time at which it can be completed, we can get more information on the activities by another procedure called the **'backward pass'.** Here, we proceed from the right-hand side to the left-hand side in the opposite direction of the arrows.

Since Activity 6-7 has a time duration of 3, the latest time at which Activity 6-7 can start is 32 – 3 = 29. This also means that the activities ending at node 6, viz. Activities

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4-6 and 5-6 can be allowed to complete latest by 29. Activity 5-6 can be allowed to start latest at 29 – 6 = 23.

This calculation of the latest allowable time for the start of the activities serves the purpose of not delaying the project, but at the same time allowing the activities to start as late as it is possible to allow them to do so.

Since the duration for Activity 4-6 is 17, the latest allowable time for its start is 29 – 17 = 12. Since Activity 5-6 starts at 23, it will not be affected if we start Activity 4-5 at 23 – 10 = 13 time periods.

So at node 4 we have two late times, viz. 13, coming from Activity 4-5 and 12 coming from Activity 4-6. Between these two if we were to choose 13, Activity 4-6 would have come to its completion after the end of 13 + 17 = 30 time periods. This is not what we want, because activity 6-7 has to start at its latest at the end of 29 time periods. Therefore, we have to choose 12 (12 + 17 = 29). This is the latest allowable time for the completion of activities feeding into node 4, viz. Activities 2-4 and 3-4. Otherwise, we would delay the entire project by one time period.

The principle in the backward pass, therefore, is to calculate the late times at a node from all the arrows emanating from that node and choose the lowest of these late times.

Applying the above principle to the next node, node 3, its late time is the minimum of (23 – 9 = 14) and (12 – 0 = 12) that is 12.

The late time for node 2 is 4 and for node 1 is obviously zero. If we put these late times of the nodes also in the boxes adjacent to these nodes in the network, we see that nodes 1, 2, 3, 4, 6 and 7 have equal early and late times. Therefore the early times are shown on the left-hand side and the late times at the right-hand side in the brackets drawn adjacent to the events or nodes. This is the convention followed for representing the early and late times.

(c) Activity Slacks or ‘Floats’

In order to find the critical path, we need to find the slacks of the different activities and identify those activities which have no slack at all. These activities will be the critical activities and will comprise the critical path. *The slacks are called, in CPM language, ‘floats’.* Let us try to calculate the floats for the activities.

(i) Total Float

Consider Activity 3-5. This activity can start at its earliest at the end of time period 12 and can be completed latest at the end of the time period 23. If the preceding activities allow Activity 3-5 to start at its earliest, viz. time 12, and if the activities down stream i.e 5-6 allow Activity 3-5 to end at the latest possible time, then Activity 3-5 has a slack or free play or float of 23 – 12 – 9 =2. (Note that 9 is the duration of 3-5.) The project duration will not be affected even if 3-5 were to use this entire float. The downstream Activity 5-6 can now start only at their latest allowable time which is 23 and, therefore, Activity 5-6 may not have the liberty of starting at its earliest possible time and having a certain amount of slack for itself.

The slack or float for Activity 3-5 which we indicated above is called the ‘total float’.

(ii) Free Float

If we do not want the downstream activities to be affected by any permitted delays in the conduct of Activity 3-5, we shall have to see that Activity 3-5 ends by time period 22

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which is the early time of event 5. In such a case, the float that is available to this activity is that of the difference between the early times of the two events minus the duration of the activity. This float is, therefore, 22 – 12 – 9 = 1. This kind of a float is called a **'free float'**. In calculating the free floats, the activities start at the early times and end at the early times of their respective nodes or events.

(iii) Independent Float

There is another kind of a float which is called the **'independent float'**. Here the activity is allowed to start at the late time, so as to allow the upstream activities to finish at their latest; and the activities are supposed to end at the early times of the end nodes, so as to allow the downstream activities a maximum amount of slack. Such a calculation of the float for an activity, will be independent of any effects either on the upstream side or on the downstream side and this is probably the reason for its name. The independent float for activity 3-5 is 22 – 12 – 9 = 1.

The activities which are on the critical path have their total and free floats equal to zero.

(d) The Importance of Floats

Total Float, if used completely, would make the succeeding activities critical. For this reason, it is not desirable to utilize this float completely, although the information that so much float is available there is helpful.

Free Float can be utilized completely without disturbing the succeeding activities. Therefore, in case of slippages in time, Free Float is first made use of before resorting to Total Float. Still, the use of Free Float has an underlying assumption that the activity can start at its earliest which, in turns, means that the preceding activities should have been finished by this time. Thus, the use of Free Float is somewhat conditional, whereas Independent Float has no such strings attached either to the preceding or to the succeeding activities. It can be freely used.

One may use the floats judiciously while managing a project. The person responsible for only one activity can be given only the Independent Float or at the most the Free Float information. The information regarding Total Float is liable not to be understood properly and may generate unnecessary complacency. At other levels of management also only the Free Float may be used first, and the Total Float may be used only exceptionally.

Free Float and Total Float are extremely useful in the allocation of resources, particularly when there are constraints on their availability and usage. In the developing countries, shortages of commodities such as cement, steel, or explosives at one time or another is common. Also capital shortage is not unusual. Under such conditions it may not always be possible to complete the project in the planned time. Rescheduling the start of various activities, making advantage of their floats, might relieve the pressure on the requirement of the resources at different points of time.

5.11 TIME ASPECT OF PROJECTS

PERT, like CPM, is also a time – oriented planning and control device. PERT analysis yields both a mean or central measure of completion time for a project and a measure of dispersion (standard deviation).

Using the mean and standard deviation of the completion time for a project, probabilities of finishing the project in less time or more time than the mean time can be determined. The basic difference between PERT and CPM is the incorporation of statistical probabilities into the network.

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5.12 ESTIMATING TIME IN A PROJECT

For every activity in PERT, three different time estimates are obtained.

Optimistic time (t_0) – It is the time taken to perform an activity if everything goes smoothly while performing the activity. It is the shortest possible time estimate for an activity.

Pessimistic time (t_p) – It is the time taken to perform an activity if everything goes wrong, while performing the activity. It is the longest possible time estimate of an activity.

Most likely time (t_m) – It is the time which is most likely to be taken, under the given circumstances. This is often based on the gut feeling or hunch of the project manager.

The actual time taken by the activity could fall anywhere between t_0 and t_p; and if the same activity was performed a number of times, it will be completed at t_m most number of times.

The values of the mean and standard deviation are calculated using the following formula-

Mean (i.e., expected) time for the activity,

$$t_e = \frac{t_0 + 4t_m + t_p}{6} \quad \text{... 5.1}$$

$$\text{Standard deviation, } \sigma = \frac{t_p - t_0}{6}$$

$$\text{Variance, } \sigma = \frac{\left(t_p - t_0\right)^2}{6^2}$$

The probability of the completion of a project within a time duration can be computed with the help of the data on individual activities. Generally, the probability of the completion of the critical path is taken as the probability of completion of the project within any given time.

Example 4:

Study the data given below for a plant construction project. Determine the critical path. What is the probability that the project will be completed within 4 years? What is the probability that it will take more than 55 months?

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Solution:

(*Time in months*)

Activity		Time Estimates		
Description	Number	to	tm	tp
Design plant	1 – 2	10	12	16
Select site	2 – 3	2	8	36
Select vendor	2 – 4	1	4	5
Select personnel	2 – 6	2	3	4
Prepare site	3 – 5	8	12	20
Manufacture generator	4 – 5	15	18	30
Prepare manual	4 – 6	3	5	8
Install generator	5 – 7	2	4	8
Train operators	6 – 7	6	9	12
License plant	7 – 8	4	6	14

$Te = \frac{to + tm + tp}{6}$	$\sigma^2 = \frac{(tp - to)^2}{6^2}$
12.33	1.00
11.67	32.11
3.67	.44
3.00	.11
12.67	4.00
19.50	6.25
5.17	.69
4.33	1.00
9.00	1.00
7.00	2.78

Path	Times
A: 1 – 2 – 3 – 5 – 7 – 8	12.33 + 11.67 + 12.67 + 4.33 + 7.00 = 48.00
B: 1 – 2 – 4 – 5 – 7 – 8	12.33 + 3.67 + 19. 50 + 4.33 + 7.00 = 46.83
C : 1 – 2 – 4 – 6 – 7 – 8	12.33 + 3.67 + 5.17 + 9.00 + 7.00 = 38.17
D: 1 – 2 – 6 – 7 – 8	12.33 + 3.00 + 9.00 + 7.00 = 31.33

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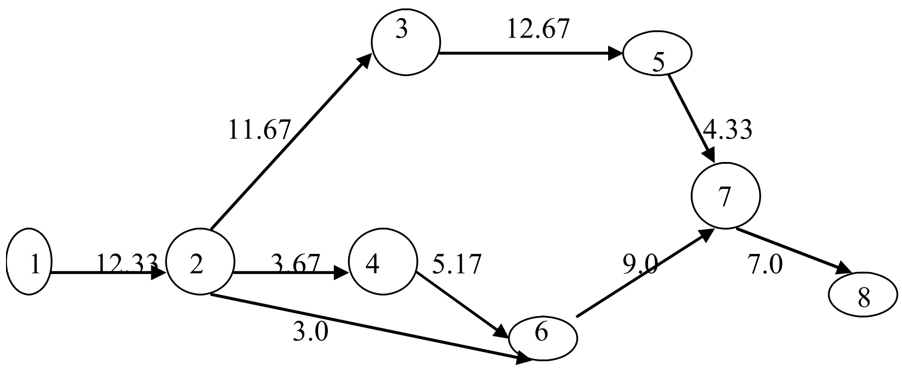
We now draw the network diagram, using the data given. The times written in the diagram will be the mean or estimated times that have been calculated.



The critical path is 1-2-3-5-7-8 with the longest time duration of 48 months.

(b) The best estimate of completion time is Te = 48.0 months, so there is a 50 percent chance that the project will be finished within the 4 – year time period.

(c) To determine any other completion time probabilities, we must calculate the standard deviation of the distribution of completion times along the critical path.

$$\sigma = \sqrt{\Sigma \sigma^2_{cp}} = \sqrt{1.00 + 32.11 + 4.00 + 1.00 + 2.78} = 6.4 \text{ months}$$

$$Z = \frac{tx - te}{\sigma} = \frac{55 - 48}{6.4} = 1.9$$

For a Z value of 1.9, we can obtain the normal distribution value from any statistical table.and subtract it from 0.50 (50%)

Therefore, probability = 0.5 – 0.3621 = 0.1379 say 0.14

5.13 CRASHING OF A PROJECT

Crashing of a project means intentionally reducing the duration of a project by allocating more resources to it. A project can be crashed by crashing its critical activities (because the duration of a project is dependent upon the duration of its critical activities). The use of more workers, better equipment, overtime, etc would generate higher direct costs for individual activities. However, shortening the overall time of the project would also reduce certain fixed and overhead expenses of supervision, as well as indirect costs that vary with the length of the project.

We know that by adding more resources, the duration of an activity can be reduced. If an activity gets completed in ten days with five men working on it, the same activity can be finished in say, six days with ten men (exact mathematical relationships don't work here) working on it. The initial direct cost was 50 man days (5 men x 10 days) and now it is 60 man days (10 men x 6 days). Therefore, the direct cost has increased by 10 men- days.

At the same time, because of the decrease in duration of the activity by four days, the indirect cost (cost of supervision) decreases. Hence, we can conclude that the direct and indirect costs are inversely proportional to each other, i.e. when one increases, the other decreases.

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An activity can be crashed by adding more resources only up to a definite limit. Beyond this limit, the duration of the activity does not decrease by adding more resources. This is due to decreasing efficiency of labour, and also increasing confusion due to a large number of resources. In our example, if we increase the number of workers to 15, the same activity can probably be done in four days; but by adding ten more men (so that 20 men work on this activity), the activity time may not decrease further.

The crash time is the shortest time that could be achieved if all effort (at any reasonable cost) were made to reduce the activity time. The limit beyond which the duration of the activity does not decrease by adding any amount of resources is called the **crash time**. It is the shortest possible activity time.

The direct cost associated with each crash time is called the **crash cost**.

The **normal time** (10 days in our example) can be defined as the duration of an activity when the minimum possible resources required for its performance are deployed.

The lowest expected activity costs are called the **normal costs.**

Project direct cost is the direct cost involved in all the activities of the project.

Project indirect cost is the costs associated with sustaining a project. They include the cost of supervision during the implementation of the project, overheads, facilities, penalty costs and lost incentive payments. The salaries paid to the project manager/supervisor etc. miscellaneous costs due to delays in the project, and rewards to the project team members for its early completion are indirect costs. Project indirect cost is dependent upon other length of duration of the project. A project having a longer duration will have a higher indirect cost (due to supervision required for longer duration).

In any projects, there is a direct relationship between the time taken to complete an activity and the project cost. On one hand, it costs money to expedite a project. Costs associated with expediting a project are called **activity direct costs**, and are different from project direct costs. Some examples of activity direct costs are – hiring more workers, buying or leasing additional equipment, drawing on additional support facilities etc.

If activity direct costs will rise, project indirect costs will fall. Therefore, in a real situation, we need to have a time cost trade-off, this means the sum of activity direct costs and project indirect costs must be minimum.

During the process of crashing of a project, the critical path may get changed. At some stage of crashing, there may even be two or more critical paths (having the same duration) simultaneously. In such situations, one activity is chosen from each of the critical paths and these activities are crashed by unit time to reduce the duration of the project by unit time.

Time-cost models search for the optimum reductions in time. *We seek to shorten the length of a project to the point where the savings in indirect project costs is offset by the increased direct expenses incurred in the individual activities***.**

Example 5:

A network has four activities with expected times as shown. The minimum feasible times and cost per day to gain reductions in the activity times are also shown. If fixed project costs are Rs 90 per day, what is the lowest cost time schedule?

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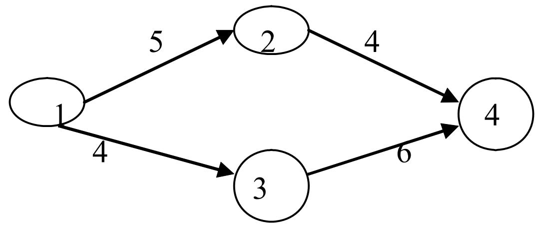
(*All costs are in Rs '000*)



Activity	Minimum Time in days	Direct Costs of Time Reduction (Rs)
1 – 2	2	40 (each day)
1 – 3	2	35 (first day, 80(second day)
2 – 4	4	None possible
3 – 4	3	45(first day), 110 (other days)

Solution:

First we must determine the critical path and critical path time cost

Path	Path Times	Total Project Cost
1-2, 2-4 1-3, 3-4	5 + 4 = 9 4 + 6 = 10	 10 days x Rs90/day = $ 900

For ease of reference, let us call the paths A and B respectively. Path B that is, 1-3-4 is the critical path with duration 10 days and cost Rs 900/-

Next, we must select the activity that can reduce critical path time at the least cost. Select activity 1- 3 at Rs 35 per day, which is less than the Rs 90 per day fixed cost. Reduce activity 1–3 to 3 days. Revise the critical path time cost

Revised Path Times	Total Fixed Cost	Savings over Previous Schedule
A: 5 + 4 = 9 B: 3 + 6 = 9	9 × Rs 90 = Rs 810	Rs900 – (810 + 35) = Rs55

Both paths are now critical, so we must select an activity on each path. Select activity 1–2 at Rs 40 per day and 3–4 at Rs 45 per day. Reduce activity 1–2 to 4 days and 3–4 to 5 days. Revise the critical path time and cost

Revised Path Times	Total Fixed Cost	Savings over Previous Schedule
A: 4 + 4 = 8 B: 3 + 5 = 8	8 x 90 = Rs720	810 – (720 + 40 + 45) = Rs 5

Let us see if we can reduce the time of both paths any further. Activity 1–2 is a good candidate on path A, for it is still at 4 days and can go to 3 for a Rs 40 cost. But when this cost is combined with the Rs 80 cost for reducing activity 1–3 another day, the sum is greater than Rs 90, so further reduction is not economically justified.

The final step in time – cost analysis is to compare the crash times and the costs associated with them (crash costs). A sufficient number of intermediate schedules are computed such that the total of the direct and indirect (fixed) project costs can be plotted.

Example 6:

Graph the total relevant costs for the previous example, and indicate the optimal time – cost tradeoff value.

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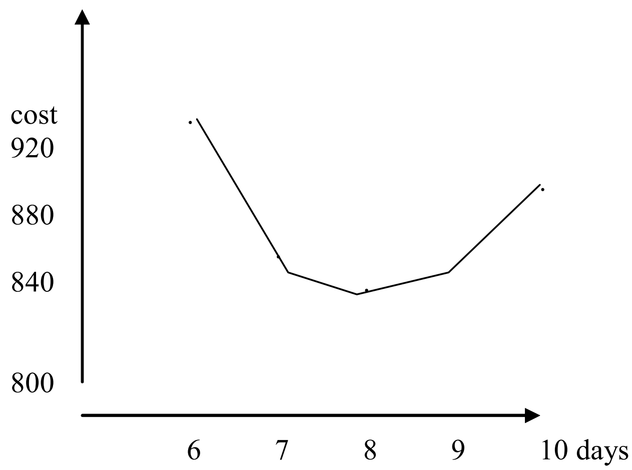
Project Length (days)	Indirect Cost	Activity Reduced	Relevant Direct Cost	Relevant Total Cost
10	900	None	0	900
9	810	1 – 3	35	810 + 35 = 845
8	720	1 – 2 and 3 – 4	35 + 85 = 120	720+40+45+35 = 840
7	630	1 – 2 and 1 – 3	120 + 120 = 240	870
6	540	1 – 2 and 3 – 4	240 + 150 = 390	930



This graph is called the crash – time diagram for completing the project. The lowest total cost is to complete the project in 8 days at a cost of Rs 840,000. However, extending it to 9 days adds only Rs 5000 to this cost.

5.14 LIMITATIONS OF CPM AND PERT

CPM and PERT have been criticized in the past for the following reasons:

1. It is difficult to identify the various activities in complex projects, i.e. to clearly define the start and end points of activities is sometimes not easy. In complex projects, a network diagram made during the planning stage may require new/modified activities due to changes in the project over time.
2. In certain types of projects, it is not possible to sequence all the activities according to precedence requirements. For example, in the construction of a road, the various activities are performed in a predetermined sequence. Each portion of the road requires some or all of these activities. It is difficult to represent the various activities by standard networking procedures because most activities can start on parts of the road before their corresponding predecessors have been completed on all preceding parts of the road.
3. The critical path focuses only on control of the duration of the project. There may also be certain non-critical paths, which can become critical when some of the activities get delayed.

Check Your Progress

1. Explain the life cycle of a project.
2. What do you know about PERT and CPM?
3. What do you understand by ‘crashing’ of a project?
4. What are the advantages of CPM?

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However, the popularity of network-based project management techniques and the large number of software packages based on these techniques indicate that network models are useful for many types of projects. Furthermore, the volume of research in this area indicates that the assumptions in CPM and PERT are acceptable to many researchers as well.

5.15 SUMMARY

In this unit, you have learned how to deal with activities which are not essentially repetitive but still utilize all the resources. However, the work in a project does not end with completion of the project. Project evaluation, which is conducted after a project has been completed and has started yielding results is equally important. The project is evaluated along the following lines:

- Were the objectives achieved? If not, why? Were the objectives realizable?
- What problems were faced during execution of the project?
- What were the assumptions made?
- What were the lessons learnt?

Such an analysis helps future projects. Today, most activities involving projects are computerized and software are available to help managers plan, schedule and control any project.

5.16 KEY TERMS

- **Project**: A project is defined as a series of related jobs usually directed towards some major output and requiring a significant period of time to perform.
- **Project management**: The British Standard for Project Management BS 6079 defines project management as 'the planning, monitoring and control of all aspects of a project and the motivation of all those involved in it to achieve the project objectives on time and to the specified cost, quality and performance.'
- **Pure project:** Pure project is one in which a self-contained team works full time on the project.
- **Matrix project:** The matrix project is an amalgamation of functional and pure project structures. Each project utilizes people from different functional areas.
- **Project definition:** This is the starting stage of the project planning process. In this stage, the individual activities that must be performed and the sequence required to perform them are listed out.
- **Resource planning**: For each activity that is identified, the resources that are needed are determined in this stage. These include personnel, time, money, equipment, materials, and so on. It is also determined whether any training is needed or not and ensured that the personnel are properly trained.
- **Project scheduling:** All the timelines are decided and the time schedules for each activity are laid out.
- **Project control:** Controls are established in order to determine the progress of the project. Alternative plans are developed in case the original plan meets roadblocks that cannot be overcome.

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- **Statement of work (SOW):** A project starts out as a statement of work (SOW). The SOW may be a written description of the objectives to be achieved, with a brief statement of the work to be done, and a proposed schedule specifying the start and completion dates. It could also contain performance measures in terms of budget and completion steps ((milestones) and written reports to be supplied.
- **Work breakdown structure (WBS):** The work breakdown structure (WBS) defines the hierarchy of project tasks, sub tasks and work packages. The WBS is important in organizing a project because it breaks down the project into manageable pieces.
- **Project direct cost:** This is the direct cost involved in all the activities of the project.
- **Project indirect cost:** This is the cost associated with sustaining a project.
- **Slack time**: The difference between the late start time and early start time is called the slack time.
- **Optimistic time:** It is the time taken to perform an activity if everything goes smoothly while performing the activity. It is the shortest possible time estimate for an activity.
- **Pessimistic time:** It is the time taken to perform an activity if everything goes wrong, while performing the activity. It is the longest possible time estimate of an activity.
- **Most likely time:** It is the time which is most likely to be taken, under the given circumstances. This is often based on the gut feeling or hunch of the project manager.
- **Crashing of a project**: Crashing of a project means intentionally reducing the duration of a project by allocating more resources to it.
- **Crash cost:** The direct cost associated with each crash time is called the crash cost.
- **Normal time**:The normal time can be defined as the duration of an activity when the minimum possible resources required for its performance are deployed.
- **Normal cost:**The lowest expected activity costs are called the normal costs.

5.17 ANSWERS TO 'CHECK YOUR PROGRESS'

1. The life cycle of a project can be broadly classified into four stages:

   (a) Conception and definition – This phase begins with the idea of the project. Once it is decided to explore the idea further, a document is prepared listing out:

   – Raw materials required
   – Location selection and plant layout
   – Technology/process selection
   – Machinery/equipment needed
   – Utilities – fuel/power, water, sanitation, etc.
   – Manpower and organization pattern
   – Resources needed

NOTES

(b) Planning and organizing phase

In this phase:

1. Necessary approvals are taken to go ahead with the project
2. Finances are arranged
3. Project infrastructure is planned – land is obtained, machinery is put in place
4. Manpower recruitment and organization structure are finalized, project leaders are appointed
5. Schedules and budgets are finalized
6. Licenses and government clearances are obtained
7. Contracts are prepared and executed
8. Site preparation is done
9. Construction resources and materials are put in place
10. Work packaging is done

(c) Implementation phase: The actual implementation work is carried out in this phase.

(d) Project close or project clean-up: All drawings, documents, operation manuals, maintenance procedures/manuals, etc., are handed over to the customer.

2. Program evaluation review technique (PERT) was developed with the objective of being able to handle uncertainties in activity completion times. It is a new project evaluation technique. In PERT, events and activities must be sequenced in the network under a highly logical set of ground rules which allow the determination of important critical and non-critical paths for analysis.

   The critical path method (CPM) is based on the assumptions that project activity times can be estimated accurately and that they do not vary. CPM is used to study the option of reducing activity times by adding more workers and/or resources, usually at an increased cost. It enables time and cost trade-offs for the various activities in the project. It is a deterministic approach using a one time estimate of the activity duration. CPM uses a mathematical procedure for estimating the time-cost trade-offs of a project, reallocation of resources from one activity to another, to achieve the shortest overall project time at the least cost.

3. Crashing of a project means intentionally reducing the duration of a project by allocating more resources to it. A project can be crashed by crashing its critical activities (because the duration of a project is dependent upon the duration of its critical activities). We know that by adding more resources, the duration of an activity can be reduced. At the same time, because of the decrease in duration of the activity, the indirect cost (cost of supervision) decreases. Hence, we can conclude that the direct and indirect costs are inversely proportional to each other, i.e., when one increases, the other decreases.

   An activity can be crashed by adding more resources only up to a definite limit. Beyond this limit, the duration of the activity does not decrease by adding more resources. This is due to decreasing efficiency of labour and also increasing confusion due to a large number of resources.

NOTES

During the process of crashing of a project, the critical path may get changed. At some stage of crashing, there may even be two or more critical paths (having the same duration) simultaneously. In such situations, one activity is chosen from each of the critical paths and these activities are crashed by unit time to reduce the duration of the project by unit time.

4. The advantages of CPM are –
   (a) It enables the management to identify the critical activities, non-critical activities, etc., and their completion times. This helps it to divert resources from non-critical to critical activities if needed, so that the project gets completed on time.
   (b) It helps the top management to focus on the critical activities and their accomplishment.
   (c) It helps in the planning and scheduling.
   (d) It provides complete information about the importance, duration, size and performance of an activity.

5.18 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is a project? What are its unique characteristics?
2. Differentiate between an activity and an event.
3. List the classifications of projects.
4. What are the inputs in a project? How does a network help in controlling the inputs?

Long-Answer Questions

1. With the help of a diagram explain the life cycle of a project.
2. What are the steps in project planning and execution?
3. Explain a work breakdown structure. What are its components?
4. What is a dummy activity? What is its relevance?
5. What is the advantage of constructing networks?
6. What are the limitations of PERT and CPM?

5.19 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

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UNIT 6 PLANT LOCATION AND LAYOUT

NOTES

Structure

6.0 INTRODUCTION

NOTES

When the Rs 1 lakh people's car Nano was launched by Ratan Tata of Tata Sons, there was widespread jubilation and anticipation of where the factory was going to come up. Various state governments offered attractive concessions to the Tatas urging them to set up the facility in their state. West Bengal was selected to house the Nano plant and work began at Singur. Not only the Tatas, but even their joint venture partners invested crores of rupees to set up their respective facilities.

However, the location option proved to be wrong. Barely months before commercial production was to start, there were agitations by the locals at Singur against the project. The situation got so out of hand that the Tatas were forced to abandon their project at Singur and relocate to Sanand, Gujarat.

So what went wrong? Without going into the reasons vis-à-vis the Tatas project, in this unit you will learn about the factors that must be taken into consideration when selecting a location for setting up a factory. You will also learn about layout plan and its various aspects.

6.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Define plant location and its objectives
- Understand the importance of facility location
- List the factors affecting location decisions
- Know how to locate foreign operations facilities
- Understand the location decision process
- Explain the objectives of designing the plant layout
- Understand the advantages of a good plant layout
- Describe the different types of layout
- Understand what is layout planning for storage and warehousing
- Discuss the methodology for layout planning

6.2 DEFINITION AND OBJECTIVES OF PLANT LOCATION

Before we look into the process of location decision, let us first define it. *Facility location is the selection of suitable location or site where the factory or facility will be installed, and from where it will function.*

There are two fundamental objectives to a facility location exercise. These are:

- Minimizing cost
- Maximizing revenue

Whatever may be the nature of the firm these objectives will govern the location decision. The planning for 'where' to locate should start from 'what' are the organization's objectives, priorities, goals, strategies, etc. and what it is doing to achieve them in the socio- economic- technical-legal environment. Unless the objectives and priorities have been clearly understood, the decision regarding the location cannot be correct.

6.3 IMPORTANCE OF FACILITY LOCATION

Why is facility location so important? What could happen if the location selection was wrong? We have read in the Introduction that the Nano project faced losses even before commercial production had begun. Moreover, the car was to have started commercial production in December 2008. This has not happened.

(a) So let us see what all can happen to a facility which is operating in an improper/ incorrect location.

  (i) The company may have to close down its operations and liquidate its assets. In that case,

    – Locating buyers for used equipment will be difficult.

    – Price received for used equipment will be a fraction of the original investment.

  (ii) The company may relocate its facility, just like the Tatas have done. But this will involve:

    – huge expenditure in shifting machinery, equipment, manpower, etc.

    – time and added costs for taking new land lease/outright purchase, registration, etc.

  (iii) If the company continues its operation at the wrong location

    – It may accumulate losses.

    – Competitors with better locations will have an edge.

    – The company will lose market share/customer goodwill.

(b) Location facility is an issue for consideration either for

Starting a new facility or for

Starting additional facility

(c) Additional or multiple facilities can be desired due to the following reasons –

  (i) Separate facilities for different products/services – eg. Videocon has different plants for its different products such as washing machines, TVs, refrigerators, microwave ovens, etc.

  (ii) Separate facilities to serve different geographical areas –eg. LPG filling plants across the country to serve different locations.

  (iii) Separate facilities for different processes – eg. Separate facilities to make pizza base.

6.4 FACTORS AFFECTING LOCATION DECISION

In this section, you will learn about the various factors that affect decisions regarding choice of location. These factors are explained in the following sections.

6.4.1 Proximity to Customers (Markets)

When the plant is located near the customers/markets, the cost of transportation is low. This reduces the product cost. Most small ancillary units are located near big automotive factories. The OEMs (Original Equipment Manufacturers) are the institutional customers of small parts, components, or sub- assemblies from these ancillary units. The Maruti

Joint Venture Complex at Gurgaon near the Maruti Suzuki car factory is a good example of how proximity to the customer reduces the transportation cost of auto ancillary units, which supply parts, components, sub-assemblies, etc. for making the Maruti car.

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Proximity to markets also allows companies to meet sudden spurt in demand, thus providing an advantage over competitors who are located at far-off places. That is why we find hospitals, schools, post offices, banks, insurance companies, etc. located in highpopulation zones so that they are able to serve a large number of customers.

6.4.2 Proximity to Raw Materials

Why are the integrated steel plants of SAIL located in Bihar, West Bengal and Orissa? This is because of the large presence of iron ore, coal, dolomite and limestone mines in these regions, which are the basic raw materials for steel making. Proximity to the source of raw materials is an important consideration for facility location, especially if the raw materials are bulky, and huge shipping costs will be incurred in transporting them. Where it becomes absolutely necessary to transport them, it is found that cost of the material is equal to the shipping cost thus making the raw materials very costly at the point where they are used.

6.4.3 Good Transportation Facilities

Good transportation facilities are necessary for movement of goods and people. Regions near metro cities have these facilities, as they have a good network of rail, air, water, and road transportation.

6.4.4 Availability of Power

Uninterrupted power supply is a basic requirement of most industries. Companies have to set up their own DG sets or have captive power plants if they are located in areas with power problems. This increases the cost of the product, besides additional problems of running the DG sets, captive power plants, etc.

6.4.5 Basic Amenities

The location site should have certain basic facilities like sewage system, piped water supply, security, etc., that are managed by the local municipality. Roads up to the factory premises are always desirable. If these basic amenities are provided, it will be easier for the employees and they will be willing to work in that factory. Availability of housing facilities, schools, colleges, banks, post office, hospitals, etc. are added advantages for locating a facility in an area.

6.4.6 Government Policies

Relaxed taxation policies, excise duty exemption and various other promotional efforts attract industrial activities in a region. Pondicherry and Daman and Diu are declared 'no sales tax regions' and we find that many companies have their offices/warehouses located there. Many state governments promote industrial activities in their regions by creating Industry Development Zones, Special Economic Zones, etc. The governments of Karnataka, Andhra Pradesh, Tamil Nadu and UP have created software development parks, where facilities such as high-speed Internet, servers, etc. are provided to software companies at subsidized rates. Agriculture gets maximum subsidies from the central as well as many state governments. Various processing plants of agricultural and horticultural products located in these states can avail of these advantages. Before locating a facility at a particular site, the government policies of that region must be considered.

6.4.7 Environmental and Community Considerations

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Many state governments have strict environmental policies, which have to be followed by the industries operating there. States such as Uttaranchal do not give permission to such industries which release toxic effluents. Opposition from the community regarding the construction of a plant in their region can disrupt the whole project. The Sardar Sarovar Dam project is an example where opposition from the locals has interrupted the construction of the dam over the Narmada.. In the Chipko Movement, started by S.L Bahuguna, the locals embraced a tree each, and did not allow the officials to cut the trees and thereby eliminate the forest. After the Union Carbide factory disaster in Bhopal some decades ago, every new factory faces close scrutiny on the environmental front in the area.

6.4.8 Proximity to Subcontractors

Small ancillary units manufacturing small components/sub-assemblies are important for any new factory. Ancillary units and joint ventures set up their facilities near the OEM. The advantage to the ancillaries is that it will reduce their component cost. The OEMs too benefit if they set up their facilities near these ancillaries. Maruti Suzuki set up its second facility at Manesar near Gurgaon (where their first facility is located) so that it could take advantage of the suppliers present at the Maruti Joint Venture Complex at Gurgaon.

6.4.9 Availability of Cheap Land

Land is the basic necessity for the construction of a new plant. Many big companies set up their facilities in backward areas because of availability of low-priced land.

6.4.10 Low Construction Costs

Construction costs of a plant may be low at a particular place due to cheap labour available there. The construction material may also be cheaper at another place. Such places are preferred for locating a plant.

6.4.11 Availability of Cheap, Skilled and Efficient Labour

Many companies locate their facilities at places where there is cheap, skilled and efficient labour. Many companies are locating their branches in South India because the people here are more disciplined, efficient and skilled.

6.5 LOCATING FOREIGN OPERATIONS FACILITIES

Globalization has made consumers expect the best products at the lowest prices irrespective of where they are produced. So while considering the location of a facility in a foreign country, in addition to all the factors listed above, the following additional factors should also be considered.

6.5.1 Cheap, Skilled and Efficient Labour in India

Many multinational companies are locating their branches in India because labour is cheap here and the people are more disciplined, efficient and skilled.

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6.5.2 Trade Barriers

The Import Export Policy of the Government of India imposes some restrictions on the import of certain goods. For some goods import duties are levied, which make these products expensive in the local market. In such situations, foreign companies overcome these trade barriers by producing the goods in that country locally.

6.5.3 Local Customers

If a foreign company has a large customer base in a country, it may be beneficial for it to start operations locally in that country. This way the company can serve the customers better and take advantage of their brand loyalty.

6.5.4 Incentives

To increase the inflow of Foreign Direct Investment, certain countries provide industrial infrastructure, insurance, tax exemptions/reductions, interest – free/subsidized loans, etc. to foreign companies that are willing to establish operations facilities in their region.

6.5.5 Share Prices and Goodwill

The market value of the firm may soar as international operations are deemed prestigious by investors.

6.5.6 Operations in Competitor's Home

Initiating operations at the competitor's home country may at times force the competitor to concentrate more on the home turf and wind up or downsize its international operations.

6.6 THE LOCATION DECISION PROCESS

Let us now learn the various steps in location planning. The process of deciding on the facility location, begins by listing the various location options. Then the advantages and disadvantages of each location are identified. These are then compared with the list of factors that are necessary for that particular industry – e.g., the essential parameters, or the factors that would be of advantage to that particular industry, etc. Then each location option is screened using various models and the locations are rated according to these models. Based on the outcome of this exercise, the most suitable location is chosen.

Various methods/ models are used nowadays to determine the most suitable location. We will learn two important methods here.

6.6.1 Techniques of Factor Rating and Location Rating

This is the simplest method for arriving at the best location. In this method, two types of ratings are given –

1. Every factor that is relevant to the industry is given a rating between 1 and 5. These factors are relevant to the industry, irrespective of the location. This is called **Factor Rating.**
2. Every factor that has been listed in (1), is given a relative rating between 1 and 5 for each of the locations proposed to be selected. This is called **Location Rating.**

We will learn how to use these two ratings to arrive at the best location, by means of an example.

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Example 1

M/s Indiana Leathers has identified three locations, Kanpur, Noida and Lucknow, to set up a leather goods manufacturing facility. The factor ratings and locations ratings have been given. Arrive at the best location using the Factor and Location Rating methods.

	Factor	*Factor rating*	*Location Rating*		
			Kanpur	*Noida*	*Chennai*
1.	Proximity to market	3	4	6	3
2.	Proximity to raw material	5	10	5	4
3.	Transportation facility	4	9	10	5
4.	Basic amenities	2	6	7	6
5.	Acceptance of leather factory by locals	4	8	3	7
6.	Availability of cheap land	3	7	2	8
7.	Low construction costs	1	5	1	6
8.	Easy availability of cheap and skilled labour	3	3	8	4

Factor ratings are 1 to 5 – 5 highest

Location ratings are 1 to 10 – 10 highest

Solution:

For each location find the product of factor and location ratings. Add them up for each location. The location having the highest product will be the best location.

Product of factor and location ratings

Factor	*Kanpur*	*Noida*	*Chennai*
1	12	18	9
2	50	25	20
3	36	40	20
4	12	14	12
5	32	12	28
6	21	6	24
7	5	1	6
8	9	24	12
Total	177	140	131

The highest score is for Kanpur. So it is the best location.

6.6.2 Break-Even Analysis Method

This method is based on the concept of break-even analysis. We know that there are two elements of cost, i.e., Fixed cost and Variable cost. Fixed cost includes capital expenditure land, building manufacturing and equipment. This is irrespective of the volume of production and will be incurred even if there is no production. Variable cost includes raw material, labour, etc., which are directly involved in the production process and are proportional to the volume of production. Total cost is the sum total of fixed cost and variable cost. When the volume of production of a product is low, the component of its fixed cost is high and variable cost is low. As the volume of production increases, the variable cost component increases and fixed cost component reduces. Till a point is reached beyond which variable cost again begins to increase. This point is called the **breakeven point** at which the total cost is lowest. This volume of production is called **breakeven volume.**

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A company wants a low break even volume so that it can recover its costs soon. A location which gives the least break even volume is preferred.

Let us understand this by means of an example.

Example 2

M/s Vignesh Steels intends to set up a rolling mill to roll different grades of high carbon steels. Potential locations selected by the company are Alipore, Bhatinda and Calicut. The cost structures for each of these locations are shown below. The product is expected to sell at Rs 130 per kg.

(a) Find the most economical location for an expected volume of 6000 kgs per year.

(b) Expected profit at that location.

(c) For what output is the range in each location best?

	FC	VC / Kg
Alipore	150,000	75.00
Bhatinda	200,000	50.00
Calicut	400,000	25.00

Solution:

Find the variable cost for producing 6000 kg. Then add the fixed cost and variable cost to arrive at the total cost.

	FC	VC/ Ton	VC for 6000 Kg	TC (FC+VC)
Alipore	150,000	75.00	450000	600 000
Bhatinda	200,000	50.00	300000	500,000
Calicut	400,000	25.00	150000	550,000

The place having the least total cost for the volume of 6000 kg is the best location. In this example, it is Bhatinda.

(b) Selling Price = 130 × 6000 = 780000

Profit = Selling Price –Total cost = 780,000 – 500,00 = 280,000 / year

(c) Make a table for outputs 1000,2000,3000,4000,5000,6000,7000,8000 units / year for each location.

For example, for Alipore, FC = Rs 150,000.

Qty	1000	2000	3000	4000	5000	6000	7000	8000
VC	75000	15000	225000	300000	375000	450000	525000	600000

For Alipore, breakeven is reached at 2000 T production. Why?

You can also draw the graph with Qty on X-axis and cost on Y-axis. The point where the lines of Fixed cost and Variable cost meet is the breakeven point.

Similarly calculate/ draw for the other locations.

6.7 LOCATION DECISION FOR WAREHOUSES

Warehousing plays a crucial role in the total distribution design.

Suppose a firm does not own any warehouses. If its factory is located far from its supplies of raw materials, the inbound transportation costs will be very high. Also longer delivery times increase the chances of material shortages for production.

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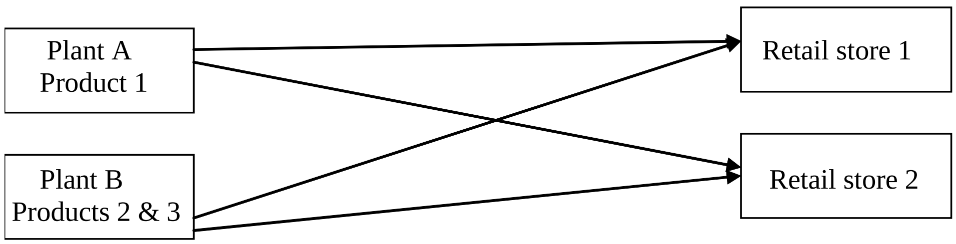
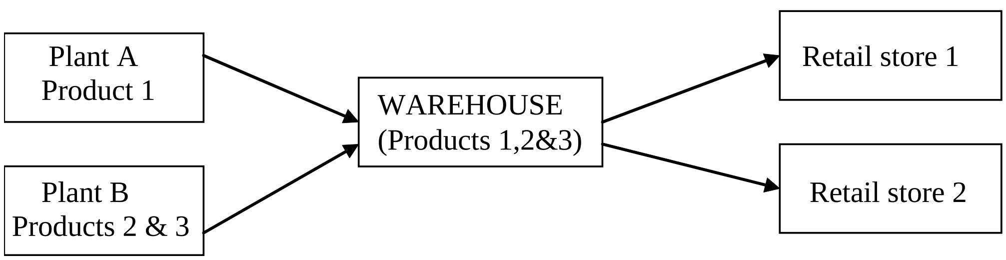
If the factory is located far from its retail stores, then transportation costs incurred in shipping from the plant to the retail stores (outbound transportation costs) are very high. The delivery times increase the chance of outofstock situations, which reduces the level of customer service.

In both the situations, the presence of warehouses, both close to the markets as well as close to the factory, can provide quick and efficient functioning of the factory as well as delivery to retail stores.

Suppose that the firm owns several manufacturing plants, which produce a variety of products. In the absence of a warehouse, the company's distribution system would look like this –



Rather than ship small quantities of each product directly from the plants to retail stores, a warehouse can be used for consolidation of orders, as shown below. The economic advantage of such a system is that it is often cheaper to ship in truckload or wagon load quantities than in small quantities. Productivity is increased, since transport vehicles are used more efficiently and unit costs are reduced.



The level of customer service also varies with the number of distribution centres. Many different productivity measures can be used to evaluate customer service. Common among these are:

- The average order processing time (the time between receipt of an order at the warehouse and its shipment)
- The percentage of shipments delivered within x days of order receipt
- The percentage of orders that are accurately filled
- The number of damaged items

The managers responsible for location decisions must therefore make decisions depending to a large extent on the overall goals and objectives of the firm and their customer service policies.

6.8 NEED FOR LAYOUT PLANNING

Once the facility location has been decided and land has been acquired, a sketch or plan is made to decide where each department/section, entrance and exit gates, restrooms, storage areas, etc., will be located. In the subsequent sections, we will see how this type of planning is done.

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6.9 DEFINITION OF LAYOUT PLANNING

We can define layout as, *'The physical location of the various departments/units of a facility within the premises of the facility.'*

The departments must be located based on some consideration. The common considerations are -

1. Logical sequence of processing operation
2. Direction of material flow and material handling
3. Aesthetic considerations
4. Government regulations
5. Special requirements

The entrance and exit gates are usually critical in the layout planning of facilities.

6.10 OBJECTIVES OF A PLANT LAYOUT

Plant layout is the method to plan and arrange materials and facilities so that a steady flow of production is ensured at minimum cost. A good plant layout always results in comfort and satisfaction of workmen and this automatically increases the production. A bad plant layout leads to accidents and unnecessary problems.

A good plant layout is designed to achieve the following objectives:

1. Economic handling of materials and finished goods
2. Fast and efficient quality production
3. Enhanced utilization of available space
4. Flexibility in change of plant design and possibility of expansion at a later date
5. Improvement in work condition leading to higher productivity
6. Unidirectional/systematic flow of production operation
7. Reduction in waiting time
8. Reduction in manufacturing cost

6.11 ADVANTAGES OF A GOOD PLANT LAYOUT

A good plant layout results in better production and lower costs. The advantages of a good plant layout are as follows:

1. **Well-organized workspace:** A good plant layout means well-organized workspace with adequate facilities provided for the machines as well as for the workmen. Proper arrangement of machineries and tools eliminates congestion. The materials required are stored in their appropriate places so there is no confusion. Workmen are also distributed to their respective departments and there is no confusion in work.

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2. **Better working conditions:** A good plant layout results in labour satisfaction due to improved and clean working conditions. It has been well-documented that motivation level increases when lighting and other aesthetics are improved. Safety of workmen is another important factor. A good plant layout ensures that the machine are properly placed, with adequate space in between so that there is no congestion and no danger of the workmen getting injured. This provides safety to the workmen and creates a good environment for work.
3. **Minimization of material handling costs:** A good plant layout minimizes material handling costs. The machinery and equipment are placed in such a manner that there is no difficulty in transferring materials between workstations. The provision of adequate material handling systems will ensure that there is minimal labour cost, labour fatigue, etc., and labour can be utilized in productive jobs.
4. **Minimization in damage and spoilage of material:** In a good plant layout, materials are handled properly which results in good quality of production. There is minimum damage and spoilage of materials. Minimizing waste also leads to increase in profits for a company.
5. **Flexibility in changing production conditions:** A good layout provides adequate space for future expansions, laying additional workstations, etc. The advantage is that in future if the market conditions change, the firm can easily put up new machinery, etc. without having to dismantle the existing ones and with minimum hindrance to the daily schedule or work.

6.12 TYPES OF LAYOUT

There are four basic types of layout.

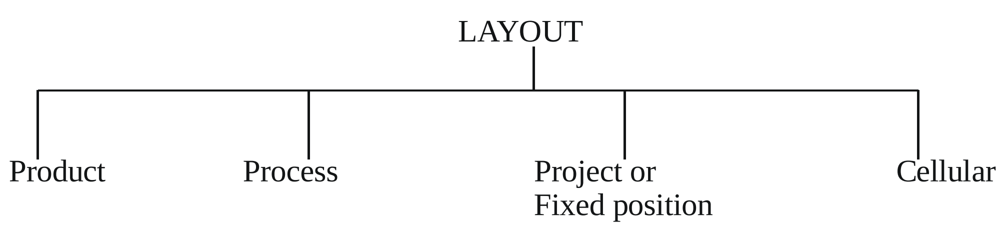

Fig. 6.1 *Types of Layout*

6.12.1 Product Layout

The placement of the equipment/machinery and materials in the order in which they are to be used for producing the product is called the **product layout** or **line layout**. This type of layout is found in industries where assembling of materials and parts takes place, such as the automobile industry. In such industries, the process starts with feeding in the raw materials and ends with the final product. The flow diagram of a Line Layout would can be seen in Figure 6.2.

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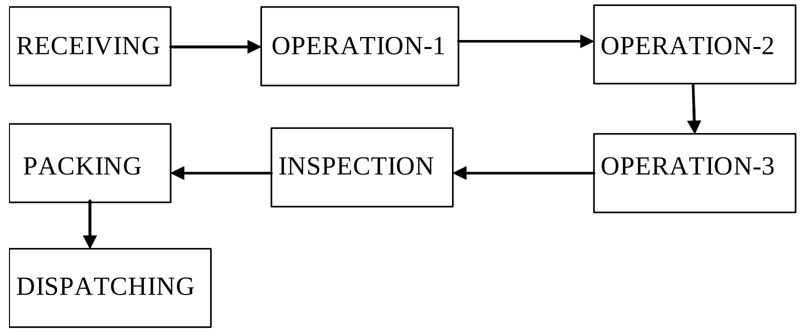

Fig. 6.2 *Flow Diagram of a Product/Line Layout*

Advantages of product layout

1. There is low work in process since output of one stage is automatically the input of next stage
2. Material handling is less since the process is automatic.
3. Labour costs are less, as there is division of labour.
4. Quality control is easier to implement.
5. Easy and accurate scheduling of materials is possible.
6. Production control is simpler due to less product variety.

Disadvantages of product layout

1. It is not easy to change the product – this will involve change in the layout and this is expensive and time consuming. So this layout is not very flexible.
2. If even one machine breaks down, the entire line will stop.
3. Expansion of work area or insertion of any machine in between other machines is not possible or is very difficult.

6.12.2 Process Layout

The layout in which all the equipment/machineries performing similar tasks are grouped together is called the **process layout** or **functional layout**; for example, the milling machines can be grouped together to form one department and the grinding machines can be grouped together to form another department. Depending on their processing requirements, parts are moved in different sequences among departments. Dividing the whole work place into small units helps in faster production and better utilization of the work place. The process layout can give a higher variety of products; for example, in a garment plant the stitching machines are kept in one place, pressing machines such as irons in another, knitting machines in another and so on.

NOTES

STORES	GRINDING	FOUNDRY
RECEIVING	PLANNING PRODUCTION CONTROL	DESPATCH
MILLING	CASTING	WELDING

Fig. 6.3 *The Process Layout*

Advantages of process layout

1. Flexibility in adapting to changing volumes, changing varieties.
2. Helps workmen learn more skills as job rotation enriches their skills.
3. Problem in one machine does not affect other machines and production need not stop.
4. In case of future expansion or increase in varieties, the existing set up need not be pulled out.

Disadvantages of process layout

1. Space requirement increases when the work volume increases.
2. Mechanization of material handling is not possible or is very costly.
3. High work in progress inventory as jobs have to queue up for each operation.
4. Difficulty in scheduling work, as different jobs have different operation sequences.
5. High level of supervision is required. Production Planning and Control is more difficult.

6.12.3 Project Layout

The layout in which the production operation is performed in a fixed position is called the **project layout** or **fixed position layout**; for example, aeroplane and ship building industries use this type of layout. While making a rocket (the real ones, not fire crackers!) the workmen/scientists, machines and tools and raw materials are moved to the place of construction of the rocket. Building bridges, roads, the Metro rail etc., are all projects.

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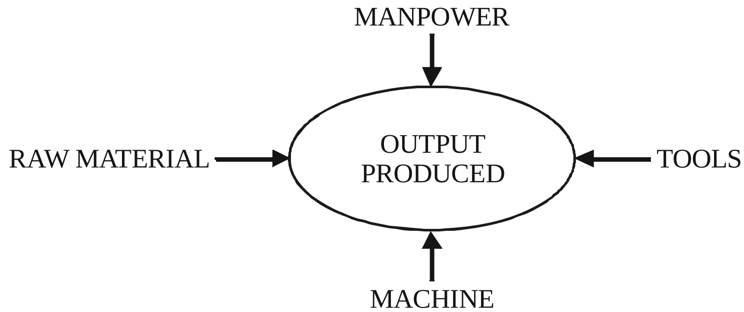

Fig. 6.4 *A Project Layout*

Advantages of project layout

1. It minimizes movement of machineries and equipment.
2. Continuity in production allows several activities to take place simultaneously.

Disadvantages of project layout

1. Skilled and versatile workers are required. The necessary combination of skills may be difficult to find. Suitable workers would have to be paid attractive salaries.
2. Once the project is over, the equipment/materials will have to be moved. Not only is this an expensive proposition but equipment utilization is also low since equipment is kept idle during the time that it is being shifted.

6.12.4 Group Layout

This layout is a combination of the layouts we have studied so far and is more commonly seen in the industry today. **Group technology,** or **cellular manufacturing** has the advantages of both process layout as well as line layout.

In group technology, parts are grouped into families. The layout consists of groups of different machines (called cells) that are necessary for the production of families of parts.

Advantages of group technology

1. The design of new products is good.
2. Production control is simpler than in Process layout or Project layout, since scheduling of machines is less complex and fewer tools and materials are required.
3. Material-handling costs are fewer than in Process layout.
4. There are savings in setup time which leads to increase in production.

6.13 LAYOUT PLANNING FOR STORAGE AND WAREHOUSING

The design and layout of a warehouse is slightly different from that of a production unit. A warehouse is used for storing raw materials and supplies, tools and equipment and semi-finished and finished goods. Warehouses are often located at a distance away from actual production or customer locations.

A warehouse should focus on achieving high productivity in day-to-day activities of material management. These productivity objectives are:

1. Maximum utilization of space.
2. Efficient stock location and identification.
3. Conservation of time, labour, and equipment.
4. Rapid and easy transfer to and from storage.

Meeting these goals depends on a variety of factors, such as the size and shape of the physical facility, type of material-handling equipment that is available, placement and arrangement of stock, and the nature and usage of items.

Small firms provide storage space within their own production facilities or in an adjacent warehouse. Larger corporations, particularly multi-plant companies and pure distribution systems such as grocery chains or retail department stores, use cubic footage to the maximum. Pallets or portable platforms are used to take advantage of vertical stacking capabilities. They are moved easily by forklift trucks and other handling equipment. Other storage methods are used for small items or those that are used infrequently. Racks, shelves, and bins are used for small items and they are usually picked by hand.

The arrangement of items in storage depends on a variety of factors. These are:

- Items subject to deterioration, such as foodstuffs, medical supplies, iron or paints must be protected from dampness, insects, or extreme temperatures.
- Valuable items need special storage locations with security provisions.
- Hazardous materials require special attention and location.
- The size, weight, and shape of items affect storage and handling. For example, fragile items cannot be stacked very high, and heavy or bulky items are best stored near the shipping area to reduce handling needs.
- Produce turnover also affects storage and handling. Fast-moving items need to be handled quickly, while slow movers can be stored in locations that require slower handling.

6.14 METHODOLOGY OF LAYOUT PLANNING

6.14.1 Line or Product Layout

This is easier to plan since the machines have to be arranged or laid out as per the sequence of operations involved in converting the raw material into finished goods. The problem in line layout is not of how to sequence or relatively position the work areas, but how to group the work elements in such a manner that there is very little idle time between the work centres.

6.14.2 Process Layout

The problem in process layout is one of arranging the different work areas in such a way that the material movement costs are kept to a minimum. It is assumed that the other relevant costs of layout will also be reduced on account of this optimizing procedure.

The material handling costs between two work areas (departments) = {distance between the two work areas} × {Load handled between the two departments during a unit period of time}. (Here, **load** means the total number of units of different products any department processes).

The sum of these products, for all the combinations of departments, should be kept to the minimum for an optimal plant layout. This can be expressed as follows:

Minimize $\Sigma D_{IJ} \times L_{IJ}Ij$ ... 6.1

where, D_{ij} is the distance between departments i and j, and L_{ij} is the number of loads per unit time moved (handled) between departments i and j.

The starting point in such a mathematical optimization procedure for the Process layout is gathering data on the number of loads per unit time moved between different combinations of the work areas. This data is called 'load summary' and is presented in matrix fashion.

6.14.3 Closeness Rating

Closeness ratings indicate the relative degree of desirability of having one department situated near another. These are very effective tools, especially in service facility layout planning; for example, in an MBA institution, it is advantageous to have the library and computer centre as close as possible to the lecture theatres. The boys' and girls' hostel should be as far apart as possible. The girls' hostel is usually located near the teachers' residential premises.

The closeness rating can be indicated as shown below.

Closeness rating	*Importance*
Absolutely necessary	1
Highly important	2
Important	3
Slightly important	4
Unimportant	5
Undesirable	6

Example 3

Indiana Hospital has made the following matrix to show the closeness ratings of the various departments for its proposed new building. The matrix shows that the closeness rating between departments D1 and D2 is 2, departments D1 and D3 is 4, D6 and D1 as 5, and so on.

Make a layout for the hospital building keeping in view the closeness ratings.

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
D_1									
D_2	2								
D_3	4	6							
D_4	1	5	1						
D_5	4	4	5	4					
D_6	5	4	3	4	6				
D_7	4	5	5	5	2	5			
D_8	5	6	3	1	4	5	3		
D_9	1	4	3	6	5	4	3	1	

Solution:

Step-1: Make a list of department pairs with ratings 1. This is necessary.

$$D_1 - D_4$$

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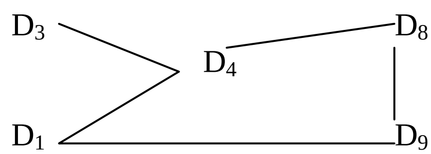
$D_3 - D_4$
$D_1 - D_9$
$D_4 - D_8$
$D_8 - D_9$

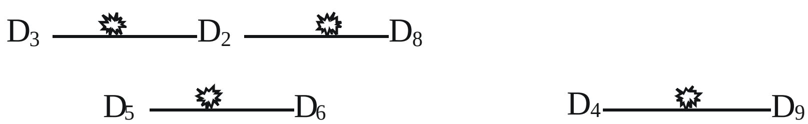
Make a list of department pairs with ratings 6. This is undesirable.

D_2 – D3
$D_5 - D_6$
$D_2 - D_8$
$D_4 - D_9$

Step-2: Now make a network of departments having the rating 1, with the department occurring most frequently (D_4) at the centre.



Similarly, make a network of departments having the rating 6, with the department occurring most frequently (D_2) at the centre.



Now, keeping in view the above combinations, place the departments in the nine cells as shown below. This placement satisfies all the conditions of not only departments with ratings 1 and 6 but also of those with other ratings. While making the placements, we have to consider only ratings 1 and 6; the other ratings are automatically satisfied.

D_2	D_4	D_3
D_6	D_1	D_8
D_7	D_9	D_5

Closeness ratings require a trial and error method for placement of departments. The Assignment method is more useful and commonly used in industry. Several computer software such as ALDEP (automated layout design programs) and CORELAP (computerized relationship layout planning) are based on the closeness ratings method. Another software, CRAFT (computerized relative allocation of facilities), is based on the load distance analysis method which is explained below.

6.14.4 Load Distance Analysis

In this method, two or more layouts can be compared to find out which one minimizes the total load-distance value of the product manufactured. Let us understand this technique by means of the following example.

Check Your Progress

1. What are the advantages of factor rating methods?
2. What do you understand by plant layout?
3. What is the objective of location planning?
4. What is the break-even analysis method of location planning?

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Example 4: The figures shown below display two layout options of a facility: Layout A and Layout B. The distance between any two adjacent departments is 10 m. No diagonal movement is possible, e.g., if a load has to be moved from Department 7 to Department 5 in Layout A, it can be done either through Departments 8, 9, and 6 or through Departments 3, 1 and 2 by travelling a distance of 40 m. The table below shows the department processing sequence of various products and their quantity produced per month. Calculate which layout is better in terms of lower total load- distance value.

LAYOUT A

1	2	5
3	4	6
7	8	9

LAYOUT B

5	3	4
9	6	1
2	7	8

PRODUCT	*PROCESSING SEQUENCE*	*QTY/MONTH*
V	5 – 7– 2 – 9	3000
W	4 – 3 – 8 – 1 – 5	4000
X	3 – 9 – 4 – 1	2000

Solution: Find the total distance travelled by a product while getting processed, according to the given sequence.

		DISTANCE	
PRODUCT	*PROCESSING SEQUENCE*	*LAYOUT A*	*LAYOUT B*
V	5 – 7 – 2 – 9	40 + 30 + 30 = 100	30+10+10=50
W	4 – 3 – 8 – 1 – 5	10 + 20 + 30 + 20 = 80	10+30+10+30=80
X	3 – 9 – 4 – 1	30 + 20 + 20 = 70	20 + 30 + 10 = 60

Now multiply the load, i.e. quantity per month with the distance calculated.

PRODUCT	*QTY*	*QTY X DISTANCE*	
		LAYOUT A	*LAYOUT B*
V	3,000	3,00,000	1,50,000
W	4,000	3,20,000	3,20,000
X	2,000	1,40,000	1,20,000
		7,60,000	5,90,000

The total load distance of Layout B is lesser than Layout A.

Hence, Layout B is a better option.

6.15 SUMMARY

In this unit, you have learned two important concepts: location planning and layout planning. Both are necessary for the success and sustained profitability of an organization. Proper location and layout planning go a long way in establishing a successful organization. Good operating and maintenance practices will enable an organization to achieve its goals of maximizing profit at minimum cost.

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Today, many software packages are available that automatically provide solutions for all the location and layout decisions. However, a study of such packages is beyond the scope of this unit.

6.16 KEY TERMS

- **Facility location**: It is the selection of suitable location or site where the factory or facility will be installed, and from where it will function.
- **Factor rating**: Every factor that is relevant to the industry is given a rating between 1 and 5. These factors are relevant to the industry, irrespective of the location. This is called factor rating.
- **Location rating**: Every factor that has been listed in factor rating is given a relative rating between 1 and 5 for each of the locations proposed to be selected. This is called location rating.
- **Break-even point:** The point at which the total cost is lowest is called the break-even point.
- **Layout**: It refers to the physical location of the various departments/units of a facility within the premises of the facility.
- **Product layout**: The placement of the equipment/machineries and materials in the order in which they are used for making the product is called the product layout or line layout.
- **Process layout**: The layout in which all the equipment/machineries performing similar tasks are grouped together is called the process layout or functional layout.
- **Project layout**: The layout in which the production operation is performed in a fixed position is called the project layout or fixed position layout.
- **Group layout**: In group technology parts are grouped into families. The layout consists of groups of different machines (called cells) that are necessary for the production of families of parts.
- **Closeness ratings**: It indicates the relative degree of desirability of having one department situated near another.
- **Load distance analysis:** In this method, two or more layouts are compared to find out which one minimizes the total load-distance value of the product manufactured.

6.17 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Factor rating method has the following advantages:
   (i) Simplicity that facilitates communication about why one location/site is better than another.
   (ii) Fosters consistency of judgements about location alternatives.
   (iii) Enables bringing diverse location considerations into the evaluation process.

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2. Plant layout is the repositioning of machineries and equipment of a plant for economic and better quality productions. Plant layout begins with the selection of work site for the facilities required in production and then arranging all the machineries so that there is steady flow of production operations. Additionally, plant layout includes arrangement of workmen, materials available, storage space and all other supporting services such as design and maintenance of a plant.
3. The objective of location planning is to minimize cost and maximize revenue**.** The planning for 'where' to locate should start from 'what' the organization's objectives, priorities, goals, strategies, etc., are and what the organization does to achieve them in the socio- economic- technical- legal environment.
4. This method is based on the concept of break-even analysis. There are two elements of cost, i.e., fixed cost and variable cost. Fixed cost includes capital expenditure land, building manufacturing and equipment. It is irrespective of the volume of production and will be incurred even if there is no production. Variable cost includes raw material, labour, etc. It is proportional to the volume of production. Total cost is the sum total of fixed cost and variable cost. When the volume of production is low, the component of fixed cost of the product is high and variable cost is low. As the volume of production increases, the variable cost component increases and fixed cost component falls. Till a point is reached beyond which variable cost again begins to increase. This point is called the **break-even point** at which the total cost is lowest. This volume of production is called **break-even volume.**

   A company likes to have a low break-even volume so that its costs are recovered soon. A location which gives least break-even volume is preferred.

6.18 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is plant layout? What are its advantages?
2. What do you understand by 'facility location' or plant location?
3. Write a short note on the parameters that affect the location of a plant in a foreign country.
4. Differentiate between line layout and process layout.
5. What is group technology?

Long-Answer Questions

1. Discuss the steps involved in selecting a location for a facility.
2. Explain the parameters that affect plant location.
3. Why is facility location important for the success of an organization?
4. Discuss the factor and location rating method.
5. How is the break-even concept used in location decision?
6. What is layout planning? What is its relevance to an organization?
7. What is the relevance of group technology? Explain with examples.

6.19 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

Bhattacharya, D. K. 2000. *Production and Operation Management.* New Delhi: Excel Books.

Evans, J.R., D.R. Anderson, D.J. Sweeney and T.A. Williams. 1984. *Applied Production and Operation Management.* St. Paul MN, US: West Publishing Co.

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UNIT 7 CAPACITY PLANNING AND MAINTENANCE MANAGEMENT

Structure

7.0 INTRODUCTION

You must be aware that whatever item a company plans to produce and whatever be the nature of the manpower it employs, if it does not have the necessary capacity or machinery to produce the desired product, all its plans will remain on paper.

Machinery need regular maintenance to retain efficiency levels. In this unit, you will learn about capacity planning and maintenance management including methods to modify capacity, needs, objectives, types and activities in maintenance management.

7.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand how capacity planning is done
- Understand the methods of modifying capacity

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- Appreciate the essentials of maintenance management
- Analyse the objectives of maintenance management
- Explain the different types of maintenance systems
- Understand the activities that constitute maintenance management

7.2 CAPACITY PLANNING

Capacity planning is an aspect of Production Planning. Capacity is the ability to produce and *Capacity planning is the process of identifying the capacity of a production unit that is required for producing so as to meet the current and future demands.*

An organization does capacity planning when

1. It is starting a new manufacturing unit.
2. It is increasing volumes of an existing manufacturing unit.
3. When new products are being introduced.
4. When there is a change in demand - addition, deletion of products.

7.2.1 Factors affecting Capacity Planning

The factors that affect capacity planning are

1. *Type of product or service*: The capacity of a company depends on the products it manufactures. If it is a tailor-made product, the volume of the products cannot be high. But if it is a general or standard product the volumes will be high.
2. *Type of process*: Whether the process is manual or automated also affects capacity. In manual processes, capacity is low. More manpower needs to be employed to increase capacity; even then there will be variations in products, performance, etc. In automated processes, the volume of output will be uniformly high.
3. *Type of technology Employed*: Capacity also depends on the technology employed. A high-end technology will produce better products at a much faster rate, and there will be less wastage. Availability of facilities such as space, power, etc. also affects capacity.
4. *Skill level of workers:* If the workers are better trained and motivated, the output will increase.
5. *Availability of raw material*: Ease of raw material availability will also affect capacity.
6. *External factors:* Government policies, tax limits, production limits, etc. also affect capacity.

7.3 METHODS TO MODIFY CAPACITY

Strategies to modify the capacity can be broadly classified into short term and long term.

7.3.1 Short-Term Methods

These methods will change the capacity or quantity produced in the short term. But they cannot be long term solutions to vary the capacity of the organization. The short term methods to vary capacity are –

1. **Inventories –** Companies may continue to produce during periods of low demand and pile up stock. This can be used during periods of increased demand.

2. **Labour –** Companies hire manpower during periods of high demand and lay off during periods of low demand. They may also pay overtime for extended working hours or allow relaxed working hours during low demand.
3. Some companies develop multiple skills of their employees. This is useful because job rotation can be done to take care of fluctuating demand.
4. **Process redesign –** Sometimes, changing job content at each work station can also take care of fluctuating demand.
5. **Subcontracting –** Many companies sub-contract part of their jobs. For example, during peak demand, some companies get their products made by another firm. Once the product is made, they inspect it and give it their brand name.
6. **Maintenance –** Some companies reschedule their routine maintenance to periods of less demand so that production during high demand periods is not affected.

7.3.2 Long-Term Methods

These methods take a long time to modify capacity. They can be of two types –

(a) Capacity expansion

(b) Capacity contraction

(a) **Capacity expansion –** This method requires considerable investment in the form of more land, new machineries, more manpower, etc. They can again be of two types –

   (i) *Expand once in five or more years* – This method is adopted when the company has to borrow externally for expansion. It requires a huge investment, but the company is assured that its supply will always meet the demand in the following years.

   (ii) *Expand a little every year* – Its advantage is that the company need not borrow heavily for investment; often the funds are generated internally. A company adopts this practice if it feels that the demand will increase a little every year.

(b) **Capacity contraction –** When a company feels that its products have entered the decline phase of their life cycle, it may decide to diversify or discontinue the product. It then sells off or transfers technology and skill to other companies. The capacity may also be reduced and allocated to other products of the company.

The capacity of a work centre is an important element for process design. Capacity is usually specified in terms of available hours, either for machines or labour. Capacity should include an efficiency factor reflecting downtime for failure and maintenance. Let us illustrate this by the following examples.

Example 1

A work centre consists of four machines, each of which is used during an 8-hour, one-shift operation. The efficiency of each machine is 85 per cent (that is, the machines are expected to be down 15 per cent of the time). Find the capacity of the work centre.

Solution:

The capacity of one machine in the work centre in one shift -

$8 \times 0.85 = 6.80$ hours

For 4 machines it is – $6.80 \times 4 = 27.2$ hours.

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Example 2

A steel melting shop is designed for production of 60 tons/heat, and the efficiency is 90 per cent. The furnace runs 168 hours in a week, i.e., 7 days running. If the average heat time is 4 hours/heat, find the rated capacity of the steel melting shop per week.

Solution:

$$\text{Rated Capacity} = \frac{168 \times 50 \times 0.9}{4} = 1{,}890 \text{ tons/week}$$

The Linear Programming method is however the most commonly used method to find capacity.

7.4 MAINTENANCE MANAGEMENT

Many years ago, when cars were owned either by the royalty or by the nouveau´ rich, men would refer to them as their 'second wives'! They would perpetually check their cars to ensure that they were in running condition, or in other words, follow rigorous maintenance practices.

Those few lucky cars which were properly maintained in their 'youth' have defied their 'age' and can still be seen at the vintage car rallies.

Not just cars, any vehicle or running machinery needs regular maintenance to retain its ability to function. Maintenance delays the wear and tear of equipment and extends its life. How this is done will be explained to you in the following section of this unit.

7.4.1 Definition of Maintenance Management

According to Allen Kent, '*Maintenance is defined as the activities required to keep a facility in its in- built condition, continuing to have its original productive capacity and maintenance management is managing the maintenance activities.*'

Maintenance can also be defined as '*the combination of tasks that are required to keep a machine or part of a machine in the desirable condition.*' It can also be defined as a '*method used to rectify the damaged and deteriorated part of machines to bring them to the functional level.*' A machine and its parts are subjected to continuous wear and tear – this results in a variation between the expected and actual performance from that machine in the immediate future and failure of that machine after some time. To prevent this from happening, maintenance practices need to be followed.

7.5 NEED FOR MAINTENANCE

Today, the production work in a plant has become highly automated with advanced technology. It is necessary to maintain the high productive rate of the plant so as to derive the maximum output from the equipment.

As the capital investment made in the industrial plants is high, the down time cost of these plants is also very high. The performance of the machines can get affected due to numerous reasons such as temperature variation, rusting, accumulation of dust, faulty operating practices, carelessness, etc. As the machinery in any plant is designed for regular production, any breakdown or malfunctioning of a machine results in stoppage of work in the whole plant.

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Maintenance of a plant is necessary at regular intervals to check the functioning of the machinery in the plant. Although deterioration of machines with time and other environment factors cannot be completely prevented, it can be delayed and managed for a considerable time by regular maintenance.

What if there was no maintenance? For the sake of argument, we may say that we need not spend money on maintenance and spend money only for repairs if equipment fails. This is not a correct argument because a plant will suffer heavy losses if there is a breakdown. Let us see what are the losses associated with the breakdown of a plant.

(a) There is the loss of profit due to non-production in a plant.

(b) For the time that the machine is under repair, the workforce will sit idle, but will have to be paid salaries. So this is another loss.

(c) Due to breakdown of one machine, the machines which are dependent on that machine will also become idle. So the loss is not just due to the breakdown machine, but all other machines on that line.

(d) If parts have been damaged they need to be replaced on an emergency basis at extra cost. If it is not easily available, the downtime and resultant loss of production will be even higher.

(e) To hasten the repair process, the maintenance crew will need to work longer hours. This means that overtime will have to be paid to maintenance staff.

(f) Due to the breakdown of a machine, the production schedule gets affected. To meet the timelines, the plant will have to work overtime and thus incur additional costs such as paying overtime to the workforce, shifting the pending work to other units, etc.

(g) If the breakdown of a machine occurs due to any accident, the plant has to bear the cost of the damaged machine and the cost of injury caused to the employees. .

(h) Due to frequent breakdown of machines, the life of the machine gets reduced and it can never work as efficiently as a new machine of the same capacity.

(i) There is customer dissatisfaction caused by not meeting delivery commitments, poor quality products, etc. This can lead to loss of market share.

(j) Frequent breakdown of machines means continuous repairs, stoppage of work and renewal of machines. This will result in additional training in case of new machine set up, formation of new deadlines, the employees will be asked to stay late or cancel their leave. All this will lead to low morale of the employees.

(k) Either the company buys the parts after the breakdown has occurred at higher cost, or it buys them beforehand in anticipation of breakdown and stores them. Storing inventory leads to carrying cost which is more than 30 per cent of the cost of machines. It also results in blocking useful capital for an indefinite period without any return.

7.6 OBJECTIVES OF MAINTENANCE MANAGEMENT

To avoid all the losses that a plant will incur if there is a breakdown, the plant should have a good maintenance system. Maintenance management is required to ensure that

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the maintenance system is applied to the plant properly and that there is continuous reduction in the downtime of the machineries and plant.

Following should be the objectives of a good maintenance management:

(a) Continuous and regular production by minimizing the plant shut down time.
(b) Eliminate risk of accidents caused due to machine breakdown or improper functioning of machines.
(c) Decrease the rate of wear and tear of the machines and their parts.
(d) Maintain the accuracy level of machines and parts.
(e) Ensure delivery timelines and customer satisfaction

It is not easy to lay down the maintenance practices for an organization. Some of the problems that are faced by organizations while laying down a maintenance policy are as follows –

1. Machine failure is often unpredictable and random.
2. Maintenance process varies from machine to machine and cannot be generalized.
3. Very often, maintenance requires replacement of parts of the machine. If the machine has been imported, either the parts need to be imported or they have to be produced indigenously. Both are difficult.

When laying down a maintenance policy, certain indicators are identified, which indicate that it is time for the next maintenance operation. Some of the common indicators are as follows –

(a) The machine is not able to work when loaded at its optimum capacity.
(b) The machine is not able to run at its rated speed.
(c) There is shortfall in the quality of goods produced.
(d) There is failure of some parts of the machine at regular intervals.
(e) Safety of people working in the plant is compromised.
(f) The component or machine itself has not been installed properly.
(g) The machine is getting heated – probably the cooling system needs to be checked.
(h) There is increase in friction between the parts of the machine.
(i) More vibration is felt or there is more noise during operation.
(j) Wrong fuel is being used in the machine.
(k) The machine is being operated in a faulty or untrained manner.
(l) Metal fatigue is observed in contact springs and locking devices.
(m) Less water in batteries, cracks in insulation, more dust on the equipment, decreased efficiency in operation, etc.

These situations should not be ignored. If not taken care of on time, they will lead to possible breakdown of the plant. Therefore, good maintenance is not just a comfort; it is a necessity for any plant to run successfully.

7.6.1 The Bathtub Curve

All equipment do not fail only due to old age. Some equipment fail during the initial stages itself due to some ‘teething problems’. This is referred to in technical parlance as **‘infant mortality’**. It can happen due to defects in design and/or installation of the machines.

For equipment failing in their **'youth'**, the cause of failure is often accidental and external.

Machines that fail in **'old age'** are due to constant wear and tear, i.e. they are worn out.

If a graph can be drawn showing the age-specific failure rate against time, it would look like a bath tub hence the name **'Bathtub Curve'**. This is shown in Figure 7.1. More failures occur during infant stage and old age than during the youth of the machines.

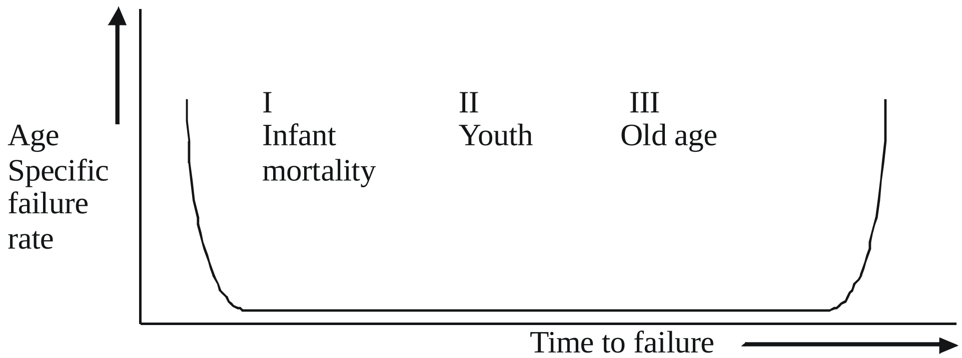

Fig. 7.1 *The Bathtub Curve*

7.7 TYPES OF MAINTENANCE SYSTEMS

Systems of maintenance can be broadly classified into two types, planned and unplanned.

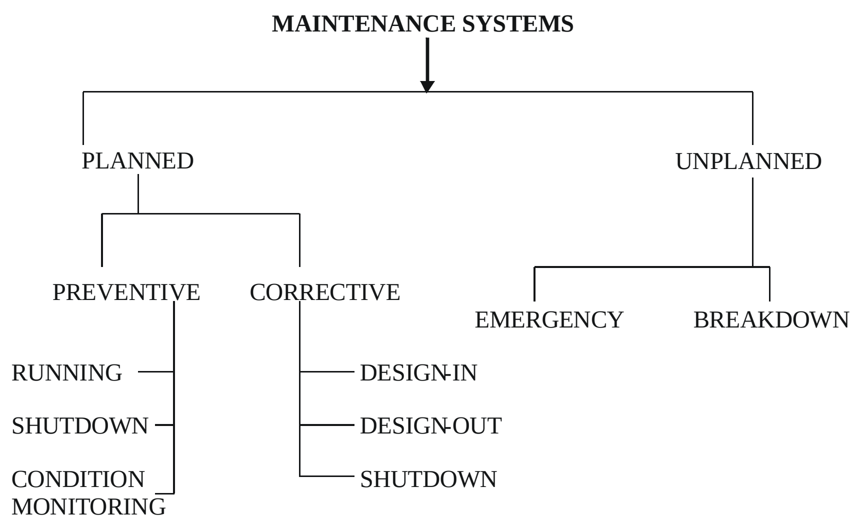

Fig. 7.2 *Types of Maintenance Systems*

7.7.1 Planned Maintenance System

As the name suggests, this maintenance activity is planned and scheduled in advance. It is also called **systematic maintenance system** and is designed to ensure that a plant is productive and functional throughout the year at a minimum cost.

Characteristics of planned maintenance

- The maintenance task is executed at the scheduled time.

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- A proper record is maintained of all the maintenance activities. This record helps in analysing the past mistakes and identifying loopholes in the maintenance system and helps to stop repetition of the same mistakes.
- The current plan is adjusted and modified based on past experience and records and present requirements.

The planned maintenance system is of two types: Preventive and Corrective.

(a) **Preventive maintenance system:** The maintenance procedures performed to keep a machine or its parts in the functional and acceptable state is termed as planned preventive maintenance system. Failures are predicted based on the records of previous maintenance tasks and necessary actions are taken to prevent recurrence of those failures.

It includes the following tasks:

(i) Inspection of machines on a regular basis

(ii) Lubrication

(iii) Cleaning and daily maintenance

(iv) Repairing or replacing the old parts of a machine

(v) Adjusting/resetting the equipment or parts

(vi) Contingent work done at regular intervals when the equipment is down. For instance, in chemical plants the rotary kilns, the multiple effect evaporators, large vessels, the thickeners and the reaction tanks are all inspected for their various parts, linings, etc. when these equipment are down. Contingency work is done particularly in those plants which otherwise operate on a continuous basis.

Benefits of preventive maintenance

(a) Reduction of the total downtime and consequent reduction in production losses.

(b) Reduction in the number of major repairs and consequently reduced maintenance expenses.

(c) Reduction in the number of rejects and an improvement in product quality.

(d) Reduction in the inventory of spare parts.

(e) Reduction in the number of accidents in the plant.

(f) Reduction in the unplanned or crisis management in maintenance.

The cost of preventive maintenance is the cost of

(1) Scheduled down time of production

(2) Cost of replacement parts and supplies

(3) Cost of instruments, e.g., in the case of condition monitoring

(4) Wages of preventive maintenance crew.

(5) Other costs such as those of record-keeping

Planned preventive maintenance system can be of three types**:** These are

- Running maintenance
- Shutdown maintenance
- Predictive maintenance or condition-based maintenance

(1) **Running maintenance:** When the preventive maintenance tasks (e.g., cleaning, lubrication) are carried out while a machine is running, it is called Running Maintenance.

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(2) **Shutdown maintenance:** When the preventive maintenance tasks (e.g. adjustments, replacement of damaged machine parts) are carried out while a machine is not working or is shut down, it is called Shutdown Maintenance.

(3) **Predictive maintenance or condition-based maintenance –** The inspection which is based on condition monitoring and is performed using condition- monitoring devices is termed as Predictive maintenance or Condition- based maintenance. It gives advance information of a probable failure of the machine.

Condition monitoring is a new technique where high cost critical equipment is monitored continuously or at frequent periodic intervals to observe the values of various parameters reflecting the condition of the equipment and the components within. The parameters monitored include temperature, vibration, noise, lubricant, corrosion, leaks, etc. Each of these parameters is an indication of some machine part malfunctioning. The monitoring of temperature might indicate coolant failure, damaged bearing, damaged insulation, improper heat generation, build-up of sediment or dust or friction and corrosion, etc. Vibrations may indicate misalignment, imbalance in rotation, bend and asymmetry in the shaft, damage in the gears, vanes, tubes, etc.

The cost of such monitoring is high, because of the requirement of sophisticated monitoring/measuring instruments but it is well justified and compensated.

(b) **Corrective maintenance system:** The procedures followed to rectify and restore a damaged and worn out machine or its parts is termed as planned corrective maintenance system. Application of maintenance measures can reduce the rate of damage in a machine and its parts but it cannot completely eradicate its wear and tear since the parts anyway deteriorate due to constant use and other environmental factors. To prevent its actual failure, corrective maintenance is done.

The corrective maintenance system includes the following tasks:

– Identifying the reasons of failure of the machine parts and rectifying them.
– Reconditioning the degraded machine parts on a regular basis.
– Replacing the worn- out parts of a machine.
– Overhauling the machine parts from time to time.
– Reducing the need for maintenance by updating the designs, parts used in a machine and improving the reliability of the machine.

Planned corrective maintenance system is of three types:

(i) **Design-out maintenance:** It involves designing or modifying a machine or its parts based on the latest technologies or system requirements. It is based on the use of statistical techniques and the concept of Mean Time Between Failures (MTBF) for repair/replacement of the equipment, etc.

(ii) **Design-in maintenance**: When the design of a machine or its parts are modified for the purpose of reducing the time and human effort needed for performing the maintenance task, it is called design in maintenance.

(iii) **Shutdown maintenance:** When the maintenance tasks (e.g., replacements, repair of parts) are carried out while a machine is not working or is shut down, it is called Shutdown Maintenance. A detailed PERT/CPM network is usually prepared for this purpose. Shut down of steel plants, power plants, paper mills, fertilizer units, etc., are common examples of shutdown maintenance.

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7.7.2 Unplanned Maintenance System

Unplanned maintenance system refers to the maintenance work that was not planned or thought about in advance. It can be categorized on the basis of ability to predict the failure, into two types – Emergency and Breakdown.

(a) **Emergency maintenance:** This refers to the maintenance required for the failure of a machine or its parts that was not catered for.

(b) **Breakdown maintenance**: This refers to the maintenance required for the failure of a machine or its parts that were conceived in advance; but the time of failure could not be estimated.

7.8 ACTIVITIES IN MAINTENANCE MANAGEMENT

There are several activities which are a part of all maintenance management systems. The most important ones have been explained below.

7.8.1 Inspection

Inspection is the most important activity of any maintenance management system as it is through inspection that the company comes to know about the condition of its equipment. Trained professionals perform inspection at pre-determined specified intervals of time. Their prime responsibility is to assess the condition of a machine. The inspection personnel will identify the worn out or deteriorated machine parts, loosened nuts or bolts, improper alignments, overheating, etc.

Inspection can be external and internal. External inspection can be done when the machine is running and when it is idle. It includes spotting the leakage of oil or water, listening to the rotation sound or air leakage, feeling the rise in temperature, feeling the roughness on surface of the machine, spotting dust or cracks on the machine, getting the smell of burning from any part of the machine, etc. Internal inspection identifies faults in the internal parts of a machine such as defects in gears or internal cracks. Internal inspection is done when a machine is not running and is also done to confirm the faults that are identified during the external inspection.

Inspection should be done without disrupting normal work. Minor inspection should be done during breaks on working days. Complete inspection can be carried out on weekly offs or on holidays. A machine can also be inspected if its standby is available. Inspection may be carried out based on the maintenance guidelines provided by the manufacturer in the instruction manual.

7.8.2 Lubrication Maintenance

Regular and proper lubrication of machines helps in reducing the rate of wear and tear maintains the temperature of the machines and reduces power consumption by the machines. It also protects a machine and its parts from corrosion and moisture. Irregular lubrication and failure of lubricating the machines has always been a major reason for the breakdown of the machines.

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Some of the pre-requisites for good lubrication are:

(a) **Identifying the right part of machine for lubrication.** Usually, all moving parts need to be lubricated.

(b) **Scheduling the frequency of lubrication:** The frequency of lubricating a machine or its parts depends upon their functions and machine requirements.

(c) **Deciding the amount of lubrication required:** To ensure proper lubrication, care should be taken that the lubricating agent or oil is used in right quantities.. Use of less quantity of lubricating oil will make a machine abrasive and damage the moving parts. Too much is also bad since it can cause overflowing.

(d) **Selecting the right lubricant:** The right quality of lubricant is essential for the long life of a machine. The right quality is often mentioned in the instruction manual provided by the manufacturer.

The lubrication manual not only lists the parts to be lubricated but also the types of lubricants to be used, process of lubrication, and frequency and quantity of lubrication.

7.8.3 Cleaning Maintenance

Machines and their parts should be regularly cleaned and maintained to avoid the coating of dust on the machines. With time, dust gets mixed with lubricants and causes abrasion, its coating is damaged and ultimately results in destruction of the moving parts of the machine. Also, regular cleaning of machines and its surroundings provides a clean and healthy environment, which in turn boosts the morale of the people working there.

A proper schedule for cleaning machines and plant is a regular and important function of maintenance management.

Some of the common areas where cleaning activities are required are:

(a) Cleaning of oil tanks, plunger pumps and oil pipes: Oil tanks need to be cleaned at regular intervals to ensure that the oil used for lubricating the machines is free from dust and dirt. In this process, the polluted oil is taken out from the oil tank, the tank is cleaned and then refilled with good quality oil. Plunger pumps are apparatus used for taking out the oil from the oil tank. They should also be checked and cleaned periodically. The lubricating pipes should also be cleaned.

(b) Regular cleaning should be done for transformers, resistors, filters, tool posts and slides, motor and fan blades, carbon brushes, electrical fuses, buttons, switches, etc.

(c) For motor bearing and bearing covers the cleaning process includes cleaning with benzene, rinsing in warm spindle oil and lubricating with grease.

(d) The entire machine should be wiped at least once a week to prevent accumulation of dust.

7.8.4 Servicing and Repairing Maintenance

(a) **Overhauling** is a detailed and thorough checkup undertaken periodically to give a new lease of life to a machine. Organizations undertake periodic overhaul of machines on a planned and scheduled basis after a pre-determined number of hours of working. Overhauling is not to be confused with ordinary repair, in which a machine is not completely dismantled.

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(b) **Re- construction or rebuilding** is the process of taking a damaged machine or part of the machine out of the production process and rectifying it. In this process, the maintenance management team performs the following actions:
   – Withdraws the damaged machine from the production line.
   – Disintegrates it into smaller units.
   – Examines the faults in the machine or identifies the non- functioning part.
   – Makes the machine run by adjusting the parts of the machine and if it does not work, replacing the worn out part with a new one.
   – Re- constructing the machine

(c) The maintenance management team constantly searches for ways to lower the need for the maintenance of the machine or its parts. This is sometimes done by modifying or improving the designs of the machines so that lesser time and effort is required for maintenance work.

(d) Maintenance of worn- out parts and replacement of non- functional parts of a machine is also a part of maintenance management. Repairing or replacing a damaged machine or parts of the machine is done while the machine is running or after it has broken down.

(e) Another important job of maintenance management is regular servicing of the machinery. It is important to increase the life of the machines and productivity of a plant. In servicing, the machines are checked and inspected for minor defaults or replacements to eliminate major faults or breakdown in future.

7.8.5 Maintenance of Records

Regular record maintenance is a very important job of maintenance management. The following records are generally maintained by the maintenance management team:

(a) **Manufacturer's instruction manual and spare parts manual:** These are the documents or catalogues, which come along with the machines or the spare parts at the time of purchasing the mother equipment. These manuals provide information regarding the installation and operation of the machines, types of lubricant to be used, how to use it and the interval of time period to be maintained. They also tell us which spare parts are to be replaced at regular intervals and help in identifying the worn - out parts. These manuals are kept safely and within reach, so that they can be accessed anytime.

(b) **Drawings of parts:** The manufacturers also provide the drawings of the parts of the machines at the time of purchase. This helps in the understanding of the part at the time of repairing. If the drawings are not provided, they should be prepared.

(c) **Circuit diagrams**: Circuit diagrams are used to better understand the functioning of a machine. These diagrams can be electrical or hydraulic and should be kept along with the instruction manuals. As they are referred to frequently, it is advisable to use their copies and keep the originals safely. This is done to avoid their wear and tear.

(d) **Machine details:** Additional details of a machine such as address of the manufacturer, purchase date and number, specifications of the machine and list of spare parts and accessories should also be maintained

Check Your Progress

1. What are the different methods of varying capacity in the long term?
2. What is capacity and when is capacity reviewed/ planned?
3. What is the importance of maintenance management in a plant?
4. What is preventive maintenance and what are its advantages?

(e) **History of the machines:** Maintaining the history of machine performance is an important activity. This record includes 'Failure Statistics', the number and nature of repairs and replacements, faults in the machine, its performance history, time and frequency of replacement of spare parts, etc.

7.8.6 Records Analysis

The records of the machines that are maintained are analysed at regular intervals by the maintenance management team.

This analysis helps to:

(a) Identify the reasons for frequent failures of machines and to take preventive actions.
(b) Schedule inspections.
(c) Identify defects and form a plan to rectify them.
(d) Identify the performance standard of machine for planning the production process.
(e) Select the worn and torn machines or their parts for replacement.
(f) Predict breakdowns and downtime of the machines

7.8.7 Maintenance Training

Proper training of the maintenance management team helps in ensuring proper functioning of the machines in a plant. The maintenance management team regularly updates itself with new modifications in the machinery and new ways of handling them. Trained maintenance personnel will be able to readily identify faults, rectify them and ensure regular productivity in a plant.

7.8.8 Performance Standards Maintenance

The maintenance management team should not only perform its jobs but also define the Standard Operating Practices (SOP) for carrying out maintenance activities. This is critical if a company wants to achieve ISO certification. This is called a **'Maintenance Policy'**. It also helps the maintenance management team to do its work uniformly at all times and to ensure that the work does not vary from person to person.

7.9 SUMMARY

In this unit, you have learned about two important topics—capacity planning and maintenance management. Both are necessary for the success and sustained profitability of an organization. Good operating practices, coupled with good maintenance practices, enable an organization to achieve its goals of maximizing profit at minimum cost.

Today, many software packages are available which offer solutions for all capacity planning and maintenance systems problems.

7.10 KEY TERMS

- **Capacity planning:** It is the process of identifying the capacity of a production unit that is required for producing so as to meet the current and future demands.

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- **Capacity expansion:** This method requires considerable investment in the form of more land, new machineries, more manpower, etc.
- **Capacity contraction:** When a company feels that its products have entered the decline phase of their life cycle, it may decide to diversify or discontinue the product.
- **Maintenance**: According to Allen Kent, 'Maintenance is defined as the activities required to keep a facility in its in-built condition, continuing to have its original productive capacity and maintenance management is managing the maintenance activities.'
- **Bathtub curve:** If a graph can be drawn showing the age specific failure rate against time, it would look like a bathtub hence the name 'Bath tub curve'**.**
- **Planned preventive maintenance system:** The maintenance procedures performed to keep a machine or its parts in the functional and acceptable state is termed as planned preventive maintenance system.
- **Running maintenance:** When the preventive maintenance tasks (e.g., cleaning, lubrication) are carried out while a machine is running, it is called running maintenance.
- **Shutdown maintenance:** When the preventive maintenance tasks (e.g., adjustments, replacement of damaged machine parts) are carried out while a machine is not working or is shut down, it is called shutdown maintenance.
- **Predictive maintenance or condition-based maintenance:** The inspection which is based on condition monitoring and is performed using condition- monitoring devices is termed as predictive maintenance or condition- based maintenance.
- **Planned corrective maintenance system:** The procedures followed to rectify and restore a damaged and worn out machine or its parts is termed as planned corrective maintenance system.
- **Unplanned maintenance system:** This refers to the maintenance work that was not planned or thought about in advance.
- **Emergency maintenance:** This refers to the maintenance required for the failure of a machine or its parts that was not catered for**.**
- **Breakdown maintenance**: This refers to the maintenance required for the failure of a machine or its parts that were conceived in advance; but the time of failure could not be estimated.
- **Inspection:** Inspection is the most important activity of any maintenance management system as it is through inspection that the company comes to know about the condition of its equipment. Trained professionals perform inspection at pre-determined specified intervals of time. Their prime responsibility is to assess the condition of a machine. The inspection personnel will identify the worn out or deteriorated machine parts, loosened nuts or bolts, improper alignments, overheating, etc.

7.11 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Capacity variation in the long term cannot be reversed easily. Increasing capacity requires considerable investment in the form of investing in more land, new machineries, more manpower, etc. Methods of capacity expansion are –
   (i) **Expand once in five or more years –** This method is adopted when the company has to borrow externally for expansion. It requires a huge investment, but the company is ensured that its supply will always meet the demand in the following years.
   (ii) **Expand a little every year –** Its advantage is that the company need not borrow heavily for investment; often the funds are generated internally. A company adopts this practice if it feels that the demand will increase a little every year.

   Capacity can be reduced permanently by capacity contraction. When a company feels that its products have entered the decline phase of its life cycle, it may decide to diversify or discontinue the product. Then it sells off or transfers technology and skill to other companies. The capacity may also be reduced and allocated to other products of the company.
2. Capacity is the ability or limiting capability to produce, in order to meet the current and future demands of an organization.

   A company does capacity planning when -
   1. It starts a new manufacturing unit
   2. It increases volumes of an existing manufacturing unit
   3. New products are being introduced
   4. There is a change in demand—addition, deletion of products
3. To avoid all the losses that a plant would incur if there is a breakdown, the plant should have a good maintenance system. Maintenance management is required to ensure that the maintenance system is applied to the plant properly, and there is continuous reduction in the downtime of the machineries and plant. A good maintenance management system helps to -
   (a) Ensure continuous and regular production by minimizing the plant shut down time.
   (b) Eliminate risk of accidents caused due to machine breakdown or improper functioning of machines.
   (c) Decrease the rate of wear and tear of the machines and their parts.
   (d) Maintain the accuracy level of machines and parts.
   (e) Ensure delivery timelines and customer satisfaction
4. The maintenance procedures performed to keep a machine or its parts in the functional and acceptable state is termed as planned preventive maintenance system. Failures are predicted based on the records of previous maintenance tasks and necessary actions are taken to prevent recurrence of those failures.

   Benefits from preventive maintenance are as follows:
   (a) Reduction of the total down time and consequent reduction in production losses.
   (b) Reduction in the number of major repairs and consequently reduced maintenance expenses.

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(c) Reduction in the number of rejects and an improvement in product quality.
(d) Reduction in the inventory of spare parts.
(e) Reduction in the number of accidents in the plant.
(f) Reduction in the unplanned or crisis management in maintenance.

7.12 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is maintenance? Why is it required?
2. What are the factors that influence the capacity of an organization?
3. Classify the different types of maintenance systems.
4. What are the functions that comprise maintenance management?
5. Write a note on the 'Bathtub Curve'.
6. How can capacity be varied in the short term?

Long-Answer Questions

1. What kind of records does a maintenance department maintain? Why do they need to be maintained?
2. What is the difference between preventive and corrective maintenance systems?
3. Compare and contrast planned and unplanned maintenance.
4. Inspection is an integral part of maintenance. Explain
5. Give a detailed account of some common indicators which show that maintenance is necessary.

7.13 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

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UNIT 8 WORK STUDY

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Structure

8.0 INTRODUCTION

In the preceding units the focus was on the design and control of the physical parameters that support production. Although a significant level of automation has been implemented in many factories, human beings still control a large part of the manufacturing process. Clearly, personnel also need to be 'managed'. The workplace has people of diverse cultural and educational backgrounds. This, is coupled with the organization's objectives, warrant a clear definition of jobs for the workforce so that maximum productivity is possible–in addition to the highest levels of quality, service and responsiveness. Also, the job should be safe, satisfying and motivating to the worker.

This is achieved by a concept called **work study**, which you will learn in this unit. You will also learn the definition and objectives of work study, and the techniques of measuring work/output.

8.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Define the concept of work study
- Understand the objectives of work study
- Understand the method study procedure
- Understand what is meant by work measurement
- Understand the objectives of measuring work
- Understand the techniques of measuring work or output

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8.2 DEFINITION OF WORK STUDY

Work study means study of human work. British Standard 3138: 1969 defined work study as, *'A management service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.'* This means that it is a procedure for understanding and determining the activities of the people, plant and machineries, identifying the factors which affect their efficiency and achieving economy through their optimum utilization. Work study is a generic term for two inter-dependent techniques, i.e., method study and work measurement.

In the same British standard, method study has been defined as '… *the systematic recording and critical examination of the factors and resources involved in existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs'*. Method study, therefore, is concerned with the way in which the work is done.

Work measurement is defined by the same British standard as *'The application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance'*.

The difference between work study and other productivity improvement techniques is that the latter involve major capital expenditure in plant or equipment. But work study ensures productivity by using **existing** resources. In work study, the human element is emphasized and importance is given to operation rather than to the technical process.

8.3 OBJECTIVES OF WORK STUDY

The primary objectives of work study are:

1. Effective use of plant and equipment
2. Effective use of human effort
3. Evaluation of human work

If the techniques of work study are not properly applied, they are likely to encounter resistance at all levels. Even trade unions acknowledge that work study provides the following benefits to workers:

a) Eliminates drudgery, frustration and unhealthy working environment
b) Provides opportunity to e workers to increase their earnings (by achieving increased rate of output)
c) Strengthens the health of the organization at micro level and the nation as a whole at macro level

In 1952, the International Labour Organization emphasized the importance of work study and consultation and cooperation between employers and workers in its 35th session held at Geneva.

In the following sections you will learn the two techniques, i.e., method study and work measurement.

8.4 METHOD STUDY

As you have learnt, method study is a method for examining, recording and analysing the existing way of doing work and proposing a method for improving the efficiency of a system. There may be unnecessary costs being incurred in the existing methods. In the method study, the reasons for these costs are identified. The critical examination of proposed methods also prevents unnecessary costs in the new jobs.

8.4.1 Objectives of Method Study

The main objectives of method study are as follows:

1. To identify the proper sequence of production operations
2. To optimize the utilization of machineries
3. To reduce the manufacturing cycle time by reducing idle time of machinery
4. To choose the right kind and amount of materials and reduce the raw material consumption per unit of production
5. To reduce wastages and production of defective products
6. To enhance the tool life and therefore reduce the tool cost per unit of production
7. To allocate work force optimally and reduce idle time of the operator by optimal utilization of human resources
8. To improve the processes and procedures involved in production
9. To improve the working environment in the workplace

8.4.2 The Method Study Procedure

Method study is a scientific and systematic method by which an organization can determine the most appropriate method to manufacture a product. Now, why should an organization study a process? It should study a process to identify delays; reduce transport distances for both materials and labour; economize processes; reduce requirements of processing time; and thereby make the total operation simple. By doing a method study, the organization aims to eliminate any stage or step in the process that does not add any value to the process.

We begin the method study by first making a flowchart for the process.

The basic procedures involved in method study are as follows:

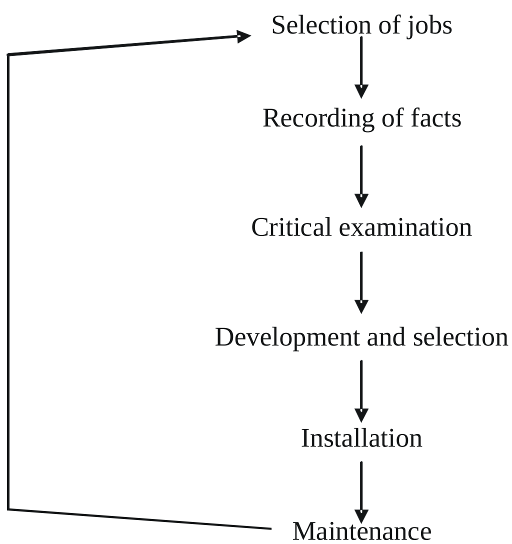

Fig. 8.1 *Flowchart of the Method Study Procedure*

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a) Selection of Jobs

Selection of a job for which method study is to be done is a managerial responsibility. The considerations for selecting a job could be economic, technical or human.

i) Economic considerations:

These include operations which could be holding up other production operations, such as:

- Needless movement of workmen and materials over long distances
- Operations that involve great deal of manpower
- Operations that involve poor utilization of men and machines
- Sections or departments from which too many suggestions for improvement are received

ii) Technical considerations:

- Operations that produce a great deal of waste or defectives
- Operations that involve repetitive work
- Complaints that performance standards cannot be achieved
- Operations requiring frequent supervision
- Jobs with incompatible quality
- Operations involving discrepancies in materials and tool performance
- Jobs involving greater number of man hours for checking and rechecking work

iii) Human considerations:

- Workers complain about being overworked
- Poor worker morale
- Frequent accidents and health hazards
- Inconsistency in the earnings of the employees due to overtime

b) Recording of Facts

Accurate and precise recording of facts related to a method determines the success of the method study. A method study generally uses the graphical method to record facts such as completion time and labour required in a method. The graphical method uses five symbols to record the facts related to a method. They are –

○ **Operation** This symbol indicates that an activity is being done. Generally an operation is any activity that is adding some value to a product. It is a transformation process.

⇨ **Transportation** This symbol indicates that the product, service or worker is moving from one location to another.

□ **Inspection** This symbol stands for checking/observing for quality/correctness/ adherence to specifications, etc.

D **Delay** This symbol indicates that the subject of study (product, service or worker) has to wait before starting the next process.

▽ **Storage** This symbol indicates storage. Sometimes, T or P is written inside the triangle to indicate temporary storage or permanent storage respectively.

The advantages of graphical method over the descriptive method are that:

- It takes less effort and time.
- It helps isolate the valuable areas of a method from the useless areas.
- Critical examination becomes easier and more effective because it is visually clear.

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c) Critical Examination

Critical examination means analysing the facts related to a method. In critical examination, the facts related to a method should be examined as they are and not as they should be. Each step should be analysed in a logical sequence and hasty decisions should be avoided.

A systematic and methodical questioning process is used to conduct the critical examination. In the questioning process, all the activities whether related to processing, inspection, material handling or any other aspect of a method are recorded in a chart. After recording all the activities involved in a method, each activity is then examined carefully. There are five major factors related to an activity that need to be considered during the questioning process. These factors include:

Purpose: Analyses whether the selected activity is necessary for completing a method or not.

The kinds of questions asked are – What activity is being done? Why is that activity being done? What will happen if that activity is not done? What else can be done? What should be done?

Place: Analyses whether the selected activity occurs at a specified place or not. Questions asked are – Where is that activity done? Why is it done there? What will happen if it is not done at that location and done elsewhere? Where else can it be done?

Sequence: Analyses whether the selected activity occurs at specified time and in a specific sequence or not. Questions asked are – When is the activity done? Is the performance of the activity at that time critical or can it be done at any time or in any sequence? Could it be combined with some other activity in the process?

Person: Analyses whether or not the right person performs the selected activity. Questions asked are – Who does the activity? Why should that person do that activity? Can it be done by someone else? Should the worker possess a high level of skills or will a lower skill level do?

Means: Analyses whether or not the selected activity is done using proper materials, tools, jigs and fixtures, measuring instruments and gauges. Questions asked are – How is the activity done? Why is it done that way? Is there a better way to do the activity?

d) Development and Selection

Development involves an analyses of all the ideas generated during critical examination and implementing these ideas practically. All the ideas generated during critical examination may not be practical. So the organization first needs to isolate the practical ideas from the conceptual ones. The selected ideas are then refined and developed during the development and selection process. The development process comprises three functions: evaluation, investigation and selection.

i) **Evaluation phase:** All the ideas generated during critical examination are evaluated to assess their true value and determine whether they should be pursued

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or discarded. To isolate the practical ideas from the useless ones, they are first categorized as-

- Useful ideas
- Ideas with technical flaws
- Ideas that cannot be used immediately because of insufficient data or lack of requisite knowledge
- Ideas with more disadvantages than advantages

Ideas which are similar are clubbed. The cost of testing and implementation is estimated

ii) **Investigation phase:** The ideas generated in the evaluation phase are investigated to determine how a suitable idea can be taken up for practical implementation. The investigation phase includes preparing layouts, organizing discussion with personnel from various departments such as design and quality control, making prototypes, conducting trial runs, getting work measurement studies redone from industrial engineering and preparing fresh cost estimates. Every idea is investigated to check its economic and technical feasibility.

iii) **Selection:** The selection stage involves choosing the best possible alternative from the available options. Various factors are taken into consideration such as investment required, production rate expressed in terms of cycle time per unit of product, manufacturing cost per unit of production and physical effort required for performing the method. Every factor is assigned some points. The points acquired by every factor are added and the alternative that acquires maximum points is selected.

e) Installation

Implementation of the proposed method is known as installation. The proposal for change in method is presented to the management indicating the sequential steps that must be taken to implement the changed proposal. On receipt of formal approval, the implementation plan is prepared. A demonstration of the proposed method can be held to clear misconceptions and apprehensions. Training of the employees who will use the new methods can also be done.

f) Maintenance

After implementing a method, it is important to monitor the performance of the method. A feedback mechanism is needed to inform the concerned authorities about the results of the monitoring process. The savings accrued by using the new method should be audited to determine whether or not the implementation work is complete. The audit will also reveal additional factors that can enhance profits and then the whole cycle will start again.

The approach followed by the practitioner is also **reviewed** at this stage.

- Did he follow the effective approach? Does it need any correction?
- Was the implementation process efficient favourable? If not, what changes are required in the approach so that the implementation of future projects is smooth?
- Which methods were used for efficient data collection? Can these methods be used in similar projects in future?

Performance appraisal: The last step in the maintenance stage involves performance appraisal. This helps determine the productivity gains of the proposed method that are evaluated at regular intervals.

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As human reactions play an important role in a method study, human consideration forms an important part in selecting a job. Workers should accept changes proposed by the method study. A change which is not fully accepted by the workers is not considered a good change. It is human nature to resist change. Opposition by the workers can be avoided by taking them into confidence. The following points should be considered in order to avoid resistance by the workers:

- Proposed changes should be intimated to the workers in advance because any surprise change is likely to be opposed.
- Approved methods must be properly introduced into the organization.
- Changes should be made slowly so that the organization can easily absorb them. This helps the workers to gradually adapt themselves to the changed methodology.
- Implement the methods in such a way that the entire human resource of the organization is won over.

8.5 WORK MEASUREMENT

Work measurement, as defined in the preceding units, is a technique to find out the time required to do any activity, at a predetermined level of performance, by a qualified worker. In order words, it is a technique to develop time standards for the performance of jobs.

To establish usable standards, the operation must first be trained to do a particular job. These methods analysis and study should provide work measurement.

8.5.1 Objectives of Work Measurement

The primary objectives of Work measurement are –

a) To establish the standard time for completing a job.
b) To fix the salary of employees and to determine and calculate incentives based on their performance.
c) To estimate the machine and labour requirements for planning and scheduling of production, the time required for jobs and when deliveries are possible, etc.
d) To distribute workload among the workers.
e) To calculate the number of employees needed for various tasks of the organization.
f) To determine the number and nature of machines that a worker can run.
g) To help managements accurately determine the costs incurred in Production.
h) To compare the efficiency of various alternative methods and determining the best alternative among them.
i) To establish standards for the performance of employees and utilization of machinery. This way, substandard workers can be identified.
j) To control costs by uncovering wastages of both machine and labour and thus help to increase the operating efficiency.
k) To track the performance of workers, their training needs, etc.

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8.5.2 Techniques of Work Measurement

There are several techniques for measuring work. The most common are:

1. Time study
2. Work sampling
3. Standard data
4. PMTS – Predetermined motion time studies.

We will now study them in detail.

Time study

This method of work measurement is generally used when the work is repetitive. It is a sampling process in which a few observations of a sample are taken. The inferences drawn from the study of the sample are used to determine the time required for the performance of the subsequent cycles by the worker.

First, the job or task selected for time studies is split or broken down into activities. Then each activity is timed separately using devices such as stopwatch.

Some principles are followed in breaking down the job into its activities. These are:-

1. Each activity should be of short duration, but at the same time long enough for it to be timed with a stopwatch.
2. The activities of the operator and activities of the machinery should be distinguished. Both should be timed separately.
3. Delays of the operator and the equipment should also be indicated separately.

Several readings need to be taken for each activity. The average of these readings will give the average time for an activity. The average time for each activity of a job is added to get the average time for a job.

The time thus obtained must be 'normalized' to make it usable for all the workers. So a rating factor is used to give the **normal time**. To take an example, if an operator completes a task in two minutes and it is estimated that he is performing 20 per cent faster than normal, then the performance rating of the operator is said to be 1.2 times or 120 per cent of the normal.

The normal time for the task will be 2 minutes × 1.2 = 2.4 minutes.

So **Normal time (NT)** = observed performance time per unit × Performance rating.

When an operator is observed for a period of time during which he produces a number of units, then the Normal time is given as -

$$NT = \frac{\text{Time worked}}{\text{No. of units produced}} \times \text{Performance rating} \qquad \text{... 8.1}$$

Standard time is calculated by adding allowances for personal needs (such as breaks for freshening up or for drinking tea), inevitable work delays (such as lack of material or breakdown of machinery), and worker fatigue (physical or mental), to the normal time.

Standard time (ST) = Normal time (NT) + (Allowances x Normal time) ... 8.2

*(**Note:** Allowances may be given in minutes or as a percentage of the normal time)*

ST = NT (1+ Allowances) Eq.8.3

This equation is most often used in practice.

Work sampling

This is another technique for measuring an activity. This method is similar to Time Sstudy in that here also, we observe a portion or sample of the work activity. Inferences are drawn based on the findings in this sample and this is applied for the activity in general.

For example, if a blacksmith is observed 100 random times during a week and it is found that he is making a hammer 30 out of the 100 times, it can be inferred that the blacksmith spends 30 per cent of his time in making hammers.

(***Note:*** *The time required to make an observation is dependant on the object or activity that is being observed. Many times, only a glance is required to determine the activity, and most of the studies require only few seconds' of observation.*)

In work sampling, the size of the sample is a major issue. The level of statistical confidence desired in the results is considered before deciding the sample size. The account of observations needed in a work sampling study can be fairly large, ranging from several hundred to several thousand, depending on the activity and level of accuracy required.

The three primary applications for work sampling are:

1. To determine the average time that the machine and labour are idle or running. This is also called 'activity time' for personnel and machinery.
2. To develop a performance index for workers. These performance measures help in performance evaluation of the workers, fixing of pay, bonus, penalties, etc.
3. To fix time standards, that is, the standard time required for a task.

Following is the sequence of activities in doing a work sampling study –

1. Identify the activity for which the study is to be done.
2. Estimate the percentage of time the selected activity takes, to the total time (e.g. the machine is working 80 per cent of the time). These estimates are made by the analyst from existing data, guesswork or a pilot work sampling study.
3. State the degree of accuracy desired in the study results.
4. Determine the particular times when each observation is to be made.
5. Two or three times during the study period, the data collected are examined and if necessary, the required sample size and number of observations to be made are altered.

In a work sampling study the number of observations to be taken is equally divided over the study period. Thus, if 500 observations are to be made over a period of 10 days, observations are usually scheduled at 500/10, or 50 per day. A specific time may also be assigned for each day's observations.

Work sampling compared to time study

Work sampling has several **advantages** over time study:

1. One observer can simultaneously conduct several work sampling studies.
2. Generally, the observer is not highly skilled. Only the analysts need to be highly trained.

NOTES

Check Your Progress

1. Define work study.
2. List the main objectives of method study.
3. What is work sampling?

NOTES

3. Timing devices are not required in work sampling.
4. Work of a long cycle time may be studied with fewer observer hours.
5. Since the duration of the study is longer the effect of short term variations is negligible.
6. The study can be temporarily delayed, without affecting the results.
7. Since work sampling involves observations made over a longer period, the worker has less chance of influencing the findings by changing his or her work method.

The **disadvantages** of work sampling over time study are:

1. Work study is not economical in case of a short cycle time. In such cases time study is more appropriate.
2. Observers in work sampling tend to develop repetitive time of taking observations and route of travel. This can make the observations predictable and the inferences may be erroneous. So the observer should adopt a random sequence of observations to lessen these errors.
3. Work sampling is more accurate when the system is stable. In a dynamic situation, work sampling may give erroneous results.

Standard data

For jobs in which there are a large number of repetitive operations with similar characteristics, companies often develop standard data through time studies or predetermined data. The advantage of having standard data is that each job need not undergo a time study. Standard data is applied in a similar manner as predetermined motion time data, except on a less detailed level.

For instance, an income tax service may develop standard data on the time required to fill out different tax forms. From this data, it is easy to provide an estimate of the cost for a client based on information about the forms required for the client. Standard data are also useful in estimating times for jobs with different characteristics through regression - type equations.

Standard data is used in the following manner. –

Example: In a warehouse the standard time required to unload 10 Kg boxes from a truck is 2 minutes per box. Due to increasing allowances for fatigue, suppose this goes up by 0.10 minutes for each additional 2 kgs. The standard time for a box of weight 'b' is 2 + 0.10/2 (b – 10) minutes.

Therefore, if 50 boxes, each weighing 18kgs are to be unloaded, the standard time required is 50 {2 + .05 (18 – 10)} = 50 × 2.4 = 120 minutes, or 2 hours.

Having an adequate data base of standard data makes such calculations easy to compute.

Predetermined motion time studies (PMTS)

An alternative to time study is the use of standard times for work elements that have been predetermined from long periods of observation and analysis. The major advantage of this method is that only motion patterns must be known; alternatives may be evaluated prior to actually trying them out. In order for such a system to be universally applied, it is necessary to define a basic set of motions into which any task can be split into.

However, these motions must be refined to account for various degrees of difficulty; for example, lifting a bag of 5 kg is easier than lifting 5 kg of cotton wool, and thus should be expected to take lesser time.

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Since it is necessary to apply micro-motion analysis to such systems, these systems are often costly to use. There are a number of different motion time systems. One of the best known and most widely used is methods time measurement (MTM). This system was developed in 1948 from studies of motion picture films of assembly operations. The basic elements used in MTM are:

1. Reach
2. Move
3. Turn and apply pressure
4. Grasp
5. Position
6. Release
7. Disengage
8. Eye travel time and eye focus
9. Body, leg, and foot motions
10. Simultaneous motions

Each of these has several subcategories. For example, there are five types of reach:

A. Reach to an object in a fixed location or in the other hand
B. Reach to an object in a general location
C. Reach to objects jumbled together
D. Reach to very small objects
E. Reach to an indefinite location, such as moving the hand out of the way

Element times are measured in TMUs (time measurement units), where one TMU is .00001 hour, or .0006 minutes. Tables of times have been developed for each activity, so that employees take an active role in increasing productivity and quality and in reducing costs.

8.6 SUMMARY

In this unit, you have learned about the concept of work study. Work studies come under the umbrella of activities of industrial engineering. Industrial engineering is a branch of study that deals with the design, progress, enhancement, operation and estimation of an assembled structure of people, knowledge, tools, energy, materials and processes. In manufacturing organization, an industrial engineer is responsible for reducing wastages of time, money, materials, energy and all other resources. Work study is the most commonly used set of techniques of studying the work done by workers.

8.7 KEY TERMS

- **Work study**: British Standard 3138: 1969 defined work study as: 'A management service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.'

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- **Method study**: It is a method for examining, recording and analysing the existing way of doing work and proposing a method for improving the efficiency of a system.
  - ○ **Operation:** This symbol indicates that an activity is being done. Generally an operation is any activity that is adding some value to a product. It is a transformation process.
  - ⇨ **Transportation:** This symbol indicates that the product, service or worker is moving from one location to another.
  - □ **Inspection:** This symbol stands for checking/observing for quality/correctness/adherence to specifications, etc.
  - D **Delay:** This symbol indicates that the subject of study (product, service or worker) has to wait before starting the next process.
  - ▽ **Storage** This symbol indicates storage. Sometimes, T or P is written inside the triangle to indicate temporary storage or permanent storage respectively.
- **Work measurement**: It is a technique to find out the time required to do any activity, at a predetermined level of performance, by a qualified worker. In order words, it is a technique to develop time standards for the performance of jobs.
- **Time study:**This method of work measurement is generally used when the work is repetitive. It is a sampling process in which a few observations of a sample are taken. The inferences drawn from the study of the sample are used to determine the time required for subsequent cycles to be performed by the worker.
- **Work sampling:** This is another technique for measuring an activity. This method is similar to Time Study in that here also, we observe a portion or sample of the work activity. Inferences are drawn based on the findings in this sample and this is applied for the activity in general.
- **Standard data:** For jobs in which there are a large number of repetitive operations with similar characteristics, companies often develop standard data through the use of time studies or predetermined data. The advantage of having standard data is that each job need not undergo a time study. Standard data is applied in a similar manner as predetermined motion time data, except on a less detailed level.
- **Predetermined motion time studies (PMTS):** An alternative to time study is the use of standard times for work elements that have been predetermined from long periods of observation and analysis. The major advantage of this method is that only motion patterns must be known; alternatives may be evaluated prior to actually trying them out.

8.8 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Work study means study of human work. British Standard 3138: 1969 defined work study as:

   'A management service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.' This means it is a procedure for understanding and determining the activities of the people, plant and

machineries, identifying the factors which affect their efficiency and achieving economy through their optimum utilization.

2. The main objectives of method study are:
    a) To identify the proper sequence of production operations.
    b) To optimize the utilization of machineries.
    c) To reduce the manufacturing cycle time by reducing idle time of machinery.
    d) To choose the right kind and amount of materials and reduce the raw material consumption per unit of production.
    e) To reduce wastages and production of defective products.
    f) To enhance the tool life and therefore reduce the tool cost per unit of production.
    g) To allocate work force optimally and reduce idle time of the operator by optimal utilization of human resources.
    h) To improve the processes and procedures involved in the production.
    i) To improve the working environment in the workplace.
3. This is a technique for measuring an activity. In this technique, we observe a portion or sample of the work activity. Inferences are drawn based on the findings in this sample and this is applied for the activity in general.

    In work sampling, the size of the sample is a major issue. The level of statistical confidence desired in the results is considered before deciding the sample size. The number of observations required in a work sampling study can be fairly large, ranging from several hundred to several thousand, depending on the activity and desired degree of accuracy.

    The three primary applications for work sampling are –
    - To determine the average time the machine and labour are idle or running. This is also called the 'activity time' for personnel and machinery.
    - To develop a performance index for workers. These performance measures help in performance evaluation of the workers, fixing of pay, bonus, penalties, etc.
    - To fix time standards that is, standard time for a task.

    The following is the sequence of activities in doing a work sampling study –
    - Identify the activity for which the study is to be done.
    - Estimate the percentage of time the selected activity takes, to the total time (e.g., the machine is working 80 per cent of the time). These estimates are made by the analyst from existing data, guesswork or a pilot work sampling study.
    - State the desired accuracy in the study results.
    - Determine the specific times when each observation is to be made.

8.9 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What are the objectives of work study?
2. What is the relevance of method study?

3. How does work measurement help an industrial engineer?
4. Write short notes on PMTS, use of symbols in method studies, work sampling and time studies.

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Long-Answer Questions

1. Explain the steps involved in method study, giving suitable examples.
2. Write a detailed note on the objectives and techniques of work measurement.
3. Is work sampling a better technique than time study for measuring work? Give reasons and examples to justify your answer.

8.10 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

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Evans, J.R., D.R. Anderson, D.J. Sweeney and T.A. Williams. 1984. *Applied Production and Operation Management.* St. Paul MN, US: West Publishing Co.

Aquilano, Chase and Jacobs. 2003. *Operation Management for Competitive Advantage*. New Delhi: Tata McGraw-Hill.

MODULE - 3

UNIT 9 JIT AND QUALITY

Structure

9.0 INTRODUCTION

In this unit, you will learn about the concepts of Just-In-Time and Quality. You are probably aware that American companies did not pay much attention to the Japanese way of manufacturing till the 1980s. In the 1970s, the Japanese had taken substantial market share in 'basic' industries such as steel and in the 1980s they had started establishing their leadership in other industries, especially automobiles and electronics.

It was only then that the full impact of the Japanese challenge hit the Americans. Companies like Xerox suddenly realized that the retail prices listed by the Japanese for small copiers were at par with or even below their cost price! Ford found that a Japanese Escort-sized car cost $1800 less than the Ford Escort in the USA! When these companies started investigating the causes, they found that manufacturing efficiency was what enabled the japanese to manufacture their products at costs that were far less than their own.

Two American Quality consultants, W. Edward Deming and Joseph Juran were not quite recognized in the US, but they were invited to Japan to teach their concept of quality to Japanese industry. Their teachings helped the Japanese to produce goods and sell them in the US market at prices that were much lower than the cost of producing similar in products America. The Americans woke up with a jolt and began to learn their lessons from the Japanese.

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So what is unique about the Japanese way of production? In this unit, you will learn two important concepts that were employed by them. These are JIT and Quality.

9.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Define Just-In-Time (JIT)
- Understand the process of JIT
- Explain the *Kanban* system
- Define quality
- Understand the costs and characteristics of quality
- Understand the process of quality
- Know what are control charts
- Understand acceptance sampling
- Know what is the operating characteristic curve
- Understand Total Quality Management
- Know what is meant by Six Sigma

9.2 DEFINITION OF JUST-IN-TIME (JIT)

JIT stands for just-in-time, a management philosophy that attempts to do away with sources of manufacturing waste by producing the correct part in the correct place at the correct time.

JIT can also be defined as an operations management philosophy whose dual objectives are –

- To reduce waste
- To increase productivity

JIT (also called **lean production system or stockless production system**) helps a company to increase its profits, improve the return on investment (ROI) by reduction in inventories, increase inventory turnover rates, reduce variations in products and services, reduce production and delivery lead times, and reduce waste.

JIT can be easily applied to repetitive manufacturing processes in which the same products and services are produced over and over again. A streamlined flow (like we see in an assembly line) is established (even when the facility uses a job or batch process layout) by interlinking the work centres so that there is a balanced and continuous flow of material throughout the production process.

The Textron Automotive Trim Division Plant at Michigan manufactures several components such as door panels and additional interior components, in nine different colour combinations and 12 different fabrics, for Daimler Chrysler cars and mini vans. The company struggled with very high work in process (WIP) and finished goods inventories. This created production bottlenecks and occupied lot of floor space. So the company had to lease space in another facility to make back side panels for the Chrysler minivans.

The company then adopted JIT. This resulted in a quantum leap in production. WIP was reduced by more than 60 per cent and average finished goods inventory was reduced from 10 hours to 2 hours. More than 10,000 sq ft of space was now available. The company terminated the lease for the back side panels for the Chrysler minivan and took it into its own production line. Over the years, lot sizes have reduced by 80 per cent and mold change time has come down by 50 per cent. Presently, mold change time is 21 minutes and the company has set itself a target of 15 minutes in two years.

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Now, the plant is pursuing new businesses. The company has signed a contract with GM Motors to supply them with interior trim products. All this within the same factory premises!

The basic elements of JIT were developed by the Toyota Motor Corporation in the 1950s, and have come to be known as the Toyota Production System (TPS). The JIT concept is built around the philosophy that inventory is evil. But it is not just a method to reduce inventories. *It is a method of producing what is needed, when it is needed, and no more.*

JIT is fundamentally based on two tenets –

- Elimination of waste, and
- Respect for humans

9.2.1 Elimination of Waste

Any activity that does not add any value may be referred to as waste. Anything over the minimum amount necessary is waste. Any activity that adds cost without adding value results in waste. Shigeo Shingo, a prominent management guru who promoted the use of JIT in manufacturing listed the **'Famous Seven Wastes'** as follows:

- Waste of motion
- Waste resulting from overproduction
- Waste resulting from waiting
- Waste resulting from transportation
- Waste resulting from stocks
- Waste resulting from making defects
- Waste as a result of processing (when the product should not be made or the process should not be used)

In other words, waste includes excess inventory, scrap and rejection, excessive materials handling, movement and time spent waiting for resources to become available and overheads related to setup times and inspections.

9.2.2 Respect for Humans

This tenet recognizes that for a system to work, humans must be actively involved. In addition, they must work as a team towards a common goal. In JIT environment, considerable effort is dedicated to building teams. Work is handled by teams on the shop floor, rather than by individuals. Instead of having each worker on the assembly line responsible for a narrowly defined task, teams are charged with the responsibility of assembling the entire part. Workers are given more responsibility. Companies that have adopted the JIT philosophy, have embraced the following:

1. Expanded job scope

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In addition to performing their tasks, workers suggest ways to improve their performance; do routine maintenance on their machines and perform their own housekeeping chores. Often, similar parts are grouped into families, and the machineries required to manufacture these parts are grouped together to form work cells. This eliminates queuing (and waiting) time and movement between operations, reduces both inventory and the manpower required. Workers, however, will have to run several machines and processes. Hence their skill levels will increase. This increases their job security and commitment to the company.

2. Factory layout

For JIT to work, the factory layout should encourage communication among team members by placing successive operations in a compact cell. In addition to making it easier for workers to communicate, it facilitates materials handling.

Another interesting fact to note is that Japanese build small specialized plants rather than large vertically integrated manufacturing facilities. Toyota has 12 plants located in and around Toyota city. They find large operations and bureaucrats difficult to manage. The bulk of Japanese plants (around 6000 and counting) employ between 30 and 1,000 workers.

3. Automation and process redesign

Monotonous and repetitive jobs are automated or designed out of the process. This improves the work environment for the worker.

4. Employee empowerment

Workers are given the authority to stop the line. They thus become inspectors, personally responsible for the quality of their output. They can also set the pace of work and thus maintain quality at the source.

These changes require that both management and workers think of their work differently. The physical changes associated with JIT such as factory layout, can be implemented within finite time frames. The change to the work culture takes longer and is an ongoing process.

9.3 PROCESS OF JIT

Figure 9.1 shows a normal operation in a factory.

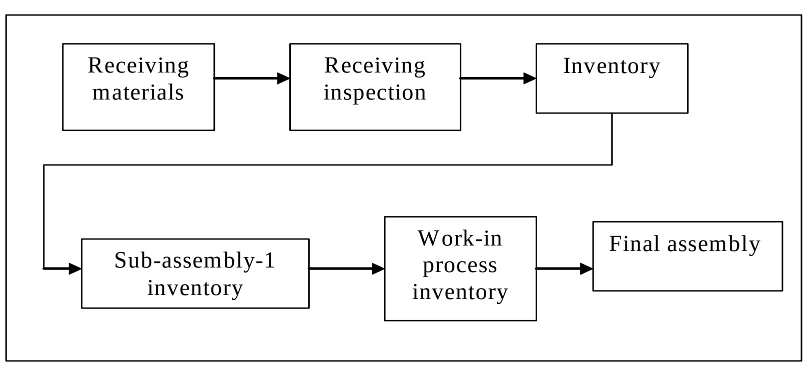

Fig. 9.1 *A Normal Operation in a Factory*

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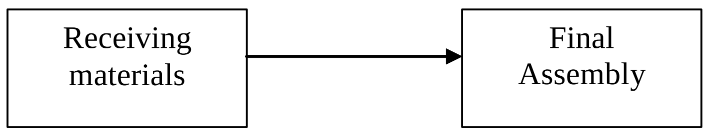
In Figure 9.1 we can see that after incoming material is received and counted, it is inspected for quality and adherence to specification. If acceptable, it is accounted for and taken into the inventory. This is then sent to subassembly operation-1 shop floor, where it becomes the shop floor inventory. After sub-assembly operation-1, is the work-in-process inventory. The material then goes to sub-assembly operation-2 and so on till the final assembly.

When JIT is implemented, the receiving inspection is completely eliminated and the responsibility of quality for incoming material rests with the supplier. Incoming material is delivered directly at the point of use at the shop floor. This eliminates the duplicate shop floor inventory. JIT calls for a thorough streamlining of the manufacturing process at the shop floor. Production scheduling should be based completely on units of the finished product rather than on the production of sub assemblies. This eliminates pile up of work in process inventory and also helps in continuous production.



In JIT, the management focuses on one goal, which is reducing work-in-process inventory. The question that is asked over and over again is, 'Why is inventory needed'? The answer usually identifies a constraint brought about by existing production practices such as set-up times, quality or machine availability. Fixing these problems improves efficiency.

Advantages of Implementing JIT

1. Reduction in set-up times

When the set-up time is high, economics dictates that the lot size must also be large. Reducing the setup time helps in making the lot sizes smaller and making more production time available. Several products can be made at shorter intervals of time. Inventories can be reduced, capacity can be increased and the company can respond more quickly to changes in demand.

Set-up time reduction can be accomplished by changing the process, introducing flexible automation, or by changing the setup procedure. One of the advantages of short setup times is that it facilitates the early discovery of poor quality parts, making it possible to correct the root cause of a problem. In fact, JIT proponents consider the ideal lot size to be one.

2. Improvement in quality

As inventory is reduced, pressure for improving quality increases. When a part is defective, it may bring the next operation to a halt if there is no inventory to act as a buffer. The key is to do it right the first time.

The impact of poor quality on the cost of a product is significant. Any good quality system includes clear specifications and documented tests for conformance. JIT also emphasizes process capability and design for manufacturability. Process capability means the ability of the process to make parts with the desired specifications. Design for manufacturability means that product designers take into account the manufacturing capabilities, as they design the product. This task is often done by integrating design and manufacturing activities.

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3. Steps in the production process are trimmed

Each step in the production process should be included only if it adds value to the product and eliminates activities that do not add value. For example, when materials are moved from a work centre to the stockroom and later from the stock room to another work centre, the double handling will add to cost with no increase in value.

4. Emphasis on maintenance

For equipment to produce quality parts consistently, they must be in good condition. Japanese factories do not have modern equipment; they only have equipment that has been well-maintained and so runs better.

A JIT factory has the discipline to allocate maintenance time on a regular basis. Workers are involved in performing the maintenance. Therefore, the operators understand their equipment better and this reduces the chance of unexplained defects. It also allows operators to enhance the process' capability.

5. Reduction in inventory

A reduction in inventory that is brought about due to JIT substantially reduces throughput time as well as labour productivity for the organization. These will directly translate into reduction in the manufacturing costs and resultin an increase in the profit for the company.

6. Consolidating the supplier base

In JIT, the supplier base composes of a manageable few, and communication between them is encouraged. The aim is to improve the suppliers' understanding of the company's needs, ensuring that the materials supplied have the correct specifications.

In JIT, the focus is on reducing the supplier base and placing all orders for an item with a single source. Emphasis is given on developing partnerships and longer term relationships to provide better quality products and reliable deliveries at competitive costs. By reducing the number of suppliers, Purchasing can manage its suppliers better, and deliveries can be scheduled more easily. For the supplier, it may yield economies that can be passed on to the buyer in terms of lower costs.

The Japanese have been very successful in using this approach. They have put together a tightly-knit family of suppliers called ***Keiretsu*** and have succeeded in obtaining better quality at lower costs than their American competitors.

Disadvantages of JIT

Although JIT is very effective in reducing lead times and work-in-process, it has several disadvantages. These are:

1. JIT has been successful mainly in assembly line manufacturing.
2. JIT requires a stable production plan (that is, one without frequent changes).
3. JIT is more effective when the number of products is less.
4. JIT still requires some work-in-process so that there is 'something to pull'. This means that some amount of completed work must be stored at each workstation, to be pulled by the next workstation.
5. Suppliers need to be located nearby because the system depends on smaller, more frequent deliveries.

9.4 THE 'KANBAN' SYSTEM

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Let us learn about the *Kanban* system, which is prevalent in factories.

Kanban means 'signboard' in Japanese**.** *It is the name given to small cards attached to containers which hold a standard quantity of a single part number.*

To understand what a *Kanban* system is, imagine two work centres A and B. Work centre A produces a part which is kept in a bin. Work centre B uses the parts from the bin. When the bin gets empty, it is a signal for the Work centre A to refill it. We say that the empty bin is the *Kanban* signal.

The following example shows how the *Kanban* system works in an industrial setup –

Company A buys parts at the rate of 1000 per day. These are delivered in containers each carrying 50 parts, i.e., 20 containers per day. The supplier makes one delivery per day – the truck leaves his premises at 9 a.m., delivers them at noon and returns to the supplier in the evening.

This means the supplier should be getting 1000 parts ready for supply the next day. There should also be 20 empty containers available at the supplier's factory, by the evening of the day before delivery.

On Day-1, the truck leaves the suppliers' premises with 20 full containers. At noon, when it reaches Company A, it delivers the 20 full containers and picks up the 20 empty containers. Meanwhile, the supplier has been working at filling the empty containers and has filled 10 of them. By the end of the day, when the truck returns, the supplier has completed filling the 20 containers. On Day-2, the same schedule is repeated.

This system has 60 *Kanban* containers. The inventory in the system is 30 full containers.

Hour of Day	***Supplier***	***Truck***	***Company A***
9 a.m.	20 E	20 F	10 F, 10E
12 noon	10F, 10E	20 F	20E

The two-card *Kanban* system: In practice, companies use systems consisting of two types of *Kanban* cards –

– **A Move card** to authorize the movement of parts from one work centre to the next.

– **A Production card** to authorize the production of parts by the work centre.

The Toyota system offers a good illustration of the two card *Kanban* system. Each part made in a plant is sourced from a single vendor. Also, the production inventory is located on the Plant floor. At each work centre, points are established where incoming inventory is to be delivered. The objective is to have inventory easily accessible. When the work centre finishes the work, the completed part is all at one location.

At Toyota, parts are moved in containers or bins. For any pair of work center, the containers are a standard size, which are fixed lot sizes. The standard container size also affects the inventory level.

9.5 QUALITY

NOTES

Quality is an important dimension of Production and Operations Management. A company may produce volumes and reach it to the market at the right time, but unless there products adhere to a defined set of specifications, they will not sustain in the market. This characteristic of a product, which makes it acceptable to a consumer, is called Quality.

Generally, the word 'Quality' is used to refer to that which is the best in the market. But the Japanese have suggested that Quality is actually a precise and measurable concept and that difference in quality reflects a difference in quantity of some product attribute.

One of the more interesting approaches to preventing problems of quality, started by the Japanese, involves working with suppliers of purchased material in order to improve their quality. Japanese manufacturers often provide free assistance to their suppliers in developing quality assurance programmes or in solving quality problems. They believe that if a manufacturer knows that his suppliers are producing quality products, then he will have to spend less effort on verifying the quality of incoming material and reworking or scrapping defectives that may be found in later stages of production. Companies around the world are now working more closely with suppliers and are beginning to insist on sound quality practices throughout their organizations.

What these attributes of Quality are, how can they be measured and controlled will be topics covered in the following sections.

9.5.1 Definition of Quality

What a customer wants and is willing to pay for it determines quality. It is a written or unwritten commitment to a known or unknown consumer in the market. Thus, quality can be defined as ***fitness for intended use*** or, in other words, how well the product performs its intended function.

Quality also means ***conformance to specifications***. That is, quality of conformance is defined as how well manufacturing is able to meet design specifications. A quality product is one that ***provides a predetermined level of performance at an acceptable price or provides conformance to design specifications at an acceptable cost***.

Quality is determined by what a customer wants and is willing to pay for. Quality does not mean producing the best. It means consistently producing the products and services that give customers their money's worth. McDonalds, the burger giant, is famous for building quality into its service delivery process. It literally industrialized its service delivery system, so that part time, casual workers could provide the same eating experience anywhere in the country.

Quality Assurance is a term that is closely related to Quality. **Quality Assurance** encompasses the entire system of policies, procedures and guidelines established by an organization in order to achieve and maintain quality. The objectives of quality assurance are –

- To improve quality
- To reduce costs
- To increase productivity

Quality Assurance is the result of two activities –

– Quality engineering
– Quality control

Quality engineering means to include quality at the time of designing the products and processes. Predicting potential quality problems is also within the gamut of Quality Engineering.

Quality control consists of making a series of predetermined measurements in order to find out whether or not quality standards are being met. If they are not being met, it involves taking corrective and/or preventive action in order to maintain quality. Statistical techniques are extremely useful in quality control.

9.5.2 Cost of Quality

We know that quality products not only improve the image of an organization, but they also benefit it monetarily. It helps in reducing external failure costs. Also, fewer appraisals will be required since the products will be made correctly the first time. Quality efforts cost money; they must be well planned and quality costs must be understood at every level of the organization.

Quality is Free is the title of the book written by the Quality guru Philip Crosby. But another quality guru J.M. Juran propounded the concept of costs of quality. Quality costs are any costs that would not occur if perfect quality could be achieved.

Each time work must be redone – for example, remanufacturing a defective item or retesting an assembly – the cost of quality increases. Many such costs are overlooked or not recognized because traditional accounting systems are not designed to identify them.

The major costs of Quality are –

a) Prevention costs

Prevention costs are costs incurred in an effort to keep nonconforming products from occurring and reaching the customer. They include process planning costs, process control costs, training costs, and general management costs. Process planning costs include the development costs for establishing procedures, manufacturing controls and setting up instructions for testing and inspection, reliability studies, new equipment design, etc. Process control costs include cost of analysis of production processes in order to improve operations and the implementation of process control plans. Training costs are those that are associated with developing and operating formal training programmes or attending seminars on quality assurance. General management costs include those for clerical staff, supplies, and communications related to quality efforts.

b) **Appraisal costs**

Appraisal costs are incurred on maintaining quality levels through measurement and analysis of data in order to detect and correct problems. Testing and inspection costs are incurred on testing and inspecting incoming materials, work in process and finished goods and include salaries for inspectors, supervisors, and other personnel. It also includes cost of equipment, cost of maintaining instruments, calibrating gauges and test equipment, repair, etc.

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c) Internal failure costs

Internal failure costs are incurred when unsatisfactory quality in a product is found prior to its delivery to a customer. These include the cost of scrapping or reworking, cost of time spent in determining the causes of failure and cost of correcting production problems. Lost revenue on account of selling a product at a discount because it does not meet the desired specifications is also an internal failure cost.

d) External failure costs

External failure costs are incurred if an unsatisfactory quality product reaches the customer. Costs of investigating complaints, product recall costs, Warranty claim costs which include the cost of repair or replacement of products during warranty periods and product liability costs of legal action and settlements are a major source of external failure costs.

In general, we may say that 60 to 90 per cent of total quality costs are due to problems of internal and external failure. In the past, the typical reaction to high failure costs has been to increase inspection. This approach, however, leads to higher appraisal costs. While external failures will be reduced with this approach, internal failures can rise. So overall, there is hardly any improvement in quality or profitability.

The key to improving quality and profitability is prevention. Better prevention of poor quality will clearly reduce internal failure costs since fewer defective items will be made. External failure costs will also be reduced. In addition, fewer appraisals will be required since the products will be made correctly the first time.

9.5.3 Characteristics of Quality

A product is called a quality product only when it satisfies various criteria for its functioning. From the **consumer point of view,** the most common characteristics of a product or service, while assessing Quality are:

1. **Performance:** How well does the product perform with respect to its intended use?
2. **Safety:** How much care has the company taken to make the product safe for users before, during or after use?
3. **Features:** What special features does the product have? (These are usually in addition to the basic function of a product) for example, a mobile phone that includes a camera, calculator, games, MMS, etc.
4. **Customer Service:** How does the seller conduct himself with the customer before, during and after the sale of the product?
5. **Reliability:** What is the probability of breakdowns, need for adjustments, replacement of parts, etc. in the product?
6. **Appearance:** How pleasant is the look, smell, taste, feel or sound of the product to customers?
7. **Serviceability:** How easily can the product be repaired and serviced? Will it cost a lot and will the process take a lot of time? How fast is the response of the company to a complaint?
8. **Durability:** How long can the product perform before it needs repairs or replacement of parts?

From a **producer's point of view**, the characteristics of Quality are as follows -

1. **Innate:** Quality is innate or inherent in the product; it is not based on any comparison regarding the features and characteristics with other similar products.
2. **Measurable:** Quality is measurable; conformance to quality can be quantified by measuring the variation.
3. **Usability-based:** Quality means making products based on specific requirements. So, the quality of a product is based on the usability or ability to satisfy the given need. A mobile phone may have several additional features but these do not improve the quality for a customer whose need is a basic mobile phone with listening and speaking clarity, at a low cost.
4. **Design-based:** Quality is defined by the design specified for a particular product, that is, a product is designed to give a particular quality.

9.6 QUALITY OF THE PROCESS

We have learnt that the performance of a product refers to the functions and services which it must give to its consumer. In other words, a watch should show accurate time, a pen should write legibly or the eraser should rub pencil marks clearly without leaving black marks or imprint of the writing. . The same quality of physical performance should be available over a reasonable length of time. So, time is also an essential aspect of Quality.

We also know that production is the culmination of the three basic steps – Input – Process – Output. So an organization can call itself quality-aware only if it maintains quality in each of the three steps. Therefore, the three aspects of assuring quality in an organization are:

– Assurance of input quality.
– Assurance that proper processes are operating on the raw materials.
– Assurance of quality of the outgoing finished goods.

Assurance of quality of incoming raw material can be done by several measures such as inspection of incoming materials, stringent specifications, supplier being made responsible for quality, buying from companies which are ISO certified, etc.

When it comes to assurance of the quality of outgoing finished goods we know that output is obtained when process acts on the input. So output will be assured if both input and process are assured. Input can be assured by the methods listed in the above paragraph. To ensure quality of the process, the organization needs to implement statistical and quantitative methods. These methods identify the deviations in the processes which are causing the deviations in the product. Once the causes have been identified, steps are taken by organizations to correct them.

We will now study the statistical methods.

9.6.1 Statistical Process Control

As we have seen above, the objective of process control is to convert the inputs (raw materials) into output (finished goods) and then monitor the processes frequently. Any deviation from the set processes should be corrected when required. Process control is nothing but the monitoring of the various physical variables operating on the materials and the correction of the variables when they deviate from the previously established norms.

NOTES

Let us learn the meaning of some commonly used terms –

a) Variations

Variations mean the small differences between the written down specifications and the actual. All processes have some variations due to causes, which may or may not be inherent. In any case, the causes responsible for the deviation of the processes from the established norms have to be rectified.

The variations which are inherent to a particular process and which are random since they are not traceable to any particular cause are said to be due to **'random causes' or 'chance causes**'. The organization can do nothing about the chance causes. In every process some random variations are present, which is expected. The process is said to be **in control** if variations are only due to random variations. For example, a machine filling toothpaste in tubes may not fill all tubes with exactly the same amount of paste; there will be some variations. In one tube the weight may be 100.051 grams, in another it may be 100.010 grams, and in still another it may be 99.998 grams. The machine is not designed to detect variation in weight up to the third place of decimal in grams. Therefore, it is expected that this much variation in weight will take place because of the inherent nature of the machine. Such small variations bother neither the manufacturer nor the customer.

In Process Control, we would be concerned only with those causes which can be rectified. These are called **assignable causes.** A worn- out tool, mistake on the part of a worker in processing the item, improper adjustment of the machine, etc. are assignable causes. When variations are due to assignable causes, the process is said to be **out of control**. The assignable causes of the variation are rectified to bring the process under control.

It is important to know when a particular deviation in the process is occurring due to chance causes and when it is occurring due to assignable causes. The difference between chance causes and assignable causes is summarized in Table 9.1.

Table 9.1 *The Differences between Chance and Assignable Causes*

Chance causes	Assignable causes
1. Natural or inherent in the process	Unnatural or external, due to causes that can be traced
2. All causes taken together give variation	A single assignable cause can lead to substantial variation
3. Slight variation in the machine, could be inherent in it	Faulty machine set up can gives rise to variation
4. Lack of human perfection in setting the instrument	Lack of human perfection in reading the instrument
5. Cannot be economically eliminated	Once detected, can be eliminated

b) **Monitoring the process**

Monitoring can happen in two ways:

– actually measuring the variables operating on the raw materials,

– measuring the characteristics of the output product.

NOTES

When a number of variables are operating on the product, it becomes easier to observe the quality of the product coming out of the process, rather than monitoring the variables operating in the system. That is why in statistical process control, an organization seeks to monitor the output of the processes and thus controls the processes by locating the causes for the deviations and rectifying the same.

c) Specification limits for output

When the quality of a particular product is being described, we usually refer to the appropriate range of performance of this product. It is not said that the diameter of the pipe has to be exactly 3 centimetres. Rather that it should be 3 centimeters plus or minus 0.002 centimetres. This range is called the **specification range or specification limits for the output.**

d) Control limits

We know that the product should not exceed the specification limits. To ensure this, the limits for an orgaization's process control purposes should be narrower than the specification limits. These limits called **Control Limits** should be such that when exceeded, a danger signal is given, but as yet it is only a signal, the product is not 'defective'.

e) Central tendency and dispersion

Variations in any process can be described in terms of two parameters: **Central tendency and Dispersion**

Central tendency has to do with accuracy and **Dispersion** with precision. To understand these two concepts, let us consider the following example.

Suppose a book weighs 150 grams. There are two weighing machines and they show the following readings for its weight:

Machine No. 1	Machine No. 2
140, 151, 159 gms	139, 139.5 140 gms

Machine No. 1 gives an average of 150 gms and therefore, this is an accurate machine. Its **central tendency** (150 gms) does not show deviation, but has a lot of '**dispersion'** (140 to 159 gms). Machine No. 2 is precise, but is not accurate because its central tendency is 139.5 lb (and not 150 gms) but its dispersion is quite low, ranging from 139 to 140 gms. This example shows that in controlling errors one has to control not only the central tendency, but also the dispersion. In other words, the mean and also amplitude of the variations has to be controlled. It needs to be checked whether a process has gone out of control in terms of the central tendency, or dispersion, or both.

During the transformation process of a batch, samples of items are taken at regular intervals and inspected for any variation from established standards. If there are variations, the cause must be found.

9.6.2 Specification and Control Limits

We have learnt above that while specifying the desired value of a variable during the design and development stages of a product, the value is not expressed in absolute terms but in terms of a range. These specification limits or tolerance limits are set by the manufacturer at the design stage of the product or specified by a customer. It is important for a QC manager to ensure that the specification limits are never exceeded during the production process, because if this happens, the defective unit produced will be rejected leading to a loss for the company.

For example, the diameter of a pencil is expressed by its manufacturer not as 7 mm but as 7 mm ± 0.05 mm. Thus, the diameter of a pencil produced by the manufacturer can vary from 6.95 mm to 7.05 mm. If these limits are exceeded in a pencil produced, the pencil is rejected.

9.7 CONTROL CHARTS

In process control, a check is kept on both Central tendency and Dispersion by a graphical method; the graphs which are used for such monitoring are called **control charts.** Process control relies mostly on such graphical or visual representations, and monitoring thereafter.

Following is the procedure for drawing Control Charts –

a) take a few samples at a time
b) measure their quality characteristics
c) find the mean of the sample
d) measure the range of dispersion in the sample
e) gather statistics for the ranges and the means of the various samples taken over frequent or regular intervals of time
f) Plot the results appropriately on a graph paper

The charts thus obtained will guide the manufacturer as to when a particular process needs to be rectified and in what manner.

In a **Control Chart,** these specification limits are shown along the y-axis. The value 7.00 mm is shown as the **central line (CL)** and is the targeted value. Theoretically, it is aimed that every pencil produced should have a diameter of exactly 7.00 mm, no more and no less. Because of random variations, though, the diameter of the pencils produced may vary slightly on either side of the CL. The value 6.95 mm becomes the **lower Specification limit (LCL)** and 7.05 mm becomes the **Upper Specification limit (UCL).**

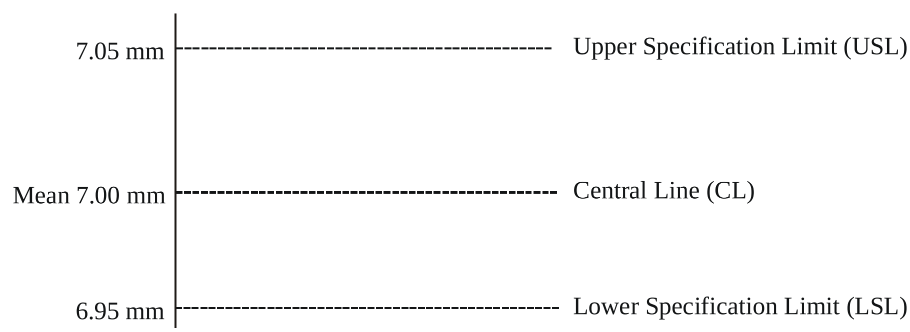

Fig. 9.2 *Control Chart showing Specification Limits for the Diametre of a Pencil*

As explained above, in order to ensure that the specification limits are never exceeded, control limits are established inside the specification limits. These limits serve as a danger signal or indication for the QC manager. Whenever these limits are exceeded by the output, the QC manager has to look for assignable causes. The **lower control limit (LCL)** is set usually at **M – 3σ** and the **upper control limit (UCL)** at **M + 3σ**.

Here, M is the Mean or targeted value of the diameter of all the pencils to be made, i.e., 7.00 mm, and σ is the standard error of the mean (i.e., the standard deviation of the distribution of sample means).

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This is to be interpreted in the following way. Suppose n pencils (sample size = n) are drawn at random and their diameters are measured and the mean of these measurements is taken. This sample mean should fall within the control limits. If the sample mean for any sample falls either above the UCL or below the LCL, the process is out of control.

Several kinds of quality charts are in use such as X-Bar chart, R Chart, p – Charts or Fraction Defective Charts, c- Charts or Number of Defects Chart, etc.

9.8 ACCEPTANCE SAMPLING

Acceptance sampling is a technique, which uses the statistical inspection method to evaluate the quality of a complete batch. In a company, inspection is done at two stages – once the raw materials are received, they are inspected to confirm that they are as required. And when the finished goods are made, they are inspected to ensure that they are as per specifications. In both these inspections, either each piece can be tested, or some out of a lot can be tested. If each and every piece has to be tested, it would require considerable time, effort and resources. It is not worth the trouble.

So what is generally done in industry is that only a few pieces from a whole batch or lot are inspected to verify that they meet the specified and acceptable standards of quality. If the sample conforms to the specified standards, then the whole batch or lot is considered accepted; otherwise it is rejected. Since only a few pieces from a lot are inspected, it is possible that the decision to accept or reject the whole lot may not be correct. Therefore, the sample should be chosen at random from the whole lot so that every portion of the lot has an equal representation. This type of sampling is called **random sampling.**

After a lot has been defined, an **acceptance sampling plan** is made. An acceptance sampling plan consists of the following –

- a set of rules that define the procedures for preparing a batch or lot
- a set of rules for selecting samples, e.g. they can be picked at random, or every fifth piece can be a sample and so on.
- procedures for conducting inspection of the samples
- fixing the criteria for accepting or rejecting the batch.

In other words, an acceptance sampling plan specifies the sample size (n) and the number of defectives 'c' that are allowed in a batch of acceptable pieces. If the number of defectives in the sample is equal to or less than the permissible number of defectives, then the lot is accepted; otherwise it is rejected.

9.8.1 Types of Sampling Plans

Different types of sampling plans are used for acceptance sampling, depending on the level of accuracy required. The common ones are:

1. The single sampling plan

In this sampling plan, the inspection results of a single sample size decide whether to accept or reject the complete lot. At the outset, the lot size is defined. From this, the number of samples to be drawn is defined. Then the **acceptance number 'a'** is defined. This refers to the maximum number of defective units which are acceptable. If the number of defectives is a+1 or more, the lot will be rejected; (a+1) is also called the **rejection number.**

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For example, in a single sampling plan:

Suppose, Lot size (N) = 5000

Sample size (n) = 150

Acceptance number a = 2

This means 150 pieces are selected from the batch of 5,000 pieces and inspected. If the number of defectives is 0, 1 or 2, the lot is accepted and if the number of defectives is 3 or more, the lot will be rejected.

2. The double sampling plan

In this sampling plan, the inspection results of two sample sizes are used to decide whether to accept or reject the complete lot. After defining the lot size, the number of samples to be drawn is defined for the first time as well as for second time. Two **acceptance numbers 'a1 and a2'** are defined. Consequently, there will be two **rejection numbers.**

In the above example, if there is a double sampling plan:

Lot size (N) = 5,000

Sample sizes: $n_1 = 150$ and $n_2 = 150$

Acceptance number: $a_1 = 2$ and $a_2 = 8$

First, a sample of 150 pieces is selected from the batch of 5,000 pieces and inspected. If the number of defectives is 0, 1 or 2, the lot is accepted and if the number of defectives is 8 or more, the lot will be rejected. But if the number of defectives is 4, 5, 6 or 7, a second sample of 100 units will be drawn.

The combined samples ($n_1 + n_2$) i.e. 250 units are inspected; if the number of defectives is 10 or less, the lot is accepted otherwise it is rejected.

3. Multiple sampling plan

When more than two samples are used for deciding the acceptance or rejection of a lot, it is called a multiple sampling plan. As the number of samples increases, the complexity of implementation increases.

Which plan we choose for Quality Control depends on the amount of precision we require, the economic aspect and the feasibility of the Quality control set up. These vary from company to company and from product to product.

9.9 THE OPERATING CHARACTERISTIC CURVE

The sampling plan has an ability to separate the good pieces from the batch, which is shown by the **Operating Characteristics (OC) curve.** It shows how a sampling plan can separate the lots of varying quality and evaluate the risks associated with any sampling plan.

Acceptance sampling decisions, i.e., whether to accept or reject a batch of items are based on the OC curve. A good sampling plan ensures that the good lots are always accepted, while the bad ones are always rejected.

Construction of the OC curve

The OC curve shows the percentage defectives (p) in a batch along the X axis and probability of acceptance (P_a) of the batch along the Y axis. As the percentage defectives increases, the probability of accepting the batch reduces. Therefore, a batch having zero percentage defectives will always be accepted, as shown in Figure 9.3.

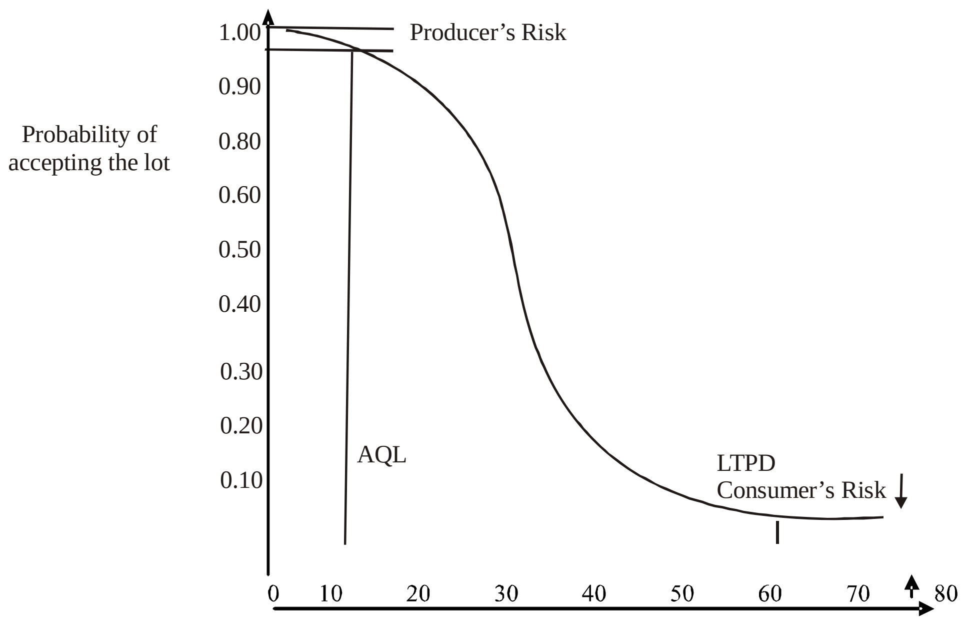

Fig. 9.3 *The Operating Characteristics (OC) Curve*

9.9.1 Parameters of an OC Curve

There are four parameters associated with an OC curve:

a) **Acceptable quality level (AQL):** It is the level of quality at which the lot is defined as a good lot, meaning the lot will be accepted. It indicates the maximum permissible number of defectives in the sample if the lot is to be accepted.

b) **Lot tolerance percentage defectives (LTPD):** It is the level of quality at which the lot is declared to be a bad lot, meaning it will be rejected. It indicates the rejection number 'r', which sets the limit for accepting the lot. This level is also called the **unacceptable quality level.**

c) **Producer's risk (á):** It represents the probability of rejecting a good lot by the sampling plan. This risk may vary between 0.01 to 10 per cent. A producer's risk is measured in terms of the probability that the lots of AQL will not be accepted.

d) **Consumer's risk (â):** It represents the probability of accepting a bad lot by the sampling plan. A consumer's risk is measured in terms of the probability that the lots of the LTPD will be accepted.

There is a strong interrelationship between AQL and Producer's risk as well as the LTPD and Consumer's risk. Lower the value of AQL, higher is the probability of accepting a good lot.

9.10 TOTAL QUALITY MANAGEMENT

NOTES

Total Quality Management is a management approach that emphasizes on quality. The concept originated in the 1950s. The term Total Quality Management (TQM) was first used by the US Department of Navy in 1985.

TQM is not a business objective by itself. But it is a way to achieve the objectives of an organization, that is providing customers with goods and services that satisfy their needs, enlarge markets and reduce costs. It requires active participation of all the members of an organization and demands that organizations must continuously improve their processes by incorporating the knowledge and experiences of workers.

The objective of TQM is 'Do the right things, right the first time, every time'.

TQM can be understood as –

Total = Quality involves every member and all activities in an organization.

Quality = Conformance to Requirements (Meeting Customer Requirements).

Management = Quality can be managed and must be managed.

Therefore, TQM is a process for managing quality. Since it is a process for managing quality, it must adopt a philosophy of perpetual improvement in everything it does. JIT and TQM have merged in theory as well as practice.

The International Organization for Standardization (ISO) offers the following definition –

TQM is a Management approach to an organization, centred on quality, based on the participation of all its members and aimed at long term success through customer satisfaction, with benefits to the members of the organization and the society.

TQM seeks to integrate the functioning of all the units of an organization such as Marketing, Finance, Design, Production, HR, Procurement, etc. to focus on fulfilling customer needs and achieving organizational objectives. It is based on the premise that employees *want* to contribute, and management must create a climate in which this can happen easily.

TQM looks at an organization as a set of processes. Some companies which have implemented TQM include Ford Motor Company, Phillips Semiconductor, SGL Carbon, Motorola and Toyota Motor Company.

9.10.1 Principles of TQM

The concept of TQM is based on the following principles:

a) Quality can be managed and must be managed.
b) Everyone has a customer and is a supplier.
c) People are not the problem, processes are the problem
d) Quality is the responsibility of each employee of an organization.
e) It is not enough to just fix the problem, the problem should be prevented.
f) Measuring of quality is a must.
g) Quality must be continuously improved.

h) The standard of quality is 'defect free'.
i) Goals cannot be negotiated; they are set on the basis of requirements.
j) The focus should be on life cycle costs instead of front-end costs.
k) Top management should lead and be involved.
l) Planning and organizing for quality improvement is a must.

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In other words, processes must be managed and continuously improved. This will involve:

- Definition of the process
- Measurement of process performance
- Review of process performance
- Identification of the shortcomings of the process
- Analysis of process problems
- Bringing about change in a process
- Measurement of the effects of the change
- Communication between supervisor and user

TQM is concerned with continuous improvement in all work. It does not aim to improve results by improvements alone, but more importantly it aims at improving capabilities to produce better results in the future. All the activities of an organization, be it high level strategic planning and decision-making or execution of work elements on the shop floor, should aim for continuous improvement. TQM encourages participation amongst shop floor workers and managers.

There is another principle of TQM which is that although people make mistakes, most of them are allowed to happen due to faulty processes and systems. Therefore by changing the process, the main cause of such errors can be eliminated.

The three primary mechanisms that can prevent such mistakes are as follows:

a) Preventing of mistakes from taking place
b) Early detection of mistakes so that they are not passed down the value added chain (if they cannot be prevented, they should be inspected and detected at source or by the operation that follows immediately).
c) Stopping production in case mistakes take place, until the process can be corrected. (This prevents more defects from being produced.)

9.10.2 Deming's 14 Points

W. Edwards Deming was an American statistician who is said to have pioneered the concept of Total Quality Management and thus the growth of Japan as a manufacturing nation. After World War II, Deming was sent to Japan to help in preparing the census of the Japanese population. While he was there, he taught 'Statistical Process Control' to Japanese engineers. Using these techniques, the Japanese were able to manufacture high-quality goods without expensive machinery. In recognition, in 1960, the Japanese Emperor awarded Deming a medal for his services to the industry.

Deming returned to the US and published his book '*Out of the crisis*' in 1982. In this book, he laid out 14 points which he said should be adopted by the US manufacturing industry to save them from being outsmarted by the Japanese.

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The **14 points of Deming** (as they are called) are outlined here:

1. Creation of constancy of purpose towards improvement. Replacement of short-term responses with long-term planning.
2. Adoption of the new philosophy by top management, that is, leading by example instead of simply expecting the workforce to do so.
3. Stop dependence on inspection. There is no need for inspecting manufactured products for shortcomings or defects as there is not likelihood of any.
4. Adoption of a single supplier for any one item. Multiple suppliers mean variation between raw materials.
5. Constant improvement. There should be a constant effort to reduce variation.
6. On-the-job training. All people will work the same way only if they are all trained. Training will reduce variation.
7. Supervision should give way to leadership. Mere supervision is not enough as it is target-based.
8. Make fear vanish. A fearful management is counter-productive in the long term as it prevents workers from acting in the best interests of the organizations.
9. No barriers between departments. The concept of 'internal customer' is central to the idea of TQM. The internal customer is served by each department, not the management, that is, other departments using its output.
10. No harassment of the workforce. People do not make mistakes, but the processes do. Therefore the processes should be improved instead of harassing the workforce.
11. Production targets only encourage the delivery of poor quality goods. Therefore, management by objectives should be eliminated.
12. Removal of barriers to pride of workmanship.
13. Self-improvement and education should be promoted.
14. Transformation is everyone's responsibility.

9.11 SIX SIGMA

Let us also learn what is meant by Six Sigma and what its themes are. Organizations have now gone beyond TQM and are now adopting Six Sigma as a solution to produce 100 per cent defect-free products. So what is Six Sigma?

Six Sigma is a data driven structured problem-solving methodology for solving chronic issues facing a business. It is a breakthrough management process that is used to improve a company's performance by variation reduction. The method encompasses breaking down the customer's requirements into steps to pinpoint problem areas in a process. This results in the reduction of defects and sustenance of process improvement.

Six Sigma is defined as a broad and comprehensive system for building and sustaining business performance, success and leadership. The key focus of Six Sigma is on processes, but with measurement of both processes and products. Six Sigma advocates variation as an enemy of quality. Companies strive to achieve the statistical Six Sigma goal of near perfection as measured at defects per million opportunities (DPMO). It is calculated as follows –

$$\text{DPMO} = \frac{\text{No. of Defects} \times 10{,}00{,}000}{\text{No. of opportunities for error/unit} \times \text{no. of units}}$$

NOTES

Here, defect is any item or event that does not meet the customers' requirement.

The **Six Sigma process** is as follows -

1. Six Sigma starts with the customer, that is, a clear definition of the customer's requirements. Customer focus is the top priority. Six Sigma improvements are defined by their impact on customer satisfaction and value.
2. Six Sigma begins by outlining the steps necessary to gauge business performance; it considers the process as the key vehicle of success irrespective of whether the organization is producing a product or a service.
3. Once the requirement has been defined, we can define a "defect" and measure almost any type of activity or process. Late deliveries, incomplete shipments, part shortages, etc. are some examples of defects.
4. Set a goal. Having an entire organization focused on a performance objective of three defects per million opportunities can create significant momentum for improvement.
5. The Management should be proactive. Define clear goals and objectives and review them frequently; set clear priorities; focus on preventing problems from occurring rather than on solving the problem after it has occurred; question 'Why do we do things this way' instead of saying 'This is the way we do things here,' etc.
6. Six Sigma emphasizes total collaboration within the company, with their suppliers as well as customers. The objective should be providing value for customers.

The **difference between TQM and Six Sigma** is that TQM programmes focus on improving each individual operation, irrespective of the process whereas Six Sigma focuses on making improvements in all operations within a process.

No company can aim to achieve Six Sigma without implementing new ideas and approaches, which always involves some risk.

A brief introduction of practices that are commonly followed in Six Sigma implementation is given below –

Executive Leaders and Champions – Champions are drawn from the rank of executives. Their job is to identify and set appropriate benchmarks in a project and to ensure that the improvement efforts do not lose focus of organization objectives. They take ownership of the project and popularize it throughout the organization.

Professionals are given training in Six Sigma techniques and given martial arts titles appropriate to their skills and roles that they will have to play, in the organization context. Different companies use different combinations of these belts. Thus we have –

Black belts – They lead a Six Sigma improvement team. They are also responsible for ensuring that the problems are fixed permanently.

Master Black Belts – They are also Black belts but for several teams.

Green Belts – They are employees participating in Six Sigma teams. They would have also received Six Sigma training.

Check Your Progress

1. What do you know about Just-in-Time?
2. What are the differences between chance causes and assignable causes?
3. Write a short note on Six Sigma.

It is the responsibility of the top management to set the objectives for improvement. Continuous reinforcement and rewards are essential in order to sustain the interest on Six Sigma.

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Six Sigma forms a major part of GE's operations. The company is spending over $600 million on Six Sigma projects every year, mostly on salaries for the experts and employees, who have undergone basic training. They believe that each step or activity in the company represents an opportunity for defects to occur and Six Sigma programmes seek to reduce the variation in the processes that lead to these defects.

9.12 SUMMARY

In this unit, you have learned about the concepts of Just-in-Time and Quality. It would not be incorrect to say that no other action a manager takes will generate improved operations, increased profits and reduced costs so quickly and with so little effort as the effort towards quality. All organizations have adopted quality management in some form or the other. However varied the methods may be, the objective is the same – 'Quality is Job # 1!'

In this unit, you have learned what is JIT, how it is used in organizations, how Quality is to be measured, what are sampling plans, OC curves and control charts. You have also learned what is meant by TQM and Six Sigma.

9.13 KEY TERMS

- **Just-in-Time:** JIT is a management philosophy that strives to eliminate sources of manufacturing waste by producing the right part in the right place at the right time.
- **Keiretsu:** A tightly-knit family of suppliers in Japan.
- **Kanban:** Kanban means 'signboard' in Japanese**.** It is the name given to small cards attached to containers which hold a standard quantity of a single part number.
- **Quality:** Quality can be defined as fitness for intended use or, in other words, how well the product performs its intended function. Quality also means conformance to specifications. That is, quality of conformance is defined as how well manufacturing is able to meet design specifications. A quality product is one that provides a predetermined level of performance at an acceptable price or provides conformance to design specifications at an acceptable cost.
- **Appraisal costs:** These are incurred on maintaining quality levels through measurement and analysis of data in order to detect and correct problems.
- **Internal failure costs:** Internal failure costs are incurred when unsatisfactory quality in a product is found prior to its delivery to a customer.
- **External failure costs:** External failure costs are incurred if an unsatisfactory quality product reaches the customer.
- **Variations:** Variations mean the small differences between the written down specifications and the actual.
- **Assignable causes:** In process control, we would be concerned only with those causes which can be rectified. These are called assignable causes**.**

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- **Control charts:** In process control, a check is kept on both Central tendency and Dispersion by a graphical method; the graphs which are used for such monitoring are called control charts.
- **Acceptance sampling:** This is a technique, which uses the statistical inspection method to evaluate the quality of a complete batch.
- **Random sampling:** When a sample is chosen at random from a whole lot so that every portion of the lot has an equal representation, this type of sampling is called **random sampling.**
- **The single sampling plan:** In this sampling plan, the inspection results of a single sample size decide whether to accept or reject the complete lot.
- **The double sampling plan:**In this sampling plan, the inspection results of two sample sizes are used to decide whether to accept or reject the complete lot.
- **Total quality management:** TQM is a management approach that emphasizes quality.
- **Six Sigma:** Six Sigma is defined as a broad and comprehensive system for building and sustaining business performance, success and leadership. The key focus of Six Sigma is on processes, but with measurement of both processes and products.

9.14 ANSWERS TO 'CHECK YOUR PROGRESS'

1. JIT is a management philosophy that strives to eliminate all sources of manufacturing waste by producing the right part, by the right method, using the right raw materials, in the right place at the right time. Its aim is to reduce waste and increase productivity. It improves profits by
   - Reducing inventory levels,
   - Reducing variability and thus improving quality
   - Reducing lead times
   - Reducing all other costs such machine setup cost, equipment breakdown cost, etc.
2. The difference between chance causes and assignable causes are as follows:

Chance causes	Assignable causes
1. Natural or inherent in the process	Unnatural or external, due to causes that can be traced
2. All causes taken together give variation	A single assignable cause can lead to substantial variation
3. Slight variation in the machine, could be inherent in it	Faulty machine set up can gives rise to variation
4. Lack of human perfection in setting the instrument	Lack of human perfection in reading the instrument
5. Cannot be economically eliminated	Once detected, can be eliminated

3. Six Sigma is a data driven structured problem-solving methodology for solving chronic issues facing a business. It improves a company's performance by variation reduction. It encompasses breaking down the customer's requirements into steps to pinpoint problem areas in a process. This results in the reduction of defects and sustenance of process improvement.

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The key focus of Six Sigma is on processes, but with measurement of both processes and products. With Six Sigma, companies strive to achieve the statistical Six Sigma goal of near perfection as measured at defects per million opportunities (DPMO). It is calculated as follows –

$$\text{DPMO} = \frac{\text{No. of Defects} \times 10,00,000}{\text{No. of opportunities for error/unit} \times \text{no. of units}}$$

Here, defect is any item or event that does not meet the customers' requirement

The **Six Sigma process** is basically as follows -

a) Six Sigma starts with the customer, that is, a clear definition of customer's requirements.

b) Once the requirement has been defined, we can define a 'Defect' and measure almost any type of activity or process. Late deliveries, incomplete shipments, part shortages etc. are some examples of defects.

c) Set a goal for performance improvement.

9.15 QUESTIONS AND EXERCISES

Short-Answer Questions

1. Why is JIT called the 'stockless production system'?
2. What are the advantages of implementing JIT?
3. Write short notes on Control Chart and Six Sigma.

Long-Answer Questions

1. It is said 'Quality is Free'. What then are the costs of quality?
2. What is the relevance of inspection in ascertaining quality? Why are statistical methods used?
3. What is sampling? What are the different types of sampling plans?
4. What are the common characteristics of quality? Explain.
5. What are the parameters of an OC curve? What is its relevance to a producer?
6. 'Systems, not people, are responsible for mistakes'. Explain this in the context of TQM.

9.16 FURTHER READING

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UNIT 10 SUPPLY CHAIN MANAGEMENT, COMPUTER SYSTEMS AND PACKAGES

Structure

10.0 INTRODUCTION

The term 'supply chain management' (SCM) which is quite a buzzword today, was probably first used by consultants in the late 1980s and then analysed by the academic community in the 1990s. Many large firms have had to bring in an entirely new management team to effect the massive reorientation and execution of SCM.

Supply chain management is all about collaboration. Organizations can no longer work in isolation. Their success depends on their ability to compete effectively while being contributing members of dynamically connected supply chain networks. In this unit, you will learn what supply chain management is, and what are its objectives and salient features. You will also learn about value chain, the concept of total cost of ownership, supply alliances and information technology.

10.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Define supply chain
- Understand the evolution of the concept of SCM
- Know the relevance of SCM
- Understand the objectives of SCM

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- Understand what constitutes a value chain
- Understand the meaning of total cost of ownership
- Understand supply alliances
- Understand the relevance of information technologyin SCM
- Know what is meant by Electronic Data Interchange
- Understand Data Warehousing

10.2 DEFINITIONS OF SUPPLY CHAIN MANAGEMENT (SCM)

Supply Chain (also sometimes called **Value Chain)** means that organizations are **'interlinked'** (like the elements of a chain). The linkage includes one between suppliers who provide inputs, between transformation processes that transform the inputs into products and between services and the distribution system that reaches the products to the consumers. A supplier in one supply chain may or may not be the supplier of another supply chain. Every supply chain has a different product or service.

S*upply chain management links all the supply interacting organizations into an integrated two- way communication system to manage high quality inventory in the most effective and efficient manner*. In other words, a firm first designs its supplier relationship, order fulfillment and customer relationship processes and then synchronizes these with the key processes of its suppliers and customers. When this is done, the flow of materials, services and information is in sync with customer demand.

One supply chain expert states, 'You cannot telephone, fax or e - mail the chain.' It means the buyer of Tungsten for laser lamp manufacturing must have a long- term relationship with the Tungsten processor and also ensure that the processor has a strategic plan to procure the raw Tungsten; i.e., monitor the supplier of each supplier to some manageable level. Why is there so much focus on supplies and the purchasing activities? Because the average manufacturing organization spends 50 to 60 per cent of its expenditure on raw materials, components, and maintenance repair operating (MRO) purchases.

10.3 EVOLUTION OF THE CONCEPT OF SCM

We must learn the historical background of the concept of SCM to appreciate and understand the enormous change from purchasing being a cost centre to supply management as a 'value adder'.

The first new broader view of purchasing was the concept of materials management. This movement was accelerated by the Second World War, the rapid growth of aerospace firms, and the influence of military logistics. By 1974, traffic and transportation activities gradually expanded and came to be called 'logistics'. Logistics is defined as a combination of materials management and physical distribution management.

The advent of materials management and computer tools created the Materials Requirement Planning (MRP) and Manufacturing Resource Planning (MRP II). For the first time, the organization looked at the entire flow of both incoming materials and outgoing finished goods, **as a system.** This integration greatly improved internal production communication but did not bring about much improvement in external communication with suppliers.

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It was not long before academicians realized that the Japanese had a totally different system of supply chain management. One of pioneers to observe this change was D.N. Burt who wrote:

> *The procurement of material and services is a process that cuts across organizational boundaries. The process includes activities in marketing, engineering, operations, production, planning, quality assurance, inventory control, purchasing, and finance. Integration of the procurement activities performed by these departments' results in a synergism – a situation where the whole is greater than the sum of its parts.*

The cross-functional team approach which builds on the synergy advantages of materials management but expands to include suppliers at the planning and design stage in a partnership atmosphere was started. Burt emphasized total ownership costs and the fact that component material price is merely one, and usually not the key cost driver as are poor quality, improper specifications, late delivery, rework and other critical cost drivers as identified by the Japanese.

As American industry adopted JIT and TQM, the improvement of transportation networks and cycle time reduction became mandatory. With suppliers far more dispersed than in Japan, any JIT system to decrease inventory required a new emphasis to reduce time to produce, ship, and use. The first real 'chain' concept was developed.

By now the term 'Distribution' had replaced 'Logistics'. Pioneers talked about 'links' and 'demand update chain' and stressed the need to eliminate the middleman as strategy No. 1.

At the heart of this integration is the real time computer data system which shares long term demand schedules and release dates with all members of the channel. Such systems require long-term partnerships based on trust which is so necessary to the sharing of sensitive information.

Many manufacturers of consumer goods are now using 'third party' service providers, such as integrated logistics firms, to run the continuous pipeline. Other requirements include the very latest material handling and bar coding equipment and the latest computer information systems. The goal of modern logistics is a network chain of continuous replenishment flow with zero or minimum storage at any distribution stage.

These developments have drastically changed the way purchasing operates with suppliers. The focus is now on a long- term relationship with fewer suppliers based on trust or 'win-win' negotiation philosophy and the sharing of confidential information. Purchasing would have to be proactive and strategic and move from 'exchange' thinking (purchase order to purchase order) to a long- term relationship. Most purchasing personnel still have real difficulty with this change given their paranoia and fascination with extensive legal documents. If one needs a 100- page contract filled with penalty clauses, the two parties obviously do not have a partnership.

D.N. Burt and M.P. Doyle in their book published in 1993, explain how a company can progress from reactive purchasing to strategic supply chain management. **'Value chain' as** defined by them is a series of organizations which begin with Mother Earth, firms which extract the ore, to firms which perform a series of value- adding activities on the ores and manufacture the finished goods or services purchased by the ultimate customer. The value chain is to be studied to know whether the right materials, services

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and technology are being purchased from the right source, at the right time, in the right quality, at the right price and in the right quantity.

10.4 RELEVANCE OF SCM

A firm's supply system must include all its internal functions and its external suppliers, in its effort to identify and fulfill the needs for materials, equipment and services in the optimum manner. The supply system must contribute to increase in profitability by

- Enhancing the quality of the firms' products
- Ensuring on time performance every time
- Reducing response times (increasing flexibility)
- Enabling inflow of technology
- Enhancing the image of the firm

In other words, supply management must be a core competency of a firm because of its direct impact on the firm's bottom line. It affects the two factors which control the bottom line – total costs and sales.

Supply management is responsible for almost 60 per cent of the total expenditure of a firm. So even a 5 per cent reduction in the total expenditure will directly translate to an increase in profits. If profits increase, the return on investment (ROI) will also increase and this will improve shareholder value.

Companies are attaining substantial competitive advantage by the manner in which they are configuring and managing their supply chains.

10.5 OBJECTIVES OF SCM

The main objectives of SCM are:

a) **To reduce product development cycle time:** Firms embrace SCM to reduce their new product development cycles and reach their products faster into the market. SCM firms adopt a cross- functional approach to product development involving the selected suppliers in the product development process. Involving the suppliers helps a firm meet unexpected changes in demand for its products. It is often seen that the first firm to introduce a successful new product or service always enjoys 40 to 60 per cent of the market even after competition has entered the market. Its profit margins are also much higher than those of its competitors.

b) **To improve quality:** Firms embrace SCM to improve the quality of their products and thus increase sales.

c) **To enable flexibility in pricing:** SCM firms enjoy a lower total cost of ownership (TCO) of their materials when compared to firms which do not follow SCM. When the cost of producing an item or service is reduced, the income of the company increases. Marketing can do this by (1) keeping the selling price and sales volume constant and thereby increasing profits, or (2) reducing the sales price and increasing profit by increasing sales volume.

d) **To facilitate innovation:** Firms embracing SCM can take advantage of each other's technology. A University of San Diego research study indicates that of

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the 240 firms surveyed, 35 per cent of all successful new products were the result of technology gained from their supply base.

e) **To enhance customer satisfaction:** Firms that follow SCM have lesser variations, consistently deliver on time, fulfil orders, respond to customer calls/ needs quickly, and are able to meet even special or unique requests.

f) **To be the supplier of choice:** By providing the best value (a combination of quality, service and price), the firm becomes the supplier of choice, both to other firms in the network and to the end customer.

g) **To enable flexibility:** SCM allows the firm to be flexible and react positively to customer desires for flexible lead time and changes in product configurations.

h) **To permit** l**ower Total cost of Ownership (TCO):** SCM helps to lower the total cost of acquisition and ownership of an item. This in turn translates to higher profits and sustainability for the firm.

i) **To allow better asset utilization and lower downtime cost:** Collaborative and alliance relationships allow members of the chain to share critical assets. The smoother, timelier inflow of materials results in less waiting time, leading to improved asset utilization. Frequent downtime is the largest component of the TCO for many items of production and operating equipment. Downtime of a machine or equipment due to non-availability of raw materials can be at an exorbitant cost and is a direct loss to the company. This can be greatly reduced in SCM firms.

j) **To minimize the risk cost:** Firms maintain huge inventories and have several sources to ensure continuity of supply to minimize the risk of non-availability of raw materials. Since SCM involves developing relationships with appropriate suppliers, such risks can be greatly minimized.

k) **To reduce cycle time:** When the cycle time for any activity is low, its cost is also low. SCM helps to reduce the cycle time to introduce new products in the market, to develop a statement of work, or to select a new source, etc.

l) **To determine the non-value added costs:** On analysing the costs involved in launching a product or service, it is discovered that often 40 to 60 per cent of the expenditure involved are not value-added costs. This can be as high as 80 to 90 per cent of the total time required to complete a cycle. James P. Womack and Daniel T. Jones, in their book *Lean Thinking*, indicate that 'it takes an average of 11 months for the can of cola in a domestic refrigerator to actually get there… During those 11 months, the time that the material is actually being converted as opposed to simply waiting is a mere three hours!'

The members of a supply management system—involved in manufacturing design and quality engineering as well as supply management must always watch out for non-value added activities at all phases in the system.

It covers the cost of selecting, training and educating the people involved in the concerned activities. It also includes the costs of the software systems required for the maintenance of the network.

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10.6 VALUE CHAIN

The supply chain comprises a series of organizations extending back, all the way, to the organizations responsible for extracting material from the earth. The chain is seen as a single, 'whole' entity rather than as fragmented groups, performing their own respective functions. Only when the final end-user purchases a product or service does money enter the supply chain. Transactions taking place within the supply chain merely assign the ultimate end-user's or consumer's money to the different members of the chain. The supply system of a chain includes all the internal functions as well as the external suppliers. These are involved in identifying and optimally fulfilling the materials, service and equipment requirements. This supply system helps the organization to play its role in the supply chain in a satisfactory manner.

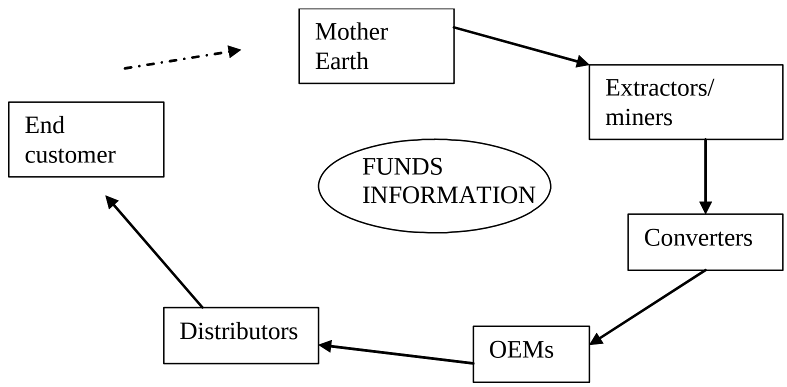

Fig. 10.1 *Supply Chain for Materials*

Figure 10.1 shows the supply chain for materials. Every material begins from Mother Earth. It is extracted or mined and sent to companies that convert it into some intermediate form such as slabs, billets, sheets, etc. This is sold to the Original Equipment Manufacturers (OEMs) who again convert it into a form which is sold widely in the market. It may either go directly to the end customer or go through a level of distributors. After we use them the materials ultimately go back to Mother Earth. Hence, it has been shown as a cycle.

The flow of funds in this cycle begins from the end customer. The end customer pays the distributor or OEM, who pays the converters, who pay the extractors or miners. The flow of information takes place in both directions.

Today, even the concept of supply 'chain' is being modified. It is being replaced by supply 'networks'. Networks are virtual systems linked together by communication systems and alliances. Networks focus on the ultimate customer. They are designed and managed such that there is a symbiotic relationship among the members and one member does not benefit at the expense of another.

10.7 CONCEPT OF TOTAL COST OF OWNERSHIP

In the concept of Total Cost of Ownership (TCO) also called Total Cost of Acquisition, the off-the-shelf price of an item alone is not taken into consideration while deciding on procurement. Instead, the total costs involved in consuming the item are considered. Let us see below how this is done.

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All the costs involved as we trace the path of a product from its raw material stage till it is consumed is called the **life cycle cost** of an item. The Purchase bill can be lowered if the total life cycle cost is optimum. In other words, the Total Cost of Acquisition and Ownership of the item must be optimum.

LEVER	COST
Wastage, spillage, pilferage	1
Inventory Carrying Cost	3
Handling and Storage Cost	1
Inspection and Testing Cost	2
Transportation and freight costs	3
Packing and forwarding costs	3
Duties and taxes	4
Margins of supplier	15
Labour and other overheads	16
Manufacturing cost	12
Raw Materials Cost	40

Total Cost of Acquisition = Rs 100

Landed Cost = Rs 95

Ex-works price = Rs 83

Supplier Cost Structure

The above illustration indicates that the supplier can control 83 per cent of an item's total cost. While 5 per cent of costs are controlled internally, 12 per cent is applied to logistics.

Each of these costs are representative of an opportunity for reduction.

It is not possible to reduce the cost of raw materials. One can play upon the margins. The opportunity for reduction exists in the handling, forwarding, packing, transporting, inspecting, etc., in other words, the supply chain. SCM, if done efficiently, can help reduce the total cost of acquisition and ownership of an item.

It is essential to know the correct supply chain for a product. This is possible only by studying TCO. Most progressive firms, across the world, which follow the concept of TCO consider the following main factors:

(a) Price
- Are the products being bought optimally?
- How many suppliers are there?
- Domestic/imported or a combination of both
- Commercial terms

(b) Logistics
- Are the products received in the correct way?
- How are products packaged and transported?
- What are the losses in handling?
- What are the inspection phases?
- Management of inventory

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(c) Specifications

- Are the specifications being used right/correct?
- Can the variants and subvariants be rationalized?
- Can there by innovations?

(d) Usage

- Is the product being used in the right manner?
- What are the parameters for operation?
- What are the work practices?
- How much of recycling or wastage is taking place?

Requirements should be looked into minutely when it comes to specifications. The number of variants, whether there is a possibility of clubbing them, how or whether lots can be formed, whether the requirements are general or tailor-made, and so on. The firm has to consider its own requirements to be able to identify alternatives. Alternate specifications can be identified through periodic diagnostic studies that help arrive at the best specifications for any item.

Identification and consolidation of the supplier base, for deciding on the most effective and suitable commercial terms, is necessary for the organization. The organization should examine the economics, margins, overheads and limitations of the supplier cost structure. It should also examine the supplier's competitors and industry benchmarks so that the opportunities of reducing cost can be identified. A lot of information can be gathered through a supplier workshop. An effective negotiation strategy based on this information can help decide on the best and most appropriate price.

Logistics is quite complex and demands that the total supply chain and its elements including inventories, freight, handling, storage and forwarding, etc. be understood well. The study is particularly important for bulky raw materials or imports, wherein there is a significant outflow of funds on freight.

It is important to study logistics in order to establish a lean supply chain which will give the benefit of quick product changeover capability, good short-term forecasting, JIT capability as well as excellent long-term forecasting.

An organization needs to attend to its operations and analyse how an item is fed or charged. It has to look into the losses incurred during charging, see whether there is a possibility of recycling, see whether there are ways to cut down pilferage and reduce wastage. In a steel plant, for example, reversing a conveyor belt with a worn-out bottom layer, and reusing it leads to postponement of its replacement for a short while. A belt with worn-out sides can be trimmed and made use of elsewhere, at another site or location where lesser width is not an impediment or where lesser width is needed.

10.8 SUPPLY ALLIANCES

Early adoption of supply management is essential for maximizing a firm's profitability.

Understanding supply alliances is important to the discussion on SCM. Supply alliance involves the inclusion of suppliers in the entire procurement process. The fundamental tenet of supply alliance is the presence of **institutional trust** in alliances. The failure to develop and manage institutional trust is the principal reason that so many supply alliances fail.

Supply alliances reap benefits as a result of physical asset collaboration as well as human collaboration. These collaborations allow for faster throughput and greater product customization.

Supply management professionals and carefully selected suppliers are moving to earlier involvement in the new product development process because of the important contribution that they can make in the areas of quality, cost, and timely market availability. This is commonly referred to as early supply management involvement or early supplier involvement.

During the 1990s, Chrysler was an interesting example of the power of alliance relationships. At that time, Chrysler was rated as the least desirable customer of the big three U.S. auto assemblers. In 1989, Chrysler had about 2,500 suppliers in its supply base. It transitioned itself from a transaction-based buyer to a collaborative one using cross- functional teams, early supplier involvement, target costing, value analysis (with incentives to suppliers in the form of additional profits or additional sales), improved communications through techniques such as location of supplier engineers at Chrysler design centres, and a supplier advisory board. This resulted in reducing the time to market by 30 per cent. The profit margins per vehicle increased by 8 to 10 per cent.

Characteristics of Supply Alliance

a) Continuous efforts at reducing costs and creating new benefits for both parties.

b) A high level of recognized interdependence and commitment.

c) An atmosphere of cooperation. When problems occur, the focus is on searching for the root cause, and not on assignment of blame.

d) The alliance is controlled through a complex web of formal and informal interpersonal connections, information systems, and internal infrastructures that enhance learning.

e) Openness exists in all areas of the relationship including, cost, long-term objectives, technology, and the supply chain itself.

f) The alliance partners share a vision of the future in the area of the interface.

g) Ethics take precedence over expediency.

h) The relationship is adaptable in the face of changing economics, competition, technology, and environmental issues.

i) Negotiations and renegotiations occur in a win- win manner.

j) Top-level commitment and alliance champions protect the alliance.

Benefits of Supply Alliances

a) **Lower total costs:** Synergies are created in alliances that cannot happen in any other relationship. The synergies result in reductions of direct and indirect costs associated with labour, machinery, materials, and overheads.

b) **Reduced time to market:** Reducing the time to design, develop and distribute products and services leads to improved market share and better profit margins.

c) **Improved quality:** The use of both the design of experiments and supplier certification are the norm with supply alliances. These two activities design and manufacture quality, rather than inspect for errors. The result is improved quality at lower total cost.

d) **Improved technology flow from suppliers:** Openness and institutional trust enhance the inflow of technology from alliance partners that leads to many successful new products. In 1999, Dell and IBM formed an alliance that was valid for ten years. Dell is harnessing IBM's vast research, development, and production abilities. It is also purchasing storage devices, custom logic chips, static random access memory and other components. The two companies are cross-licensing patents i.e. they are sharing relevant technologies.

e) **Improved continuity of supply:** Alliance customers are the least likely group to experience supply disruptions.

10.9 INFORMATION TECHNOLOGY

In this part of the Unit, you will learn about the enabling information technologies which are redefining the subject. We will learn about four topics here. These include e-Commerce, EDI, Data warehousing and RFID.

10.9.1 E-Commerce

According to Schneider and Perry, e-commerce is defined as *'activities conducted using electronic data transmission via the Internet and the World Wide Web'*. The elements covered are as follows:

- B2C or business-to-consumer—consumer shopping on the Web
- B2B or business-to-business — transactions that take place between business on the Web
- The business processes, transactions or deals that help the sale and supply of management activities on the Web

The Internet is the key to making e-commerce for supply chains less expensive, quick and reliable. The Internet is a big system comprising interconnected computer networks spanning the globe. Individuals and companies are capable of easily communicating with each other through the Internet. The World Wide Web, which is a part of the Internet, is actually a subset of the computers on the Internet that are connected to each other in a certain manner that makes those computers and their contents accessible to each other.

The Internet allows supply managers to manage their supply chains in a synchronized and collaborative manner. This results in reduced cost, improved time management, enhanced competitiveness and increased profits for all the members in the chain.

Implementation of e-commerce requires sound technology which will integrate the existing systems with speed and accuracy and at the same time provide visibility of transactions. Some firms develop their e-procurement capability by themselves, but most prefer to buy off-the-shelf solutions depending on their requirements. Some leading vendors of e-procurement solutions in the world today are – Ariba (and Indiamarkets), Commerce One, i2, ICG Commerce, Oracle, VerticalNet, etc. While selecting the e-procurement solution provider, firms need to look at several aspects such as –

- Cost
- Availability
- Functionality and features

- Catalogue functionality
- E-marketplace features
- Value-added business services
- Systems integration and interoperability
- Security
- Ease of use
- Local / global presence
- Reputation and financial strength
- Quality of team
- Service level and customer support

Advantages of e-commerce

The following are advantages of using e-commerce technologies in managing supply management activities.

a) Enables collaboration among supply chain members and functional areas on design of new products and services, modification of products and processes, customer demand, etc. The information can be electronically dispersed, both efficiently, effectively and accurately.

b) Enables companies to share information about quality problems.

c) Identifies new suppliers all over the world through the Internet.

d) Compares potential suppliers quickly on wide criteria, such as quality, price and delivery.

e) Provides a wider range of choices than traditional commerce. The supply manager can consider many different products and services from a diverse group of sellers.

f) Provides an easy way to customize the level of detail in the information obtained about both the prospective supplier and the purchase.

g) Runs 24/7, 365 days a year.

h) Reduce the cost of the purchase order by automating the procurement process.

All companies have not been able to adopt e-commerce successfully. Several problems have been encountered, which are –

a) Costs and benefits are hard to quantify and justify.

b) e-Commerce requires highly educated supply professionals who are expensive to find, recruit, develop and retain.

c) Incompatible existing databases, standards, data accumulation systems, and software. This makes integration difficult.

d) Internet exposes a company to several global issues such as restrictions on import and export, local business customs, currency conversions and laws of each country in which a supplier resides, etc. This can make international e-commerce difficult.

e) Small companies who otherwise are very good suppliers are left out because of the high cost of entry into the supply chain.

f) Resistance to change may be high. Employees, customers and suppliers who are accustomed to conducting businesses using traditional methods, such as phone, fax and face-to-face meetings may have difficulty with the new technology. The apprehension that it may result in reduction of staff also makes implementation difficult.

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E-commerce as an enabler

The benefits of e-commerce for supply management are recognized when one considers the amount of purely administrative work involved in the procurement cycle of a company. Technologies available today in e-Commerce can make these routine, non-value-added work tasks much simpler, more accurate and instantaneous. Examples of such tasks are–

- Maintenance of inventory records
- Computation of indenting quantities
- Preparation of purchase requisitions
- Preparation of Request for Quotation
- Preparation of purchase orders
- Maintenance of order status records
- Automatic preparation of follow-up memos
- Posting of cost, delivery and quality records, by part and by supplier
- Preparation of numerous operating reports for management
- Provision of decision support system information
- Auditing of invoices and preparation of checks for payment
- Electronic data interchange communication

E-commerce enables supply managers to receive real time data for decision making. The Internet's speed allows a computer system to process reports virtually instantaneously which otherwise might take weeks to prepare and update. The timeliness of such reports enables supply professionals to do a more effective and profitable job of managing the flow of materials throughout the internal operations and supply chain.

10.9.2 Electronic Data Interchange

Once a firm has an effective supply management system in place, a logical extension would be to link it with the order-handling computer system of the selected suppliers. The term generally given to this type of supply chain communications operation is electronic data interchange or EDI.

When standard business forms, that is, invoices, shipping notices, purchase orders and other data are transmitted directly and electronically between two organizations, from computer-to-computer, it is called EDI. In a supply environment, documents are transmitted electronically, eliminating the need to generate hard copies and to distribute them manually. EDI increases the speed of information flow while simultaneously decreasing the potential for data errors. 'Non-repudiation' is the ability to establish that a particular transaction has actually occurred. It prevents each party from repudiating or denying the transaction's validity or existence.

Wal-Mart's POS system using EDI

Wal-Mart, the largest retailer in the world, built much of its core competency by leveraging point-of-sale (POS) technologies coupled with EDI. When a customer purchases an item at Wal-Mart, the item's bar code is scanned at the billing station. Scanning serves two purposes – faster customer movement at the checkout and ability to gather POS information on the items sold. A computing system records this data into a database, aggregates the quantities, and electronically sends the information to a centralized information processing location. This location aggregates the demands by location for the item and sends the information to the appropriate supplier, such as Procter and Gamble or Ranbaxy, etc. The supplier is responsible for its own inventories, for delivery of merchandise, and for placing it on the shelves of Wal-Mart.

Wal-Mart's POS system has improved customer service, decreased inventories throughout its supply chain and improved the overall competitive capability of the company. EDI is the underlying technology that enables the system to work.

Benefits of EDI to suppliers

- Demand is visible.
- Obsolete stocks are minimized.
- Volume is increased.
- Capacity planning is improved. Wal-Mart's networked supply chain process has helped to change the way consumer products companies and wholesaler distributors do business with retailers.

10.9.3 Data Warehousing

Data warehousing provides a way for companies and supply chains to centralize selected data electronically. For example, consider a university that has a data warehouse filled with student information. Suppose a professor needs to access grade information for all students within six months of graduation so he or she can plan a graduation party for seniors. All that the professor would have to do is query the data warehouse (by using a password to gain entry into the data warehouse interface). The whole process would take only a few minutes. However, if there was no data warehouse then the professor would have to fill out a form and use campus mail to send the request to the University's Management Information System (MIS) department. MIS would receive the query the next day. After several telephonic/ personal reminders, the MIS employee will go into the department's database and print off the information requested. The document would be put back in the campus mail to the professor. The whole process could take several days, besides costing a lot more.

Imagine such inefficiencies when working with supply chain data. No wonder data warehousing has become so essential to SCM.

From the perspective of managing an enterprise's information assets, data warehousing and ERP have similar – and complementary – goals. Just as ERP traditionally promised great efficiencies and economies of scale by tying enterprise processes into a single application, data warehousing's principal value is in the way an enterprise can leverage all its information assets quickly and effectively.

10.9.4 Radio Frequency Identification (RFID)

All major retail companies such as Wal-Mart, Albertsons, MetroAG, etc. have started extensive use of RFID technology, which has software as a major component.

So what is RFID? *RFID is short for Radio Frequency Identification which is an automatic technique of identification using radio waves, to not only identify but monitor and also manage individual objects while they move from one physical location to another.* It is a smart sensing technology and consists of several components – tags/transponders, tag readers, antenna, middleware/application software.

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RFID generates large volumes of data. Retailers, wholesalers and manufacturers need to redesign their basic supply chain and data management processes and alter their supporting functions such as goods receiving, warehousing, inventory tracking, delivery, etc. in order to generate efficiency in the supply chain. All this requires investment in infrastructure and mandates compulsory supplier participation.

Advantages of using RFID

1. RFID does not require human intervention for data transmission.
2. RFID tags need only be in the range of the reader to be read or scanned. They do not need any specific orientation to establish line of sight.
3. RFID tags can withstand chemical or heat damage.
4. RFID tags can be read rapidly in bulk to provide simultaneous reading of contents – such as in a stockroom or in a container.
5. RFID tags can contain a larger amount of data when compared to bar codes.

Some of the current uses of RFID are –

1. **Retail, SCM and warehouse management.** It helps in inventory tracking, saves time and labour, ensures strict inventory control, improves vendor managed inventory, consignment management and tracking and identifying grey market goods and counterfeits. It helps to make the store more secure and reduces losses due to theft, etc.
2. **Product tracking**
    - RFID tags are being used by many world-class companies to deliver a tightly integrated supply chain, from warehouse to consumer.
    - RFID tags are used commercially in tracking of goods – in pallet and shipping container tracking, truck and trailer tracking, airline baggage tracking, in libraries and bookstores for book tracking, etc.
    - They are also used in identification badges, which are replacing earlier magnetic stripe cards. These badges need only be held within a certain distance of the reader to authenticate the holder. The American Express Blue credit card now includes a high-frequency RFID tag.
    - RFID can also be used in hospitals for infant tracking or patient tracking, in toll gates for collection of toll taxes, security systems for cars, etc.
    - The Canadian Cattle Identification Agency uses RFID tags to identify a bovine's herd of origin and this is used for trace back when a packing plant condemns a carcass. The USDA is currently developing its own programme.

In India, the Wireless Planning and Development Authority department has announced the freeing up of radio frequency in UHF 865-867 MHz band, to enable various applications of RFID across supply chains of various sectors. Some of the implementation stories of RFID in India are –

1. Ranbaxy Laboratories is one of the first domestic pharmaceutical companies to install EPC-(electronic product code) based RFID tags, but presently it is doing it only on the cases being supplied to Wal-Mart.
2. Infosys Technologies has implemented RFID on its campus on a pilot study basis.

Whatever may be the present bottlenecks of RFID, it cannot be denied that RFID is cheaper and more efficient. According to one industry projection, one trillion RFID tags will be required by 2012. RFID is the technology for the future.

Check Your Progress

1. Why should companies incorporate supply chain management?
2. What is RFID?
3. What are the advantages of e-commerce?

10.10 SUMMARY

In this unit, you have learned about supply chain management. It may come as a surprise to you that while the term 'supply chain management' is so much in vogue, only the *Fortune 500*- level firms (and not all of them at that) have, or are actually implementing, this concept. The relevance of this concept is immense, especially with the revolution in IT and consequent breakdown of geographical barriers. A combination of meticulous analysis, sensible strategy and effective implementation can enable a company to manage its profitability.

Supply chain management requires a balanced emphasis. This total systems view is extremely difficult to translate into actual operation. As Burt and others cited in this unit have for so long argued: 'Tear down these departmental, functional walls and think macro. Plan strategically, and then act locally with the proper integrated tactics.'

10.11 KEY TERMS

- **Supply chain:** Supply chain (also sometimes called Value Chain) means that organizations are 'interlinked' (like the elements of a chain).
- **Supply chain management:** Supply chain management links all the supply interacting organizations into an integrated two- way communication system to manage high quality inventory in the most effective and efficient manner.
- **Supply chain cost:** It is the cost of developing and managing the supply chains and supply networks.
- **Life cycle cost:** All the costs involved as we trace the path of a product from its raw material stage till it is consumed is called the life cycle cost of an item.
- **E-commerce:** According to Schneider and Perry, e-Commerce is defined as 'activities conducted using electronic data transmission via the Internet and the World Wide Web'.
- **Electronic data interchange**: Once a firm has an effective supply management system in place, a logical extension would be to link it with the order-handling computer system of the selected suppliers. The term generally given to this type of supply chain communications operation is electronic data interchange or EDI.
- **Data warehousing**: Data warehousing provides a way for companies and supply chains to centralize selected data electronically.
- **Radio frequency identification (RFID):** RFID is an automatic identification method that uses radio waves to identify, monitor and manage individual objects as they move between physical locations.

10.12 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Supply management must be a core competency of a firm because of its direct impact on the firm's bottom line. It affects the two factors which control the bottom line – total costs and sales.

   Supply management is responsible for almost 60 per cent of the total expenditure of a firm. So even a 5 per cent reduction in the total expenditure will

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directly translate into an increase in profits. If profits increase, the return on investment (ROI) will also increase and this will improve shareholder value.

Companies can achieve significant competitive advantage by the way they configure and manage their supply chains.

2. RFID is an automatic identification method that uses radio waves to identify, monitor and manage individual objects as they move between physical locations. It is a smart sensing technology and consists of several components – tags/ transponders, tag readers, antenna, middleware/application software.

   RFID generates large volumes of data. Retailers, wholesalers and manufacturers need to redesign their basic supply chain and data management processes and alter their supporting functions such as goods receiving, warehousing, inventory tracking, delivery, etc. in order to generate efficiency in the supply chain. All this requires investment in infrastructure mandates compulsory supplier participation.

3. The advantages of e-commerce are:
   a) Enables collaboration among supply chain members and functional areas on design of new products and services, modification of products and processes, customer demand, etc. The information can be electronically dispersed, both efficiently, effectively and accurately.
   b) Enables companies to share information about quality problems.
   c) Identifies new suppliers throughout the Internet-connected world.
   d) Compares potential suppliers quickly on wide criteria, such as quality, price and delivery.
   e) Provides a wider range of choices than traditional commerce.
   f) Provides an easy way to customize the level of detail in the information obtained about both the prospective supplier and the purchase.
   g) Runs 24/7, 365 days a year.
   h) Reduces the cost of the purchase order by automating the procurement process.

10.13 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What do you understand by SCM?
2. Why should firms progress to SCM?
3. How does information technology help SCM?

Long-Answer Questions

1. What is the role of supply alliance in supply chain management?
2. The foundation of good supply chain management is the understanding of TCO. Explain.
3. What is RFID? Explain its advantages.
4. What is data warehousing? What are its benefits to an organization?

10.14 FURTHER READING

Bedi, Kanishka. 2007. *Production and Operations Management*. New Delhi: Oxford University Press.

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UNIT 11 RANDOM VARIABLES AND PROBABILITY DISTRIBUTIONS

Structure

11.0 INTRODUCTION

In this unit, you will learn that random variable is a function that associates a unique numerical value with every outcome of an experiment. The value of the random variable will vary from trial to trial as the experiment is repeated. There are two types of random variables, discrete and continuous. The probability distribution of a discrete random variable is a list of probabilities associated with each of its possible values. It is also sometimes

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called the probability function or the probability mass function. The probability density function of a continuous random variable is a function which can be integrated to obtain the probability that the random variable takes a value in a given interval. The binomial distribution is used in finite sampling problems where each observation is one of two possible outcomes ('success' or 'failure'). The Poisson distribution is used for modeling rates of occurrence. The exponential distribution is used to describe units that have a constant failure rate. The term 'normal distribution' refers to a particular way in which observations will tend to pile up around a particular value rather than be spread evenly across a range of values, i.e., the Central Limit Theorem. It is generally most applicable to continuous data and is intrinsically associated with parametric statistics (e.g., ANOVA, t-test, regression analysis). Graphically the normal distribution is best described by a 'bell-shaped' curve. This curve is described in terms of the point at which its height is maximum, i.e., its 'mean' and its width or 'standard deviation'.

11.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Differentiate between a discrete and continuous random variable
- Understand the techniques of assigning probabilities
- Calculate the mean of random variable
- Calculate the expected value of random variable
- Calculate the variance and standard deviation of random variable
- Understand the basic concept of probability distribution
- Explain the types of probability distribution
- Describe the binomial distribution based on Bernoulli process
- Describe the Poisson distribution
- Analyse Poisson distribution as an approximation of binomial distribution
- Understand exponential distribution
- Explain the basic theory, characteristics and family of normal distributions
- Measure the area under the normal curve
- Do calculations using the rules for summations and expected values

11.2 WHAT IS RANDOM VARIABLE?

A *random variable is a variable that takes on different values as a result of the outcomes of a random experiment.* In other words, a function which assigns numerical values to each element of the set of events that may occur (i.e., every element in the sample space) is termed a random variable. The value of a random variable is the general outcome of the random experiment. One should always make a distinction between the random variable and the values that it can take on. All this can be illustrated by a few examples shown in the Table 11.1.

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Table 11.1 *Random Variable*

Random Variable	*Values of the Random Variable*	*Description of the Values of the Random Variable*
X	0, 1, 2, 3, 4	Possible number of heads in four tosses of a fair coin
Y	1, 2, 3, 4, 5, 6	Possible outcomes in a single throw of a die
Z	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	Possible outcomes from throwing a pair of dice
M	0, 1, 2, 3, ... S	Possible sales of newspapers by a newspaper boy, S representing his stock

All these above stated random variable assignments cover every possible outcome and each numerical value represents a unique set of outcomes. *A random variable can be either discrete or continuous*. If a random variable is allowed to take on only a limited number of values, it is a discrete random variable but if it is allowed to assume any value within a given range, it is a continuous random variable. Random variables presented in the above table are examples of discrete random variables. We can have continuous random variables if they can take on any value within a range of values, for example, within 2 and 5, in that case we write the values of a random variable x as follows:

$$2 \leq 5 \leq x$$

11.2.1 Techniques of Assigning Probabilities

We can assign probability values to the random variables. Since the assignment of probabilities is not an easy task, we should observe certain rules in this context as given below:

(*i*) A probability cannot be less than zero or greater than one, i.e., $0 \leq pr \leq 1$ where pr represents probability.

(*ii*) The sum of all the probabilities assigned to each value of the random variable must be exactly one.

There are three techniques of assignment of probabilities to the values of the random variable:

(a) *Subjective probability assignment.* It is the technique of assigning probabilities on the basis of personal judgement. Such assignment may differ from individual to individual and depends upon the expertise of the person assigning the probabilities. It cannot be termed as a rational way of assigning probabilities but is used when the objective methods cannot be used for one reason or the other.

(b) *A-priori probability assignment.* It is the technique under which the probability is assigned by calculating the ratio of the number of ways in which a given outcome can occur to the total number of possible outcomes. The basic underlying assumption in using this procedure is that every possible outcome is likely to occur equally. But at times the use of this technique gives ridiculous conclusions. For example, we have to assign probability to the event that a person of age 35 will live upto age 36. There are two possible outcomes, he lives or he dies. If the probability assigned in accordance with a-priori probability assignment is half then the same may not represent reality. In such a situation, probability can be assigned by some other techniques.

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(c) *Empirical probability assignment*. It is an objective method of assigning probabilities and is used by the decision-makers. Using this technique the probability is assigned by calculating the relative frequency of occurrence of a given event over an infinite number of occurrences. However, in practice only a finite (perhaps very large) number of cases are observed and relative frequency of the event is calculated. The probability assignment through this technique may as well be unrealistic, if future conditions do not happen to be a reflection of the past.

Thus, what constitutes the 'best' method of probability assignment can only be judged in the light of what seems best to depict reality. It depends upon the nature of the problem and also on the circumstances under which the problem is being studied.

11.2.2 Mean of Random Variable or The Expected Value of Random Variable

Mean of *random variable* is the sum of the values of the random variable weighted by the probability that the random variable will take on the value. In other words, it is the sum of the product of the different values of the random variable and their respective probabilities. Symbolically, we write the mean of a random variable, say X, as $\overline{X}$. *The Expected value of the random variable* is the average value that would occur if we have to average an infinite number of outcomes of the random variable. In other words, it is the average value of the random variable in the long run. The expected value of a random variable is calculated by weighting each value of a random variable by its probability and summing over all values. The symbol for the expected value of a random variable is $E(X)$. Mathematically, we can write the mean and the expected value of a random variable, X, as follows:

$$\overline{X} = \sum_{i=1}^{n} (X_i).pr.(X_i)$$

and

$$E(X) = \sum_{i=1}^{n} (X_i).pr.(X_i)$$

Thus, the mean and expected value of a random variable are conceptually and numerically the same but usually denoted by different symbols and as such the two symbols, viz., $\overline{X}$ and $E(X)$ are completely interchangeable. We can, therefore, express the two as follows:

$$E(X) = \sum_{i=1}^{n} (X_i).pr.(X_i) = \overline{X}$$

Where X_i is the ith value X can take.

11.2.3 Sum of Random Variables

If we are given the means or the expected values of different random variables, say *X*, *Y*, and *Z* to obtain the mean of the random variable (*X* + *Y* + *Z*), then it can be obtained as under:

$$E(X+Y+Z)=E(X)+E(Y)+E(Z)=\overline{X}+\overline{Y}+\overline{Z}$$

Similarly, the expectation of a constant time a random variable is the constant time the expectation of the random variable. Symbolically, we can write this as under:

$$E(cX)=cE(X)=c\overline{X}$$

Where *cX* is the constant time random variable.

11.2.4 The Variance and Standard Deviation of Random Variable

The mean or the expected value of random variable may not be adequate enough at times to study the problem as to how random variable actually behaves and we may as well be interested in knowing something about how the values of random variable are dispersed about the mean. In other words, we want to measure the dispersion of random variable (*X*) about its expected value, i.e., E(*X*). The variance and the standard deviation provide measures of this dispersion.

The variance of random variable is defined as the sum of the squared deviations of the values of random variable from the expected value weighted by their probability. Mathematically, we can write it as follows:

$$\text{Var}(X)=\sigma_X^2=\sum_{i=1}^{n}\left[X_i-E(X)\right]^2.pr.(X_i)$$

Alternatively, it can also be written as,

$$\text{Var}(X)=\sigma_X^2=\sum X_i^2\,pr.(X_i)-\left[E(X)\right]^2$$

Where, *E* (*X*) is the expected value of random variable.

X_i is the *i*th value of random variable.

pr. (X_i) is the probability of the *i*th value.

The standard deviation of random variable is the square root of the variance of random variable and is denoted as,

$$\sqrt{\sigma_X^{2i}}=\sigma_X$$

The variance of a constant time random variable is the constant squared times the variance of random variable. This can be symbolically written as,

$$\text{Var }(cX)=c^2\text{ Var }(X)$$

The variance of a sum of independent random variables equals the sum of the variances.

Thus,

$$\text{Var }(X+Y+Z)=\text{Var}(X)+\text{Var}(Y)+\text{Var}(Z)$$

If *X*, *Y* and *Z* are independent of each other.

The following examples will illustrate the method of calculation of these measures of a random variable.

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Check Your Progress

1. What is a random variable?
2. What is the difference between discrete and continuous variables?
3. How will you assign probability values to each value of a random variable?
4. Distinguish between subjective, a-priori and empirical probability assignments.

Example 1:

Calculate the mean, the variance and the standard deviation for random variable sales from the following information provided by a sales manager of a certain business unit for a new product:

Monthly Sales (in units)	*Probability*
50	0.10
100	0.30
150	0.30
200	0.15
250	0.10
300	0.05

Solution:

The given information may be developed as shown in the following table for calculating mean, variance and the standard deviation for random variable sales:

Monthly Sales (in units)[1] X_i		*Probability* $pr(X_i)$	$(X_i)\ pr\ (X_i)$	$(X_i - E(X))^2$	$X_i - E(X)^2$ $pr(X_i)$
X_1	50	0.10	5.00	$(50 - 150)^2 = 10000$	1000.00
X_2	100	0.30	30.00	$(100 - 150)^2 = 2500$	750.00
X_3	150	0.30	45.00	$(150 - 150)^2 = 0$	0.00
X_4	200	0.15	30.00	$(200 - 150)^2 = 2500$	375.00
X_5	250	0.10	25.00	$(250 - 150)^2 = 10000$	1000.00
X_6	300	0.5	15.00	$(300 - 150)^2 = 22500$	1125.00
			$\Sigma(X_i)\ pr\ (X_i) = 150.00$		$\Sigma[X_i - E(X)^2]\ pr\ (X_i) = 4250.00$

Mean of random variable sales = $\bar{X}$

or $\quad E(X) = \Sigma(X_i).pr(X_i) = 150$

Variance of random variable sales,

or $$\sigma_X^2 = \sum_{i=1}^{n}\left(X_i - E(X)\right)^2 .pr\left(X_i\right) = 4250$$

Standard deviation of random variable sales,

or $$\sigma_X = \sqrt{\sigma_X^2} = \sqrt{4250} = 65.2 \text{ approx.}$$

The mean value calculated above indicates that in the long run the average sales will be 150 units per month. The variance and the standard deviations measure the

1. Computations can be made easier if we take 50 units of sales as one unit in the given example, such as, 100 as 2, 200 as 4 and so on.

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variation or dispersion of random variable values about the mean or the expected value of random variable.

Example 2:

Given are the mean values of four different random variables viz., *A*, *B*, *C*, and *D*.

$$\overline{A} = 20, \quad \overline{B} = 40, \quad \overline{C} = 10, \quad \overline{D} = 5$$

Find the mean value of the random variable $(A + B + C + D)$

Solution:

$$\because \quad E(A + B + C + D) = E(A) + E(B) + E(C) + E(D)$$
$$= \overline{A} + \overline{B} + \overline{C} + \overline{D}$$
$$= 20 + 40 + 10 + 5$$
$$= 75$$

Hence, the mean value of random variable $(A + B + C + D)$ is 75.

Example 3:

If *X* represents the number of heads that appear when one coin is tossed and *Y* the number of heads that appear when two coins are tossed, compare the variances of the random variables *X* and *Y*. The probability distributions of *X* and *Y* are as follows:

X_i	$pr(X_i)$	Y_i	$pr(Y_i)$
0	1/2	0	1/4
		1	1/2
1	1/2	2	1/4
	Total = 1		Total = 1

Solution:

$$\text{Variance of } X = \sigma_X^2 = \left(0-\frac{1}{2}\right)^2 \cdot \left(\frac{1}{2}\right) + \left(1-\frac{1}{2}\right)^2 \cdot \left(\frac{1}{2}\right)$$

$$= \frac{1}{8} + \frac{1}{8} = \frac{1}{4} = 0.25$$

$$\text{Variance of } Y = \sigma_Y^2 = (0-1)^2 \cdot \left(\frac{1}{4}\right) + (1-1)^2 \cdot \left(\frac{1}{2}\right)$$

$$+ (2-1)^2 \cdot \left(\frac{1}{4}\right) = \left(\frac{1}{4}\right) + 0 + \frac{1}{4} = 0.50$$

The variance of the number of heads for two coins is double the variance of the number of heads for one coin.

11.3 MEANING OF PROBABILITY DISTRIBUTION

Once the random variable of interest has been defined and the probabilities have been assigned to all its values, we call it a probability distribution. The following table illustrates the probability distribution for various sales levels (sales level being the random variable represented as *X*) for a new product as stated by the sales manager:

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Sales (in units) X_i	*Probability* *pr.* (X_i)
X_1 50	0.10
X_2 100	0.30
X_3 150	0.30
X_4 200	0.15
X_5 250	0.10
X_6 300	0.05
Total	1.00

Sometimes the probability distribution may be presented in the form called a cumulative probability distribution. The above stated probability distribution can also be presented in the form of cumulative probability distribution as under:

Sales (in units) (X_i) $\propto$	*Probability* *pr* (X_i)	*Cumulative Probabilities* *pr.* $(X_i \leq \propto)$
X_1 50	0.10	0.10
X_2 100	0.30	0.40
X_3 150	0.30	0.70
X_4 200	0.15	0.85
X_5 250	0.10	0.95
X_6 300	0.05	1.00

The meaning of probability distribution can be made more clear if we state:

(a) *An Observed Frequency Distribution* (often called simply as a frequency distribution) is a listing of the observed frequencies of all the outcomes of an experiment that actually occurred while performing the experiment.

(b) *A Probability Distribution* is a listing of the probabilities of all the possible outcomes that could result if the experiment is performed. Assignment of probabilities may be based, as stated above, either on theoretical considerations or it may be a subjective assessment or may be based on experience.

(c) *A Theoretical Frequency Distribution* is a probability distribution that describes how outcomes are expected to vary. In other words, it enlists the expected values (i.e., observed values multiplied by corresponding probabilities) of all the outcomes.

11.3.1 Types of Probability Distributions

Probability distributions can be classified as either discrete or continuous. In a *discrete probability distribution* the variable under consideration is allowed to take only a limited number of discrete values along with corresponding probabilities. The two important discrete probability distributions are, the Binomial probability distribution and the Poisson probability distribution. In a *continuous probability distribution*, the variable under consideration is allowed to take on any value within a given range.

Important continuous probability distributions are, Exponential probability distribution and Normal probability distribution.

All these probability distributions and their functions are described in this unit.

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11.3.2 Probability Functions

In probability distribution, it is not always necessary to calculate probabilities for each and every outcome in the sample space. There exist many mathematical formulae for many commonly encountered problems which can assign probabilities to the values of random variables. Such formulae are generally termed as probability functions. In fact, a probability function is a mathematical way of describing a given probability distribution. To select a suitable probability function that best fits in the given situation we should work out the values of its parameters.[2] Once we have worked out the values of the parameters, we can then assign the probabilities, if required, using the appropriate probability function to the values of random variables. Various probability functions will be explained shortly while describing the various probability distributions.

11.4 BINOMIAL DISTRIBUTION

Binomial distribution (or the Binomial probability distribution) is a widely used probability distribution concerned with a discrete random variable and as such is an example of a discrete probability distribution. The binomial distribution describes discrete data resulting from what is often called as the Bernoulli process. The tossing of a fair coin a fixed number of times is a Bernoulli process and the outcome of such tosses can be represented by the binomial distribution. The name of Swiss mathematician Jacob Bernoulli is associated with this distribution. This distribution applies in situations where there are repeated trials of any experiment for which only one of two mutually exclusive outcomes (often denoted as 'success' and 'failure') can result on each trial.

11.4.1 The Bernoulli Process

Binomial distribution is considered appropriate in a Bernoulli process which has the following characteristics:

(a) *Dichotomy*. This means that each trial has only two mutually exclusive possible outcomes, e.g., 'Success' or 'failure', 'Yes' or 'No', 'Heads' or 'Tails' and the like.

(b) *Stability*. This means that the probability of the outcome of any trial is known (or given) and remains *fixed* over time, i.e., remains the same for all the trials.

(c) *Independence*. This means that the trials are statistically independent, i.e., to say the happening of an outcome or the event in any particular trial is independent of its happening in any other trial or trials.

11.4.2 Probability Function of Binomial Distribution

The random variable, say *X*, in the Binomial distribution is the number of 'successes' in *n* trials. The probability function of the binomial distribution is written as under:

$$f(X = r) = {}^nC_r p^r q^{n-r}$$

$$r = 0, 1, 2 \ldots n$$

Where, n = Numbers of trials

p = Probability of success in a single trial

Check Your Progress

5. What is mean of random variable?
6. Distinguish between random variable and expected value of random variable.
7. What are probability functions?
8. Explain the types of probability distributions.
9. Explain various types of discrete and continuous probability distributions.

1. Computations can be made easier if we take 50 units of sales as one unit in the given example, such as, 100 as 2, 200 as 4 and so on.

$q = (1 - p)$ = Probability of 'failure' in a single trial

r = Number of successes in 'n' trials

NOTES

11.4.3 Parameters of Binomial Distribution

This distribution depends upon the values of p and n which in fact are its parameters. Knowledge of p truly defines the probability of X since n is known by definition of the problem. The probability of the happening of exactly r events in n trials can be found out using the above stated binomial function.

The value of p also determines the general appearance of the binomial distribution, if shown graphically. In this context the usual generalizations are:

(a) When p is small (say 0.1), the binomial distribution is skewed to the right, i.e., the graph takes the form shown in Fig. 11.1.

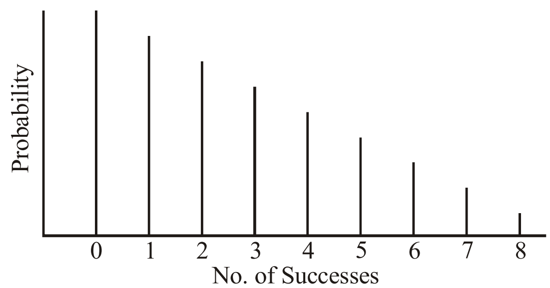


Fig. 11.1

(b) When p is equal to 0.5, the binomial distribution is symmetrical and the graph takes the form as shown in Fig. 11.2.

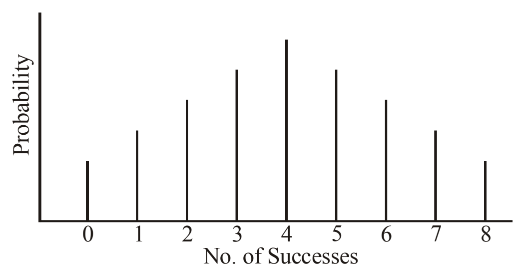


Fig. 11.2

(c) When p is larger than 0.5, the binomial distribution is skewed to the left and the graph takes the form as shown in Fig. 11.3.

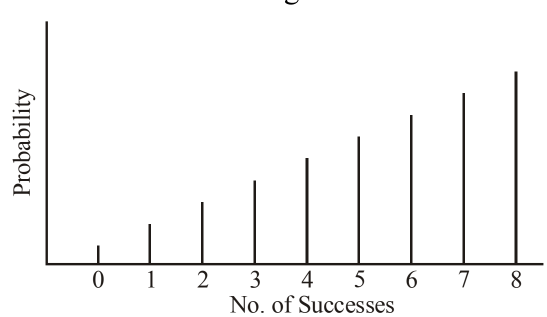


Fig. 11.3

But if 'p' stays constant and 'n' increases, then as 'n' increases the vertical lines become not only numerous but also tend to bunch up together to form a bell shape, i.e., the binomial distribution tends to become symmetrical and the graph takes the shape as shown in Fig. 11.4.

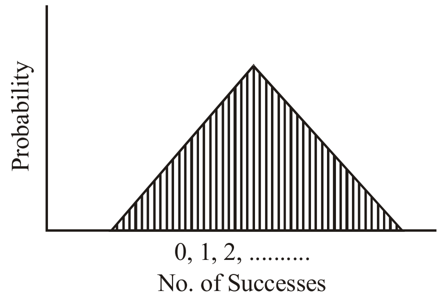


Fig. 11.4

11.4.4 Important Measures of Binomial Distribution

The expected value of random variable [i.e., $E(X)$] or mean of random variable (i.e., $\bar{X}$) of the binomial distribution is equal to *n.p* and the variance of random variable is equal to *n. p. q* or *n. p.* $(1 - p)$. Accordingly the standard deviation of binomial distribution is equal to $\sqrt{n.p.q}.$ The other important measures relating to binomial distribution are as under:

$$\text{Skewness} = \frac{1-2p}{\sqrt{n.p.q}}$$

$$\text{Kurtosis} = 3+\frac{1-6p+6q^2}{n.p.q}$$

11.4.5 When to Use Binomial Distribution

The use of binomial distribution is most appropriate in situations fulfilling the conditions outlined above. Two such situations, for example, can be described as follows.

(a) When we have to find the probability of 6 heads in 10 throws of a fair coin.

(b) When we have to find the probability that 3 out of 10 items produced by a machine, which produces 8% defective items on an average, will be defective.

Example 4:

A fair coin is thrown 10 times. The random variable X is the number of head(s) coming upwards. Using the binomial probability function, find the probabilities of all possible values which X can take and then verify that binomial distribution has a mean: $\bar{X} = n.p.$

and variance: $\sigma^2 = n.p.q$

Solution:

Since the coin is fair and so, when thrown, can come either with head upward or tail upward. Hence, p (head) $=\frac{1}{2}$ and q (no head) $=\frac{1}{2}.$ The required probability function is,

$$f(X = r) = {}^nC_r\, p^r q^{n-r}$$

$$r = 0, 1, 2\ldots10$$

NOTES

The following table of binomial probability distribution is constructed using this function.

X_i (Number of Heads)	Probability pr_i			$X_i\ pr_i$	$(X_i - \bar{X})$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2.p_i$
0	$^{10}C_0\ p^0\ q^{10}$	=	1/1024[3]	0/1024	–5	25	25/1024
1	$^{10}C_1\ p^1\ q^9$	=	10/1024	10/1024	–4	16	160/1024
2	$^{10}C_2\ p^2\ q^8$	=	45/1024	90/1024	–3	9	405/1024
3	$^{10}C_3\ p^3\ q^7$	=	120/1024	360/1024	–2	4	480/1024
4	$^{10}C_4\ p^4\ q^6$	=	210/1024	840/1024	–1	1	210/1024
5	$^{10}C_5\ p^5\ q^5$	=	252/1024	1260/1024	0	0	0/1024
6	$^{10}C_6\ p^6\ q^4$	=	210/1024	1260/1024	1	1	210/1024
7	$^{10}C_7\ p^7\ q^3$	=	120/1024	840/1024	2	4	480/1024
8	$^{10}C_8\ p^8\ q^2$	=	45/1024	360/1024	3	9	405/1024
9	$^{10}C_9\ p^9\ q^1$	=	10/1024	90/1024	4	16	160/1024
10	$^{10}C_{10}\ p^{10}\ q^0$	=	1/1024	10/1024	5	25	25/1024
				$\Sigma\bar{X}$ = 5120/1024 $\bar{X}$ = 5			Variance = σ^2 = $\Sigma\ (X_i - \bar{X})^2.pr_i$ = 2560/1024 = 2.5

The mean of the binomial distribution is given by $n.\ p. = 10 \times \frac{1}{2} = 5$ and the variance of this distribution is equal to $n.\ p.\ q. = 10 \times \frac{1}{2} \times \frac{1}{2} = 2.5$

These values are exactly the same as we have found them in the above table. Hence, these values stand verified with the calculated values of the two measures as shown in the table.

11.4.6 Fitting a Binomial Distribution

When a binomial distribution is to be fitted to the given data, then the following procedure

is adopted:

(a) Determine the values of 'p' and 'q' keeping in view that $\bar{X} = n.\ p.$ and $q = (1 - p)$.

(b) Find the probabilities for all possible values of the given random variable applying the binomial probability function, viz.,

$$f(X_i = r) = {}^nC_r p^r q^{n-r}$$
$$r = 0, 1, 2, \ldots n$$

(c) Work out the expected frequencies for all values of random variable by multiplying N (the total frequency) with the corresponding probability as worked out in case (*ii*) above.

(d) The expected frequencies so calculated constitute the fitted binomial distribution to the given data.

---

3. The value of the binomial probability function for various values of n and p are also available in tables (known as binomial tables) which can be used for the purpose to ease calculation work. The tables are of considerable help particularly when n is large. (See Appendix)
4. For Binomial distribution we had stated that mean = $n.\ p.$

$\therefore$ Mean for Poisson distribution (or λ) = $n.\ p.$

$\therefore$ $p = \lambda/n$

Hence, mean = $\frac{\lambda}{n}.n$

11.5 POISSON DISTRIBUTION

NOTES

Poisson distribution is also a discrete probability distribution with which is associated the name of a Frenchman, Simeon Denis Poisson who developed this distribution. This distribution is frequently used in context of Operations Research and for this reason has a great significance for management people. This distribution plays an important role in *Queuing* theory, Inventory control problems and also in Risk models.

Unlike binomial distribution, Poisson distribution cannot be deducted on purely theoretical grounds based on the conditions of the experiment. In fact, it must be based on experience, i.e., on the empirical results of past experiments relating to the problem under study. Poisson distribution is appropriate specially when probability of happening of an event is very small (so that q or $(1-p)$ is almost equal to unity) and n is very large such that the average of series (viz. $n.\ p.$) is a finite number. Experience has shown that this distribution is good for calculating the probabilities associated with X occurrences in a given time period or specified area.

The random variable of interest in Poisson distribution is number of occurrences of a given event during a given interval (interval may be time, distance, area etc.). We use capital X to represent the discrete random variable and lower case x to represent a specific value that capital X can take. The probability function of this distribution is generally written as under:

$$f(X_i = x) = \frac{\lambda^i e^{-\lambda}}{x}$$

$$x = 0, 1, 2\ldots$$

Where, λ = Average number of occurrences per specified interval.[4] In other words, it is the mean of the distribution.

e = 2.7183 being the basis of natural logarithms.

x = Number of occurrences of a given event.

11.5.1 The Poisson Process

The distribution applies in case of Poisson process which has following characteristics.

- Concerning a given random variable, the mean relating to a given interval can be estimated on the basis of past data concerning the variable under study.
- If we divide the given interval into very very small intervals we will find:

  (a) The probability that exactly one event will happen during the very very small interval is a very small number and is constant for every other very small interval.

  (b) The probability that two or more events will happen with in a very small interval is so small that we can assign it a zero value.

  (c) The event that happens in a given very small interval is independent, when the very small interval falls during a given interval.

  (d) The number of events in any small interval is not dependent on the number of events in any other small interval.

Check Your Progress

10. Explain the Bernoulli process.
11. Write the probability function of binomial distribution.
12. Explain the different parameters of binomial distributions.
13. Explain the important measures of the binomial distribution.
14. Under what circumstances will we use binomial distribution?

NOTES

11.5.2 Parameter and Important Measures of Poisson Distribution

Poisson distribution depends upon the value of λ, the average number of occurrences per specified interval which is its only parameter. The probability of exactly *x* occurrences can be found out using Poisson probability function stated above.[5] The expected value or the mean of Poisson random variable is λ and its variance is also λ.[6] The standard deviation of Poisson distribution is, $\sqrt{\lambda}$

Underlying the Poisson model is the assumption that if there are on the average λ occurrences per interval *t*, then there are on the average *k* λ occurrences per interval *kt*. For example, if the number of arrivals at a service counted in a given hour, has a Poisson distribution with λ = 4, then *y*, the number of arrivals at a service counter in a given 6 hour day, has the Poisson distribution λ =24, i.e., 6×4.

11.5.3 When to Use Poisson Distribution

The use of Poisson distribution is resorted to those cases when we do not know the value of '*n*' or when '*n*' can not be estimated with any degree of accuracy. In fact, in certain cases it does not make many sense in asking the value of '*n*'. For example, the goals scored by one team in a football match are given, it cannot be stated how many goals could not be scored. Similarly, if one watches carefully one may find out how many times the lightning flashed but it is not possible to state how many times it did not flash. It is in such cases we use Poisson distribution. The number of death per day in a district in one year due to a disease, the number of scooters passing through a road per minute during a certain part of the day for a few months, the number of printing mistakes per page in a book containing many pages, are a few other examples where Poisson probability distribution is generally used.

Example 5:

Suppose that a manufactured product has 2 defects per unit of product inspected. Use Poisson distribution and calculate the probabilities of finding a product without any defect, with 3 defects and with four defects.

Solution:

If the product has 2 defects per unit of product inspected. Hence, λ = 2.

Poisson probability function is as follows:

$$f\left(X_i = x\right) = -\frac{\lambda^x . e^{-\lambda}}{x}$$

$$x = 0, 1, 2, \ldots$$

Using the above probability function, we find the required probabilities as under:

$$P(\text{without any defects, i.e., } x = 0) = \frac{2^0 . e^{-2}}{0}$$

$$= \frac{1.\left(0.13534\right)}{1} = 0.13534$$

---

5. There are tables which gives the $e^{-\lambda}$ values. These tables also give the $e^{-\lambda}\ \frac{\lambda^x}{x}$ values for $x = 0, 1, 2, \ldots$ for a given λ and thus facilitate the calculation work.
6. Variance of the Binomial distribution is *n. p. q.* and the variance of Poisson distribution is λ. Therefore, λ = *n. p. q.* Since *q* is almost equal to unity and as pointed out earlier *n. p.*= λ in Poisson distribution. Hence, variance of Poisson distribution is also λ.

$$P(\text{with 3 defects, i.e., } x = 3) = \frac{2^3.e^{-2}}{3} = \frac{2 \times 2 \times 2(0.13534)}{3 \times 2 \times 1}$$

$$= \frac{0.54136}{3} = 0.18045$$

NOTES

$$P(\text{with 4 defects, i.e., } x = 4) = \frac{2^4.e^{-2}}{4} = \frac{2 \times 2 \times 2 \times 2(0.13534)}{4 \times 3 \times 2 \times 1}$$

$$= \frac{0.27068}{3} = 0.09023$$

11.5.4 Fitting a Poisson Distribution

When a Poisson distribution is to be fitted to the given data, then the following procedure is adopted:

(a) Determine the value of λ, the mean of the distribution.

(b) Find the probabilities for all possible values of the given random variable using the Poisson probability function, viz.

$$f(X_i = x) = \frac{\lambda^x.e^{-\lambda}}{x}$$

$$x = 0, 1, 2, \ldots$$

(c) Work out the expected frequencies as follows:

$$n.p.(X_i = x)$$

(d) The result of case (c) above is the fitted Poisson distribution to the given data.

11.5.5 Poisson Distribution as an Approximation of Binomial Distribution

Under certain circumstances Poisson distribution can be considered as a reasonable approximation of Binomial distribution and can be used accordingly. The circumstances which permit all this are when '*n*' is large approaching to infinity and *p* is small approaching to zero (*n* = number of trials, *p* = probability of 'success'). Statisticians usually take the meaning of large *n*, for this purpose, when $n \geq 20$ and by small '*p*' they mean when $p \leq 0.05$. In cases where these two conditions are fulfilled, we can use mean of the binomial distribution (viz. *n.p.*) in place of the mean of Poisson distribution (viz. λ) so that the probability function of Poisson distribution becomes as stated below:

$$f(X_i = x) = \frac{(n.p)^x.e^{-(np)}}{x}$$

We can explain Poisson distribution as an approximation of the Binomial distribution with the help of following example.

Example 6:

Given is the following information:

(a) There are 20 machines in a certain factory, i.e., $n = 20$.

(b) The probability of machine going out of order during any day is 0.02.

NOTES

What is the probability that exactly 3 machines will be out of order on the same day? Calculate the required probability using both Binomial and Poissons Distributions and state whether Poisson distribution is a good approximation of the Binomial distribution in this case.

Solution:

Probability as per *Poisson probability function* (using $n.p$ in place of λ)

(since $n \geq 20$ and $p \leq 0.05$)

$$f(X_i = x) = \frac{(n.p)^x . e^{-np}}{x}$$

Where, x means number of machines becoming out of order on the same day.

$$P(X_i = 3) = \frac{(20 \times 0.02)^3 . e^{-(20 \times 0.02)}}{3}$$

$$= \frac{(0.4)^3 .(0.67032)}{3 \times 2 \times 1} = \frac{(0.064)(0.67032)}{6}$$

$$= 0.00715$$

Probability as per *Binomial probability function,*

$$f(X_i = r) = {}^nC_r \, p^r q^{n-r}$$

Where, $n = 20,\ r = 3,\ p = 0.02$ and hence $q = 0.98$

$\therefore$ $f(X_i = 3) = {}^{20}C_3 (0.02)^3\ (0.98)^{17}$

$= 0.00650$

The difference between the probability of 3 machines becoming out of order on the same day calculated using probability function and binomial probability function is just 0.00065. The difference being very very small, we can state that in the given case Poisson distribution appears to be a good approximation of Binomial distribution.

Example 7:

How would you use a Poisson distribution to find approximately the probability of exactly 5 successes in 100 trials the probability of success in each trial being $p = 0.1$?

Solution:

In the question we have been given,

$n = 100$ and $p = 0.1$

$\therefore$ $\lambda = n.p = 100 \times 0.1 = 10$

To find the required probability, we can use Poisson probability function as an approximation to Binomial probability function as shown below:

$$f(X_i = x) = \frac{\lambda^x . e^{-\lambda}}{x} = \frac{(n.p)^x . e^{-(n.p)}}{x}$$

or $$P(5)^7 = \frac{10^5 . e^{-10}}{5} = \frac{(100000)(0.00005)}{5 \times 4 \times 3 \times 2 \times 1} = \frac{5.00000}{5 \times 4 \times 3 \times 2 \times 1}$$

$$= \frac{1}{24} = 0.042$$

11.6 EXPONENTIAL DISTRIBUTION

Exponential probability distribution is the probability distribution of time, (say t), between events and as such it is continuous probability distribution concerned with the continuous random variable that takes on any value between zero and positive infinity. In the exponential distribution, we often ask the question: What is the probability that it will take x trials before the first occurrence? This distribution plays an important role in describing a large class of phenomena, particularly in the area of reliability theory and in *queuing* models.

The probability function of the exponential distribution is as follows:

$$F(x) = \mu e^{-\mu x} \quad x \geq 0$$

Where, μ = The average length of the interval between two occurrences[8]

e = 2.7183 being the basis of natural logarithms

The only parameter of the exponential distribution is μ.

The expected value or mean of the exponential distribution is $1/\mu$ and its variance is $1/\mu^2$.

The cumulative distribution (less than type) of the exponential is,

$$F(x) = P(X \leq x) = 1 - e^{-\mu x},\ x \geq 0$$
$$= 0, \text{ elsewhere}$$

Thus, for instance, the probability that $x \leq 2$ is $1 - e^{-2\mu}$.

Example 8:

In an industrial complex the average number of fatal accidents per month is one-half. The number of accidents per month is adequately described by a Poisson distribution. What is the probability that four months will pass without a fatal accident?

Solution:

We have been given that the average number of fatal accidents per months is one-half and the number of accidents per month is well described by a Poisson distribution.

Hence, $\lambda = 0.5$

$\therefore$ The average length of the time interval between two accidents $= \dfrac{1}{\lambda} = \dfrac{1}{0.5} = 2$ months, assuming exponential distribution.

Now by using the cumulative distribution of the exponential, we can find the required probability that four months will pass without a fatal accident (i.e., $x > 4$) as under:

$\because \quad F(x) = P(X \leq x) = 1 - e^{-\mu x}$

$\therefore \quad P(X > x) = e^{-\mu x}$

$\therefore \quad P(X > x) = e^{-2(4)} = e^{-8} = 0.00034$

Thus, 0.00034 is the required probability that 4 months will pass without a fatal accident.

Check Your Progress

15. What is Poisson distribution?
16. Where and when will we use Poisson distribution?
17. Under what circumstances, is a Poisson distribution considered as an approximation of binomial distribution?
18. What is an exponential distribution?
19. What is the use of exponential distribution?

---

7. As per binomial probability function this would have been worked out as under: $p(5 \text{ successes}) = {}^{100}C_5(0.1)^5(0.9)^{95}$

8. μ is equal to $\dfrac{1}{\lambda}$, where λ is the mean of Poisson distribution.

NOTES

11.7 NORMAL DISTRIBUTION

Among all the probability distributions the normal probability distribution is by far the most important and frequently used continuous probability distribution. This is so because this distribution well fits in many types of problems. This distribution is of special significance in inferential statistics since it describes probabilistically the link between a statistic and a parameter (i.e., between the sample results and the population from which the sample is drawn). The name of Karl Gauss, eighteenth century mathematician-astronomer, is associated with this distribution and in honour of his contribution, this distribution is often known as the Gaussian distribution.

The normal distribution can be theoretically derived as the limiting form of many discrete distributions. For instance, if in the binomial expansion of $(p + q)^n$, the value of '*n*' is infinity and $p = q = \frac{1}{2}$, then a perfectly smooth symmetrical curve would be obtained. Even if the values of *p* and *q* are not equal but if the value of the exponent '*n*' happens to be very very large, we get a curve normal probability smooth and symmetrical. Such curves are called normal probability curves (or at times known as normal curves of error) and such curves represent the normal distributions.[9]

The probability function in case of normal probability distribution[10] is given as:

$$f(x) = \frac{1}{\sigma.\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Where, μ = The mean of the distribution.

σ^2 = Variance of the distribution.

The normal distribution is thus defined by two parameters viz., μ and σ^2. This distribution can be represented graphically as under:

9. Quite often mathematicians use the normal approximation of the binomial distribution whenever '*n*' is equal to or greater than 30 and *np* and *nq* each are greater than 5.
10. Equation of the normal curve in its simplest form is,

$$y = y_0 . e^{\left(x^2 / 2\sigma^2\right)}$$

Where, y = The computed height of an ordinate at a distance of X from the mean.
y_0 = The height of the maximum ordinate at the mean. It is a constant in the equation and is worked out as under:

$$y_0 = \frac{N_i}{\sigma\sqrt{2\pi}}$$

Where, N = Total number of items in the sample
i = Class interval
π = 3.1416
$\therefore$ = $\sqrt{2\pi} = \sqrt{6.2832} = 2.5066$
and e = 2.71828, base of natural logarithms
σ = Standard deviation
X = Any given value of the dependent variable expressed as a deviation from the mean.

NOTES

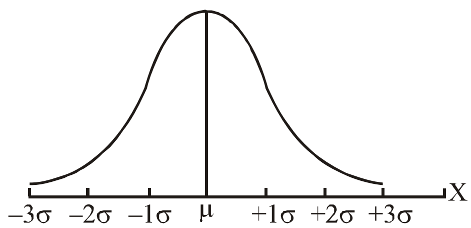
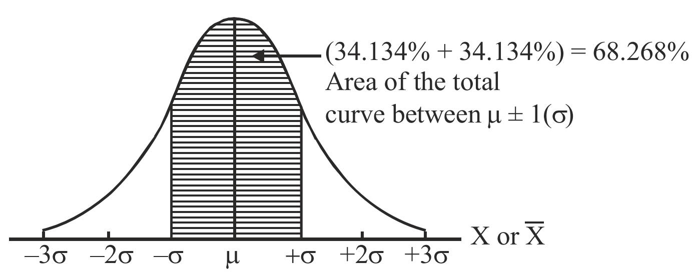


Fig. 11.5 *Curve Representing Normal Distribution*

11.7.1 Characteristics of Normal Distribution

The characteristics of the normal distribution or that of normal curve are as given below:

1. It is symmetric distribution.[11]
2. The mean μ defines where the peak of the curve occurs. In other words, the ordinate at the mean is the highest ordinate. The height of the ordinate at a distance of one standard deviation from mean is 60.653% of the height of the mean ordinate and similarly the height of other ordinates at various standard deviations (σ_s) from mean happens to be a fixed relationship with the height of the mean ordinate.
3. The curve is asymptotic to the base line which means that it continues to approach but never touches the horizontal axis.
4. The variance (σ^2) defines the spread of the curve.
5. Area enclosed between mean ordinate and an ordinate at a distance of one standard deviation from the mean is always 34.134% of the total area of the curve. It means that the area enclosed between two ordinates at one sigma (S.D.) distance from the mean on either side would always be 68.268% of the total area. This can be shown as follows:



11. A symmetric distribution is one which has no skewness. As such it has the following statistical properties:
   (a) Mean=Mode=Median (i.e., $X=Z=M$)
   (b) (Upper Quantile – Median)=(Median – Lower Quantile) (i.e., $Q_3 - M = M - Q_1$)
   (c) Mean Deviation=0.7979(Standard Deviation)
   (d) $\frac{Q_3 - Q_1}{2} = 0.6745$ (Standard Deviation)

NOTES

Similarly, the other area relationships are as follows:

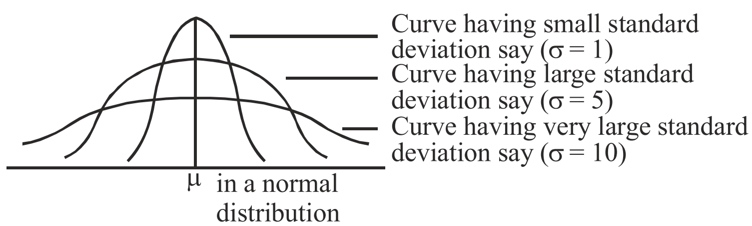
Between		*Area Covered to Total Area of the Normal Curve*[12]
$\mu \pm 1$	S.D.	68.27%
$\mu \pm 2$	S.D.	95.45%
$\mu \pm 3$	S.D.	99.73%
$\mu \pm 1.96$	S.D.	95%
$\mu \pm 2.578$	S.D.	99%
$\mu \pm 0.6745$	S.D.	50%

6. The normal distribution has only one mode since the curve has a single peak. In other words, it is always a unimodal distribution.
7. The maximum ordinate divides the graph of normal curve into two equal parts.
8. In addition to all the above stated characteristics the curve has the following properties:
   (a) $\mu = \overline{x}$
   (b) $\mu_2 = \sigma^2 =$ Variance
   (c) $\mu_4 = 3\sigma^4$
   (d) Moment Coefficient of Kurtosis = 3

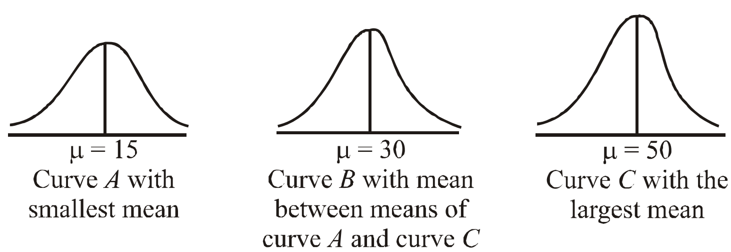
11.7.2 Family of Normal Distributions

We can have several normal probability distributions but each particular normal distribution is being defined by its two parameters viz., the mean (μ) and the standard deviation (σ). There is, thus, not a single normal curve but rather a family of normal curves. We can exhibit some of these as under:

Normal curves with identical means but different standard deviations:



Normal curves with identical standard deviation but each with different means:

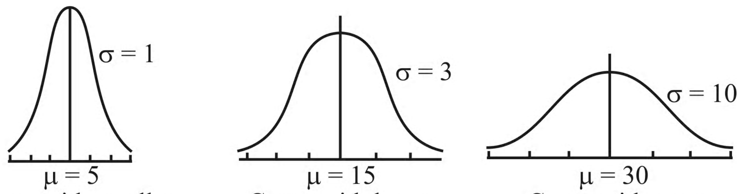


12. This also means that in a normal distribution the probability of area lying between various limits are as follows:

Limits	Probability of area lying within the stated limits
$\mu \pm 1$ S.D.	0.6827
$\mu \pm 2$ S.D.	0.9545
$\mu \pm 3$ S.D.	0.9973 (This means that almost all cases lie within $\mu \pm 3$ S.D. limits)

NOTES

Normal curves each with different standard deviations and different means:



Curve with smaller mean and smaller standard deviation

Curve with larger mean and larger standard deviation

Curve with very large mean and very large standard deviation

11.7.3 How to Measure the Area under the Normal Curve?

We have stated above some of the area relationships involving certain intervals of standard deviations (plus and minus) from the means that are true in case of a normal curve. But what should be done in all other cases? We can make use of the statistical tables constructed by mathematicians for the purpose. Using these tables we can find the area (or probability, taking the entire area of the curve as equal to 1) that the normally distributed random variable will lie within certain distances from the mean. These distances are defined in terms of standard deviations. While using the tables showing the area under the normal curve we talk in terms of standard variate (symbolically Z) which really means standard deviations without units of measurement and this 'Z' is worked out as under:

$$Z = \frac{X - \mu}{\sigma}$$

Where, Z = The standard variate (or number of standard deviations from X to the mean of the distribution).

X = Value of the random variable under consideration.

μ = Mean of the distribution of the random variable.

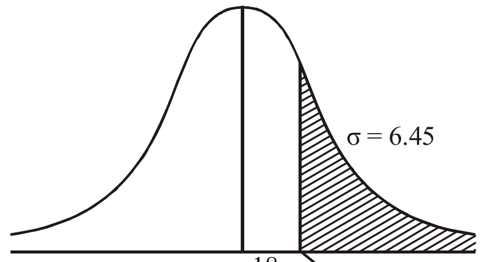
σ = Standard deviation of the distribution.

The table showing the area under the normal curve (often termed as the standard normal probability distribution table) is organized in terms of standard variate (or Z) values. It gives the values for only half the area under the normal curve, beginning with $Z = 0$ at the mean. Since the normal distribution is perfectly symmetrical the values true for one half of the curve are also true for the other half. We now illustrate the use of such a table for working out certain problems.

Example 9: A banker claims that the life of a regular saving account opened with his bank averages 18 months with a standard deviation of 6.45 months. Answer the following: (a) What is the probability that there will still be money in 22 months in a savings account opened with the said bank by a depositor? (b) What is the probability that the account will have been closed before two years?

Solution: (a) For finding the required probability we are interested in the area of the portion of the normal curve as shaded and shown below:

NOTES

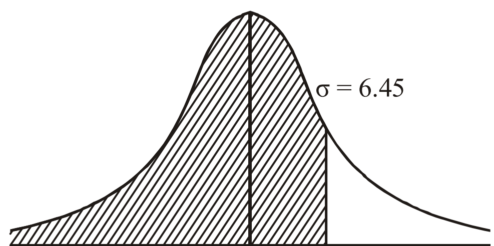


Let us calculate Z as under:

$$Z = \frac{X - \mu}{\sigma} = \frac{22 - 18}{6.45} = 0.62$$

The value from the table showing the area under the normal curve for Z = 0.62 is 0.2324. This means that the area of the curve between μ = 18 and X = 22 is 0.2324. Hence, the area of the shaded portion of the curve is (0.5) – (0.2324) = 0.2676 since the area of the entire right hand portion of the curve always happens to be 0.5. Thus the probability that there will still be money in 22 months in a savings account is 0.2676.

(b) For finding the required probability we are interested in the area of the portion of the normal curve as shaded and shown in figure:



For the purpose we calculate,

$$Z = \frac{24 - 18}{6.45} = 0.93$$

The value from the concerning table, when Z = 0.93, is 0.3238 which refers to the area of the curve between μ = 18 and X = 24. The area of the entire left hand portion of the curve is 0.5 as usual.

Hence, the area of the shaded portion is (0.5) + (0.3238) = 0.8238 which is the required probability that the account will have been closed before two years, i.e., before 24 months.

Example 10: Regarding a certain normal distribution concerning the income of the individuals we are given that mean=500 rupees and standard deviation =100 rupees. Find the probability that an individual selected at random will belong to income group,

(a) Rs 550 to Rs 650; (b) Rs 420 to 570.

Solution: (a) For finding the required probability we are interested in the area of the portion of the normal curve as shaded and shown below:

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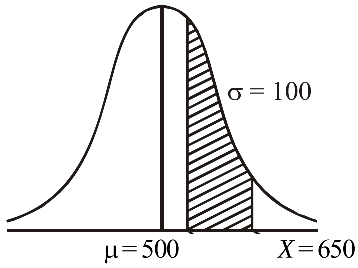


For finding the area of the curve between X = 550 to 650, let us do the following calculations:

$$Z = \frac{550 - 500}{100} = \frac{50}{100} = 0.50$$

Corresponding to which the area between $\mu = 500$ and $X = 550$ in the curve as per table is equal to 0.1915 and,

$$Z = \frac{650 - 500}{100} = \frac{150}{100} = 1.5$$

Corresponding to which the area between $\mu = 500$ and $X = 650$ in the curve as per table is equal to 0.4332

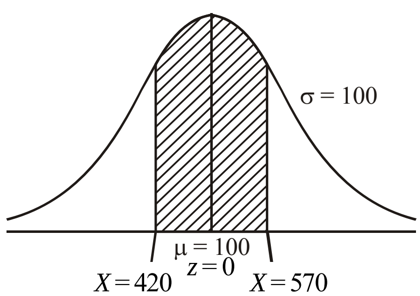
Hence, the area of the curve that lies between $X = 550$ and $X = 650$ is,

$$(0.4332) - (0.1915) = 0.2417$$

This is the required probability that an individual selected at random will belong to income group of Rs 550 to Rs 650.

(b) For finding the required probability we are interested in the area of the portion of the normal curve as shaded and shown below:

To find the area of the shaded portion we make the following calculations:



$$Z = \frac{570 - 500}{100} = 0.70$$

Corresponding to which the area between $\mu = 500$ and $X = 570$ in the curve as per table is equal to 0.2580.

and $$Z = \frac{420 - 500}{100} = -0.80$$

Corresponding to which the area between $\mu = 500$ and $X = 420$ in the curve as per table is equal to 0.2881.

Hence, the required area in the curve between $X = 420$ and $X = 570$ is,

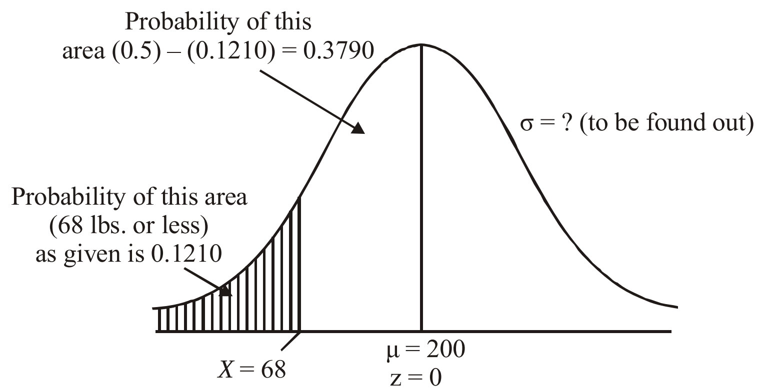
$$(0.2580) + (0.2881) = 0.5461$$

This is the required probability that an individual selected at random will belong to income group of Rs 420 to Rs 570.

NOTES

Example 11: A certain company manufactures $1\frac{1''}{2}$ all-purpose rope made from imported hemp. The manager of the company knows that the average load-bearing capacity of the rope is 200 lbs. Assuming that normal distribution applies, find the standard deviation of load-bearing capacity for the $1\frac{1''}{2}$ rope if it is given that the rope has a 0.1210 probability of breaking with 68 lbs. or less pull.

Solution: Given information can be depicted in a normal curve as shown below:



If the probability of the area falling within $\mu = 200$ and $X = 68$ is 0.3790 as stated above, the corresponding value of Z as per the table[13] showing the area of the normal curve is – 1.17 (minus sign indicates that we are in the left portion of the curve)

Now to find σ we can write,

$$Z = \frac{X - \mu}{\sigma}$$

or $$-1.17 = \frac{68 - 200}{\sigma}$$

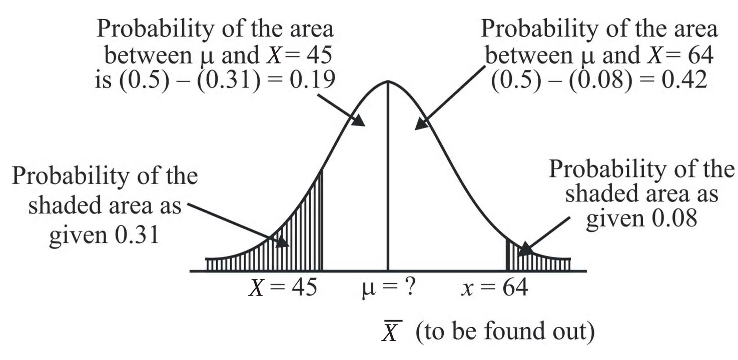
or $$-1.17\sigma = -132$$

or $$\sigma = 112.8 \text{ lbs. approx.}$$

Thus, the required standard deviation is 112.8 lbs. approximately.

Example 12: In a normal distribution, 31 per cent items are below 45 and 8 per cent are above 64. Find the $\overline{X}$ and σ of this distribution.

Solution: We can depict the given information in a normal curve as shown below:



13. The table is to be read in the reverse order for finding Z value (See Appendix).

NOTES

If the probability of the area falling within μ and $X = 45$ is 0.19 as stated above, the corresponding value of Z from the table showing the area of the normal curve is – 0.50. Since, we are in the left portion of the curve so we can express this as under,

$$-0.50 = \frac{45-\mu}{\sigma} \qquad (1)$$

Similarly, if the probability of the area falling within μ and $X = 64$ is 0.42 as stated above, the corresponding value of Z from the area table is +1.41. Since, we are in the right portion of the curve so we can express this as under,

$$1.41 = \frac{64-\mu}{\sigma} \qquad (2)$$

If we solve equations (1) and (2) above to obtain the value of μ or $\bar{X}$, we have,

$$-0.5\,\sigma = 45-\mu \qquad (3)$$

$$1.41\,\sigma = 64-\mu \qquad (4)$$

By subtracting the equation (4) from (3) we have,

$$-1.91\,\sigma = -19$$

$$\therefore \qquad \sigma = 10$$

Putting $\sigma = 10$ in equation (3) we have,

$$-5 = 45-\mu$$

$$\therefore \qquad \mu = 50$$

Hence, $\bar{X}$ (or μ)=50 and σ=10 for the concerning normal distribution.

11.8 RULES FOR SUMMATIONS AND EXPECTED VALUES

11.8.1 Rules for Summations

(*i*) For summation of the given values of X as X_1, X_2, X_3 . . .

$$\sum_{i=1}^{n} X_i = X_1 + X_2 + X_3 + \ldots + X_n$$

(*ii*) For a constant, c,

$\sum cX = c\sum X$

(*iii*) For a constant, c,

$\sum(X + c) = \sum X + nc$

(*iv*) If X and Y are two variables with the same number of values,

$\sum(X + Y) = \sum X + \sum Y$

11.8.2 Rules for Expected Values

(*i*) $E(cX) = cE(X)$

Where c is a constant and $E(X)$ is the mean of the random variable X or its expected value.

(*ii*) Var. $(cX) = c^2$. Var (X)

Check Your Progress

20. What is a normal distribution?
21. Explain any four characteristics of normal distribution.
22. How can we measure the area under the curve?

Where c is a constant and Var (X) is the variance of the random variable X.

(*iii*) $\sigma cX = \sqrt{\text{Var}(cX)} = \sqrt{c^2.\text{Var}(X)} = c\sigma_X$

NOTES

(*iv*) $E(X + Y) = E(X) + E(Y)$

For X and Y independent random variables.

(v) $E(XY) = E(X)\ E(Y)$

For X and Y independent random variables.

(*vi*) Var $(X) = E(X^2) - [E(X)]^2$

(*vii*) Var $(X + Y)$ = Var(X) + Var (Y), for X and Y independent variables.

If $Z = a + bX$

Where a and b are constants and X is a random variable, then we can work out the expected value of Z and its variance with the help of following mathematical relationships even without constructing a probability distribution for Z.

$E(Z) = E(a + bX)$

$\text{Var}(Z) = \sigma_z^2 = \sigma_{a+bX}^2$

and $E(a + bX)$ and σ_{a+bX}^2 can be worked out as under.

(a) $E(a + bX) = a + bE(X)$

Where a and b are constants.

(b) $\sigma_{a+bX}^2 = b^2\sigma_X^2$

11.9 SUMMARY

In this unit, you have learnt that binomial distribution is probably the best known of discrete distributions. The normal distribution, or Z-distribution, is often used to approximate the binomial distribution. However, if the sample size is very large, the Poisson distribution is a philosophically more correct alternative to binomial distribution than normal distribution. One of the main differences between the Poisson distribution and the binomial distribution is that in using the binomial distribution all eligible phenomena are studied, whereas in the Poisson only the cases with a particular outcome are studied. Exponential distribution is a very commonly used distribution in reliability engineering. The reason for its widespread use in its simplicity, so much that it has even been employed in cases to which it does not apply directly. Amongst all, the normal probability distribution is by far the most important and frequently used distribution because it fits well in many types of problems.

NOTES

11.10 KEY TERMS

- **Random variable:** It is referred as a variable that takes different values as a result of the outcome of a random experiment and can be discrete or continuous in nature.
- **Binomial distribution:** It is also called as Bernoulli process and is used to describe discrete random variable.
- **Poisson distribution:** It is used to describe the empirical results of past experiments relating to the problem and plays important role in queuing theory, inventory control problems and risk models.
- **Exponential distribution:** It is a continuous probability distribution and is used to describe the probability distribution of time between two events.
- **Normal distribution:** It is referred as most important and frequently used continuous probability distribution as it well fits in many types of problems.

11.11 ANSWERS TO 'CHECK YOUR PROGRESS'

1. A random variable is a variable that takes on different values as a result of the outcomes of a random experiment. In other words, a function that assigns numerical values to each element of the set of events that may occur is termed a random variable. The value of a random variable is the general outcome of the random experiment.
2. A discrete variable can take only a limited number of values, while a continuous variable can take any number of values within a given range.
3. There are three techniques for assigning probability values to each value of a random variable. They are:
   (a) Subjective probability assignment
   (b) A-priori probability assignment
   (c) Empirical probability assignment
4. In subjective probability assignment technique, probabilities are assigned on the basis of personal judgement, which may differ from individual to individual and must depend upon the expertise of the person assigning the probabilities. On the other hand, in a-priori probability assignment technique, the probability is assigned by calculating the ratio of the number of ways in which a given outcome can occur to the total number of possible outcomes. Furthermore, empirical probability assignment is an objective method of assigning probabilities where probabilities are assigned by calculating the relative frequency of occurrence of a given event over an infinite number of occurrences.
5. Mean of random variable is the sum of the values of the random variables weighted by the probability that the random variable will take on the value. In other words, it is the sum of the product of the different values of the random variable and their respective probabilities.

NOTES

6. Mean of random variable is the sum of the values of the random variables weighted by the probability that the random variable will take on the value, whereas the expected value of the random variable is the average value that would occur if we have to average an infinite number of outcomes of the random variable.
7. There are many mathematical formulae for several commonly encountered problems that can assign probabilities to the values of random variables. Such formulae are known as probability functions.
8. There are two types of probability distributions, discrete and continuous probability distributions. In discrete probability distribution, the variable under consideration is allowed to take only a limited number of discrete values along with corresponding probabilities. On the other hand, in a continuous probability distribution, the variable under consideration is allowed to take on any value within a given range.
9. There are two types of discrete probability distributions, binomial probability distribution and Poisson probability distribution. The binomial probability distribution is a widely used probability distribution that is concerned with a discrete random variable. It describes discrete data resulting from what is often called as the Bernoulli process. This distribution is applied in situations where there are repeated trials of any experiment for which only one of two mutually exclusive outcomes can result on each trial. Unlike, binomial distribution, Poisson distribution cannot be deducted on purely theoretical grounds based on the conditions of the experiment. Poisson distribution is frequently used in context of Operations Research and for this reason it has a great significance for management people. This distribution plays an important role in queuing theory.

   The continuous probability distributions, is also of two type, i.e., exponential probability distribution and normal probability distribution. Exponential probability distribution is the probability distribution of time between events and as such it is the continuous probability distribution concerned with the continuous random variable that takes on any value between zero and positive infinity. Among the probability distribution, the normal probability distribution is by far the most important and frequently used continuous probability distribution. This distribution is of special significance in inferential statistics since it describes probabilistically the link between a statistic and a parameter. The normal distribution can be theoretically derived as the limiting form of many discrete distributions.
10. Bernoulli process or Binomial distribution is considered appropriate and has the following characteristics;
    (a) *Dichotomy:* This means that each trial has only two mutually exclusive possible outcomes. For example, success of failure, yes or no, heads or tail, etc.
    (b) *Stability:* This means that the probability of the outcome of any trial is known and remains fixed over time, i.e. remains the same for all the trials.
    (c) *Independence:* This means that the trials are statistically independent, i.e., to say the happening of an outcome or the event in any particular trial is independent of its happening in any other trial or trials.
11. The probability function of binomial distribution is written as under:

$$f(X=r) = {}^nCrp^r q^{n-r}$$
$$r = 0,1,2,...n$$

Where, n = Numbers of trials.

p = Probability of success in a single trial.

q = $(1 - p)$ = Probability of failure in a single trial.

r = Number of successes in n trials.

12. The parameters of binomial distribution are p and n, where p specifies the probability of success in a single trial and n specifies the number of trials.
13. The important measures of binomial distribution are:

$$\text{Skewness} = \frac{1-2p}{\sqrt{n.p.q}}$$

$$\text{Kurtosis} = 3 + \frac{1-6p+6q^2}{n.p.q}$$

14. We need to use binomial distribution under the following circumstances:
    (a) When we have to find the probability of heads in 10 throws of a fair coin.
    (b) When we have to find the probability that 3 out of 10 items produced by a machine, which produces 8% defective items on an average, will be defective.
15. Poisson distribution is a discrete probability distribution that is frequently used in the context of Operations Research. Unlike binomial distribution, Poisson distribution cannot be deduced on purely theoretical grounds based on the conditions of the experiment. In fact, it must be based on the experience, i.e., on the empirical results of past experiments relating to the problem under study.
16. Poisson distribution is used when probability of happening of an event is very small and n is very large such that the average of series is a finite number. This distribution is good for calculating the probabilities associated with X occurrences in a given time period or specified area.
17. When n is large approaching to infinity and p is small approaching to zero, Poisson distribution is considered as an approximation of binomial distribution.
18. Exponential distribution is the probability distribution of time between events and as such it is continuous probability distribution concerned with the continuous random variable that takes on any value between zero and positive infinity.
19. Exponential distribution is used in describing a large class of phenomena, particularly in the area of reliability theory and in queuing models.
20. Normal distribution is the most important and frequently used continuous probability distribution among all the probability distributions. This is so because this distribution well fits in many types of problems. This distribution is of special significance in inferential statistics since it describes probabilistically the link between a statistic and a parameter.
21. The characteristic of a normal distribution are:
    (a) It is symmetric distribution.
    (b) The curve is asymptotic to the base line, which means that it continues to approach but never touches the horizontal axis.
    (c) The variance (σ^2) defines the spread of the curve.
    (d) The normal distribution has only one mode since the curve has a single peak. In other words, it is always a unimodal distribution.

NOTES

22. For measuring the area under a curve, we make use of the statistical tables constructed by mathematicians. Using these tables, we can find the area that the normally distributed random variable will lie within certain distances from the mean. These distances are defined in terms of standard deviations. While using the tables showing the area under the normal curve, it is considered in terms of standard variate, which means standard deviations without units of measurement and it is calculated as:

$$Z = \frac{X - \mu}{\sigma}$$

Where, Z = The standard variate or number of standard deviations from X to the mean of the distribution

X = Value of the random variable under consideration

μ = Mean of the distribution of the random variable

σ = Standard deviation of the distribution

11.12 QUESTIONS AND EXERCISES

Short-Answer Questions

1. Explain random variable with the help of example.
2. Differentiate between discrete and continuous random variable.
3. Describe the techniques used to assign probabilities to random variables.
4. What do you mean by expected value of random variable?
5. Write the equations used to calculate the variance and standard deviation of random variable.
6. Define probability distribution and probability functions.
7. Describe binomial distribution and its measures.
8. How a binomial distribution can be fitted to a given data?
9. Describe Poisson distribution and its important measures.
10. Poisson distribution can be an approximation of binomial distribution. Explain.
11. When is the Poisson distribution used?
12. Describe exponential distribution.
13. Define normal distribution.
14. Explain any six characteristics of normal distribution.
15. Write the formula for measuring the area under the curve.
16. Explain the circumstances when the normal probability distribution can be used.

Long-Answer Questions

1. Explain the meaning of the term random variable. Briefly describe the various techniques of assigning probabilities to the different values of the random variables.
2. (a) Is there any difference between the mean and the expected value of a random variable? Explain.

   (b) What does the mean of a random variable indicate?

NOTES

3. Given is the following probability distribution:

X_i	$pr(X_i)$
0	1/8
1	2/8
2	3/8
3	2/8

Calculate the expected value of X_i, its variance, and standard deviation.

4. If $E(X)$=15 and $\sigma_X^2 = 5$

Find (a) $E(10X)$

(b) σ_X

(c) $E(5X–3)$

5. A coin is tossed 3 times. Let X be the number of runs in the sequence of outcomes: first toss, second toss, third toss. Find the probability distribution of X. What values of X are most probable?

6. Find the expected value of the sum of the number of dots on the top faces of two ordinary cubical dice on one throw.

7. (a) Explain the meaning of Bernoulli process pointing out its main characteristics.

(b) Give a few examples narrating some situations wherein binomial *pr.* distribution can be used.

8. State the distinctive features of the Binomial, Poisson and Normal probability distributions. When does a Binomial distribution tend to become a Normal and a Poisson distribution? Explain.

9. Explain the circumstances when the following probability distributions are used:

(a) Binomial distribution

(b) Poisson distribution

(c) Exponential distribution

(d) Normal distribution

10. Certain articles were produced of which 0.5 per cent are defective, are packed in cartons each containing 130 articles. When proportion of cartons are free from defective articles? What proportion of cartons contain 2 or more defective? (Given $e^{-0.5}$=0.6065).

11. The following mistakes per page were observed in a book:

No. of Mistakes Per Page	*No. of Times the Mistake Occurred*
0	211
1	90
2	19
3	5
4	0
Total	345

NOTES

Fit a Poisson distribution to the data given above and test the goodness of fit.

12. In a distribution exactly normal, 7 per cent of the items are under 35 and 89 per cent are under 63. What are the mean and standard deviation of the distribution?
13. Assume the mean height of soldiers to be 68.22 inches with a variance of 10.8 inches. How many soldiers in a regiment of 1000 would you expect to be over six feet tall?
14. Fit a normal distribution to the following data:

Height in inches	*Frequency*
60–62	5
63–65	18
66–68	42
69–71	27
72–74	8

11.13 FURTHER READING

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UNIT 12 INVENTORY MANAGEMENT

NOTES

Structure

12.0 INTRODUCTION

Statements like 'inventory is evil,' 'inventory is a waste,' 'inventory is an asset,' 'inventory is a double-edged sword,' 'inventory is blocked working capital,' 'inventory takes care of a rainy day,' are heard very often. These are all conflicting and radically different views about the same practice. The big question is, what is inventory? What is inventory management?

The main objective of any business enterprise is to get 'return on investment' or what is normally called 'profit'. The profit motive of a company is embedded in all its activities. That is why the concept of 'profit centre' has evolved to evaluate the purpose, performance and contribution of each and every division of a company to its common goal. Any money saved on material costs will improve the bottom line of the company in terms of liquidity, working capital and overall profit, and will help the company withstand the onslaught of competition. In this unit, you will learn about inventory management and the various activities related to it.

12.1 UNIT OBJECTIVES

NOTES

After going through this unit, you will be able to:

- Understand the importance of inventory management
- Know the concepts of reorder point, safety stock and lead time
- Understand how materials planning is done
- Explain the materials requirement planning (MRP) process
- Understand the concept of distribution requirements planning
- Know how to classify inventories
- Understand how JIT works
- Explain the concepts of purchase management and stores management and their benefits
- Explain the various warehousing strategies

12.2 INVENTORY MANAGEMENT

These days, in most manufacturing firms, inventories form the second largest type of assets in the balance sheet. Inventories frequently account for more than 30 per cent of the firms' invested capital.

The advantages of holding a sizeable inventory are:

1. They make possible efficient and smooth operation of a manufacturing concern by decoupling the individual segments of the total operation. For example, if one of the processes in an assembly line has broken down or is under repair, this need not stop the entire assembly line and the rest of the activities can proceed using the inventories.
2. The daily production can be planned with flexibility and unforeseen problems in producing a given component can be reduced and a different component can be produced at short notice if the required raw materials are in hand.
3. The marketing manager can sell different products depending on the market demand. The company can react swiftly to changing demands and release goods in the market ahead of their competitors.
4. The purchasing manager can place fewer and larger orders, thus reducing the ordering costs. Larger orders also give volume discounts from suppliers. They can plan the procurement depending on market conditions, without depending too much on the shop floor operations.

The disadvantages of carrying a large inventory are:

1. Inventory hides quality problems. Sometimes suppliers supply poor quality and off-spec materials. If this goes unnoticed at the time of receiving the goods, it is a severe loss since the supply has been paid for. For, either the supply will not be used and remain in the inventory, or else, if it is used, it will lead to substandard finished goods. Either way, it amounts to loss.
2. Inventory hides production inefficiencies. On a given day if the daily production plan does not get fulfilled, it does not get highlighted because of the existing inventory which does not cause any slippages in the next process. An unfulfilled

daily production plan and high inventory of a particular sub-assembly/assembly reveals a more dangerous situation; that there is dissimilarity in capacities between a particular activity and it's next activity. Productivity inefficiencies also get camouflaged due to high inventory.

3. Inventory adds unnecessary costs to the production operation, such as inventory carrying costs, insurance costs, cost of deterioration/ obsolescence, etc.

Thus, inventory can be defined as an organization's blocked working capital in the form of materials. Since this is the blocked working capital, theoretically, it should be zero, although it is impossible to do so.

12.3 REORDER POINT, SAFETY STOCK AND LEAD TIME

Every company fixes certain 'levels' for holding inventory. These are called stock levels. The important ones are given below.

(a) Maximum stock level: This is the maximum stock, which a company can hold for a particular item. This will depend on the storage space, sunk costs, etc. The company should order only that much quantity so that the sum of the delivered quantity plus the safety stock/ existing stock, etc. do not cross the maximum stock level.

(b) Minimum stock level: This is the quantity that should be carried by the company so that the production is not affected before the next delivery arrives. It is often same as the safety stock. The next delivery should ideally arrive when the stock reaches the minimum stock level.

(c) Reorder level: This is the point when the stocks are just sufficient to meet demands during one normal lead time without dipping below the minimum level or into safety stocks. At this level, the orders should be placed so that stocks arrive just when the stock reaches the minimum stock level.

(d) Danger warning level: This is the level at which stocks are just sufficient to meet the demands during one normal lead time without getting totally exhausted and resulting in stockouts. This would be lower than the reorder level by the quantum of planned and provided safety stocks. It is the point after which stockout is inevitable if any delay occurs. In this time the purchase department should put extra pressure on the supplier and see that the delivery is received without any delay. Good supplier relationships will be of help here.

(e) Safety/buffer stock level: This is also called an amber zone. This is the stock that is required to take care of fluctuations in supply. Any fluctuations beyond this will result in stockout. At this stage, the purchase department, in addition to putting extra pressure on the supplier and ensuring that the delivery is received without any delay, should also try for supplies from an alternate source and inform production to revise their production plan and plan to manufacture items for which materials are available in plenty.

(f) Stockout level: Stockout level is also called a red zone. It is a situation in which no material is left in stock. The purchase department should take emergency measures, such as borrowing from other similar organizations, buying from stockists at listed price, etc. It always extracts a price from the organization, hence should be absolutely avoided.

By exercising continuous vigilance, the purchase manager can operate in the green zone without having to enter into the amber zone or red zone.

Safety Stock

NOTES

To meet the uncertainties arising from fluctuating demands, fluctuating lead times, unforeseen situations, etc., an extra stock is invariably maintained for each item in the inventory. This extra stock is termed as buffer stock or safety stock. Safety stocks arise due to variations in consumption rates and variations in lead times.

There are various factors which influence the determination of safety stock. They are:

1. **Nature of the item:** Items which are tailor-made, i.e., needed for a particular equipment or machinery, which are made based on drawings or specifications require a safety stock to be maintained to take care of the lead time required to manufacture those items. Standard items, i.e., those available off the shelf, such as motors, batteries, tyres, etc., may not require a safety stock to be maintained as they can be procured immediately.
2. **Annual usage:** Class A items having high consumption would be more prone to fluctuations than class B or class C items and require more safety stock.
3. **Lead time of manufacture:** Items having longer lead times for manufacture and/ or supply are more prone to fluctuations and therefore require a safety stock to be maintained, e.g., imports, mechanical spares, etc.
4. **Stockout cost:** If the stockout cost of an item is high, i.e., non-availability of the item would result in high loss of production, such items should have a considerable safety stock
5. **Seasonality:** For items which are manufactured only during a particular season, it may be sensible to stock till the next season arrives. Even though the item may be available throughout the year, the factor of price comes into play.
6. **Risk of obsolescence/ deterioration:** For items which have low shelf life, e.g., medicines, vulcanizing solution, certain electronic items, etc., it may not be prudent to carry a large stock. A small safety stock would be sufficient.
7. **Macro/environmental issues:** Uncertainty in supplies, such as impending war, change in policies, government restrictions, etc., may cause a larger safety stock to be maintained.

Then, how much safety stock should be maintained? It should neither be so high as to lock scarce working capital nor so low as to result in stockouts.

Safety stock is a function of two parameters, which are:

- Consumption rate
- Lead time

Four combinations of the two factors are possible. These are:

1. Both consumption rates and lead times are constant.
2. Consumption rate varies but lead time is constant.
3. Consumption rate is constant but lead time varies.
4. Both consumption rate and lead time varies.

We will now learn each of these in detail.

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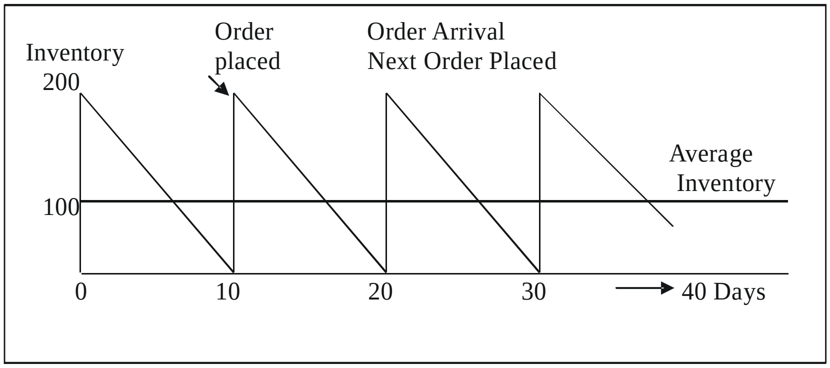
1. **Both consumption rates and lead times are constant:** This is an ideal situation. Supply against fresh order arrives just when the quantity against the previous order has exhausted. No safety stock is required.



Most homes buy a set amount of milk every day. This system is too simplistic and is not usable in industry. It should be learnt for theoretical purposes.

2. **Consumption rate varies but lead time is constant:** In the previous example, consumption rate (CR) is 200/10 = 20 units/day.

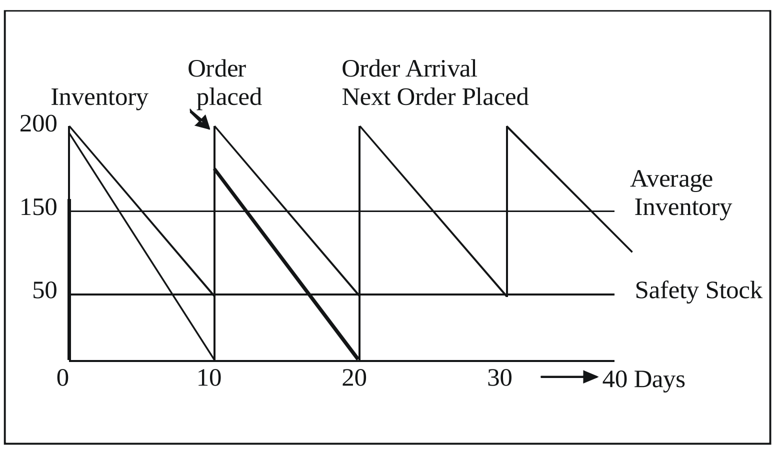
   Let the CR increase to 25 units/day, while lead time remains at 10 days.

   The inventory would become zero on day 8 (200/25). So there would be a stockout for 2 days, i.e., stockout of 50 units in total.

   Hence, if the variation in demand is + or – 5 units, it is necessary to maintain a safety stock of 50 units to take care of variations in demand.

   The average inventory would therefore be 200/2 + 50 = 150 units.

   This can be represented diagrammatically as follows:



3. **Consumption rate is constant but lead time varies:** The previous example is continued here.

   Let the CR remain at 20 units/day, while lead time varies by 2 days. If it arrives 2 days early, there is no problem. But if it arrives 2 days late, there would be a stockout for 2 days. So the stockout quantity will be 20 × 2 = 40 units.

   Hence, one can say that if the variation in lead time is + or – 2 days and never more, a safety stock of 40 units would be required to be maintained, to take care of variations in lead time.

The average inventory would therefore be 200/2 + 40 = 140 units.

This can be represented diagrammatically as follows:

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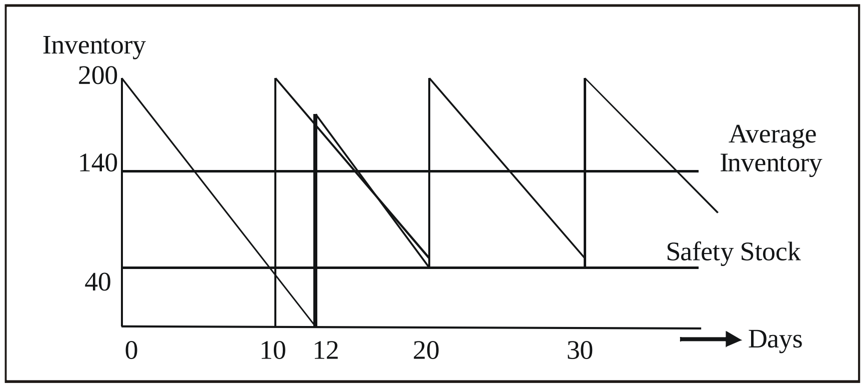


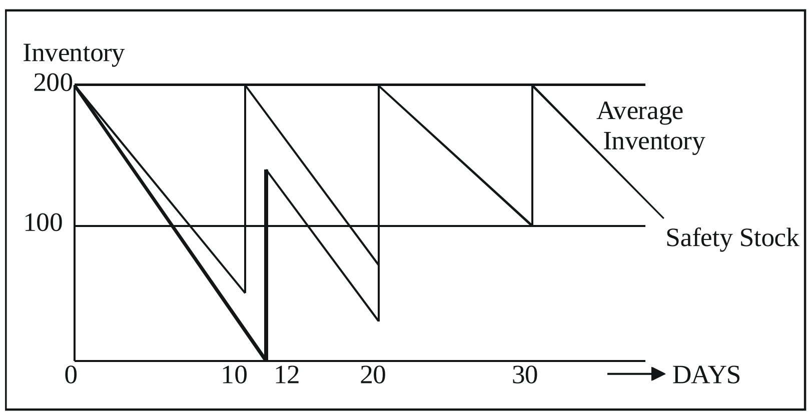
4. **Both consumption rate lead time varies:** As in the previous examples, let the consumption rate (CR) increase to 25 units/day, and lead time increase to 12 days.

The inventory would become zero on day 6, i.e., there would be a stockout for 4 days at 25 units per day, i.e., stockout of 100 units in total.

Therefore, a safety stock of 100 units would be required to be maintained, to take care of variations in demand.

The average inventory would therefore be 200/2 + 100 = 200 units.

This can be represented diagrammatically as follows:



Based on these four situations, one decides when to order an item. By the same logic, there are two parameters which decide when to place an order. They are,

- Quantity
- Interval between orders

A combination of these two parameters could lead to four situations.

1. Both quantity and interval between orders are fixed.
2. Order quantity is fixed but interval between orders is variable.
3. Order quantity is variable but interval between orders is fixed.
4. Both order quantity and interval between orders are variable.

12.4 DEPENDENT ITEMS AND INDEPENDENT ITEMS

NOTES

The risk of carrying additional inventory depends on the nature of the demand. Each type of demand carries with it a different type of risk. And this adds to the cost and quantum of inventory held by the organization.

For example, marketing experts hold Edsel designed by Ford Motor Company as a supreme example of corporate America's failure to understand the nature of consumer demand. Edsel was created as an automobile that would meet consumer demands for a new generation of Americans. It was the hot new car that everybody was talking about. It turned out to be a major failure. The company suffered greatly because it did not consider the risks associated with getting the figures wrong.

Inventory items can be classified into two broad categories: Independent demand, and dependent demand items. In inventory management it is important to distinguish between dependent and independent demand.

An item has an independent demand when it cannot be controlled or tied directly to the demand of another item. The Ford case was an example of independent demand. Though Ford tried manipulating demand through pricing incentives and other marketing efforts, Edsel failed. As the results of the Edsel show, the firm can try to predict or influence independent demand, but independent demand for the product is ultimately determined by the marketplace.

In order to predict independent demand, firms use different types of forecasting methods. Forecasting looks at the marketplace to determine how much of the product the consumers want.

In forecasting, both the accuracy of data and the method are important. It is important to know the source of the data as well as if it is useful. Several applications can be considered to decide the best method. The input and the quality of the output is equally important. Feedback on the output makes it possible correct any mistake that might have occurred during the initial input of data. The first thing one should look at is the various methods used in various situations.

Manufacturing requirements are primarily derived from dependent demand, while retailing requirements basically depend on independent demand. Dependent demand is by far the most common type of demand. An item has dependent demand when its demand is directly controlled or tied to the production of some other thing. Continuing with the Edsel example, let us suppose Ford decided to manufacture 15,000 units of the automobile for the first year on the basis of a forecast of independent demand. Based on this forecast, Ford knew exactly the time and the number of steering wheels needed. This is because the demand for the item is dependent on the production schedule of 15,000 automobiles for the year. The steering wheels has dependent demand because:

- The demand is controlled by the firm through the production schedule.
- Their demand is linked to the automobile production.

Dependent demand in a manufacturing unit is based on the components or subassemblies or raw materials that are part of the Bill of Materials (BOM) for the finished items. These items' demand is indirect or comes from the demand of the finished products.

12.4.1 Materials Planning

NOTES

Inventory is predicted on whether demand is derived from an end item or is related to the item itself. Since independent demand is uncertain, extra inventory needs to be carried to reduce the risk of stocking out.

To determine the quantities of an independent item that must be produced, firms usually use a variety of techniques, including customer surveys and forecasting. However, a balance is sometimes difficult to obtain because of the difficulty in estimating stockout costs, as was discussed in the last section. It is generally difficult to accurately calculate the effects of lost customers, lost profits or late penalties.

An analysis of inventory is useful to determine the level of stocks. Analysis of inventory is carried out through a number of models for stock-keeping decisions that specify:

1. When should the items be ordered?
2. How large should the order be?
3. 'When' and 'how many to deliver'?

Economic Order Quantity (EOQ) models, due to their simplicity and versatility, are often used for material planning when independent demand is the most important issue. EOQ models are simple models which base their decisions on the historic data to arrive at an average consumption for a given period. Given the average lead time for the item, it is possible to calculate the quantity that needs to be maintained in inventory till the material is replenished. Once the quantity reaches that level, an order is placed based on the economic order quantity.

EOQ is a simple technique that works. There are a number of variants of the technique, mainly differing in the quantity that is ordered or on the timing of the order. The assumptions of these models are:

- The demand is fairly regular
- The supplier supplies the material within the lead time
- The material is available relatively easily in the market
- The material is delivered as a single package

These models work well for planning inventories, only when the above assumptions are true. But the question is: how many of these assumptions are true and for how many items?

Materials Requirement Planning (MRP) considers both independent demand and dependent demand. It uses the basic principle that external demand is generally independent and internal demand is generally dependent. It gets the independent demand and calculates the total demand by working downwards at the highest level of the bill of materials after deducting on-hand quantities. Once this is done for high-level items, the bills of material are exploded to calculate the components required. This process is repeated further down the levels till the raw material requirements are arrived at.

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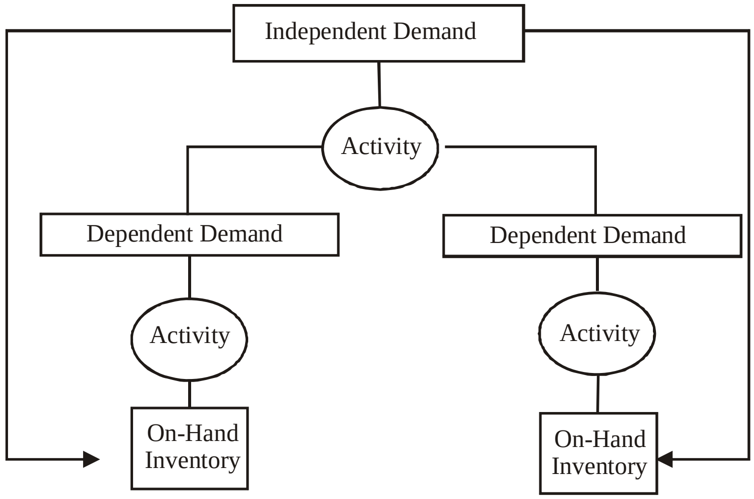

Fig. 12.1 *Independent and Dependent Demand in MRP Models*

12.4.2 Managing Independent Demand

It must be remembered that inventory is costly and large amounts are generally undesirable. As inventory can have a significant impact on a company's productivity as well as delivery time, different methods have to be found to reduce inventory. One approach is to reduce the risks associated with inventory. If risks are reduced, inventory levels can also be reduced.

It has been found that the risks due to independent demand can be reduced through process design. Process design can minimize the risk if we reduce demand uncertainty of independent demand by positioning the process from the push–pull point of view. What is the push–pull view?

Push–Pull view to modulate independent demand: Processes can be categorized into two types depending upon whether the execution is in response to an order of a customer or in anticipation of orders from customers–pull processes and push processes. Customer order initiates pull processes, whereas *push* processes are initiated and performed anticipating processes customer orders. In other words, in push independent demand has a high level of uncertainty, while in pull processes demand uncertainty is low as the process is initiated on the demand being known.

Figure 12.2 graphically shows the push–pull system in a retail network. It can be clearly seen from the dotted arrow in Figure 12.2 which represents the pull process, that the manufacturing and replenishment cycle is initiated when customer demand is known with certainty, i.e., it is executed after the customer order arrives. Whereas for a push process, represented by the solid arrows, demand is unknown and must be forecast as the customer order is yet to arrive.

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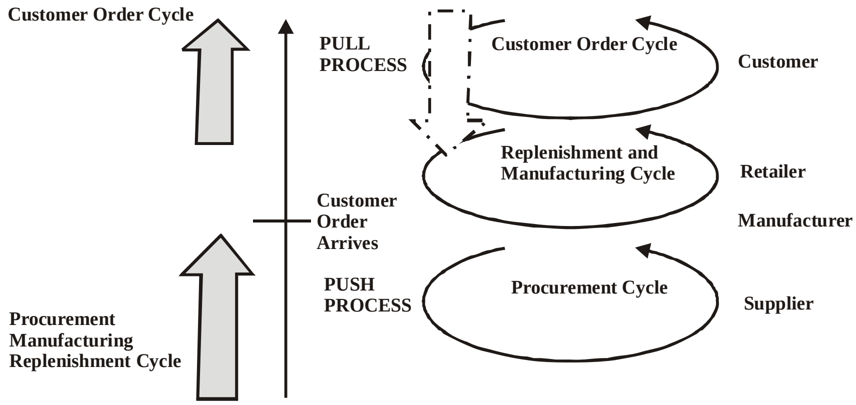


Fig. 12.2 *Push–Pull Processes for a Retail Network*

Based on the criterion of how they relate to the customer order, pull processes are called reactive processes as they react to the demand of the customer. Push processes are called speculative processes as they react to the forecast rather than actual demand.

Many processes combine both the push and pull systems. In a supply chain, the push–pull boundary separates push processes from pull processes.

A push–pull view of demand is very useful when considering inventory build-up. However, the systems to manage inventory in these two types of processes differ significantly. Inventory levels in push processes need to cater to the uncertainties in the demand forecast, while inventory for pull processes is dependent on the customer order only and therefore, safety stock that is meant to cater to demand uncertainties is significantly reduced.

A push process can become a pull process if the responsibility for some processes can be passed onto a different stage of the supply chain. For example, computer makers like Dell are moving to a pull system of dependent demand, where computers are built-to-order (BTO) and components can be obtained on short notice. In Dell's case, it takes them an average of 15 minutes to get the components as they use this in conjunction with a vendor-managed-inventory (VMI) arrangement.

One clear conclusion in studying these two processes is that a supply chain that has fewer stages and more pull processes has a significant impact on inventory reduction. Manufacturers are moving from a production push environment which is largely focused on production efficiency with large safety stocks to consumer pull environment which is focused on meeting expected consumer demand with a minimum inventory requirement.

The push–pull view has become very popular in modulating independent demand, as organizations using it find that it helps in bringing down unnecessary inventory and improves the number of times the inventory turns over, i.e., inventory turns. Both of these are measures of good inventory management.

Demand management: Demand management describes the process of influencing the volume or consumption of the product or service through management decisions. It is another technique available to the organization to reduce the uncertainty of independent demand. For example, air conditioner and refrigerator manufacturers offer discounts for their products in winter, when the demand for the products falls. Electricity tariffs in India are designed on slabs based on consumption. The idea is to provide incentive for reducing the consumption of electricity.

NOTES

The objective of such exercises of demand management is to help organizations use their resources and production capacity more effectively. As the demand for a particular product is high during the peak time, the costs are also high. Many organizations avoid this situation by offering price incentives or by using promotional strategies so that customers make purchases before or after traditional periods of peak demand.

The idea is to shift demand or to spread demand more evenly without losing the custom. Telephone companies all over the world provide special offers for calls made during late hours or at night. For instance, MTNL offered a 50 per cent discount for calls made after 10.00 p.m. but before 6.00 a.m.

The same principle is involved when doctors and other professionals require prior appointments to meet their patients and clients.

Both these concepts are very important in controlling the uncertainty associated with independent demand and are commonly used by organizations to reduce the negative impact due to the nature of the different types of demand.

12.5 BASIC MRP STRUCTURE

All processes begin with planning. In the given context, one needs to plan and calculate the requirements and schedules of the materials to be supplied, based on the demand. The time phased priority planning system is called materials requirement planning (MRP). It could be defined as 'a computer-based production management system that uses sales forecasts to make sure that needed parts and materials are available at the right time and in the right place'. MRP is a powerful tool in the planning and control of manufacturing inventories. It helps us to determine our procurement in terms of:

– What needs to be procured

– How much should be procured

– When should it arrive

The output of the MRP system would be:

- Current order releases to the purchase department and/or to previously selected suppliers, with firm due dates of delivery
- Planned order releases for the successive time periods

Below are the definitions of some commonly used terms.

1. **Dependant demand:** Dependant demand means the demand for an item is related directly to the demand for some other product. The item may be a component, raw material or subassembly. It should be remembered that demand for a company's end product may often be forecasted, but the demand for raw materials and component parts is not forecasted but calculated. The assumption generally made is that demand for the item in the inventory will occur at a gradual, continuous rate. However, in reality, in a manufacturing situation, demand for the raw materials and components may occur in large increments rather than in continuous units. Such demand is called lumpy demand. The large increments may correspond to the quantities needed to make a certain batch of the final product. MRP is the appropriate approach for dealing with inventory situations characterized by lumpy demand.

NOTES

2. **Lead time:** The lead time for a job is the time that must be given to complete the job from start to finish. In manufacturing, there is ordering lead time as well as manufacturing lead time. The ordering lead time encompasses the time required from initiation of the purchase requisition to the time the material is received at stores. Manufacturing lead time is the time required for the part to be manufactured/processed through the sequence of machines till the final product. MRP considers all these lead times. The order placement date is obtained from the date the material is required, after considering the lead time of the item. Each order when released in the time period shown by the MRP output should arrive exactly at the time it is needed by the next production stage.

12.5.1 Prerequisite Inputs for MRP

Three prerequisite inputs for making MRP work are:

1. Master Production Schedule (MPS)
2. Bill of Materials (BOM)
3. Inventory Records File

1. Master production schedule (MPS): Formulation of an aggregate plan is the starting point for MRP and is based on the expected receipt of a certain number of orders for a given family of products during the planning period. Various forecasting techniques are used to determine an approximate aggregate demand for the product family. The plan must be firmed up for a reasonable period of time because the overall production volume cannot be changed abruptly without incurring significant unplanned costs. Every production volume utilizes a given mix of labour, materials and equipment. When the output rate is changed, a new optimal mix must be achieved by readjusting the usage rate of the various resources. Even though it is possible to change in the long run, in the short run, it is difficult to do it efficiently.

The master production schedule is derived from the aggregate plan. It translates the aggregate plan into specific numbers of specific products to be produced in identified time periods.

The example below illustrates the difference between aggregate plan and master production schedule for a car manufacturing company.

Aggregate Plan **Figures in '000**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No. of cars	70	80	80	60	55	52	55	60	70	70	75	75

Master Production Schedule (For producing Cars) **Figures in '000**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Model A	25	30	30	25	20	20	25	20	25	25	25	25
Model B	30	35	30	25	25	22	20	25	30	30	30	30
Model C	15	15	20	10	10	10	10	15	15	15	20	20

The time interval used in MPS varies from firm to firm. It depends on the type of products used, the volume of production and the lead times of the materials used. This span of time that the MPS covers is called the planning horizon. Typically, within the framework of a six to twelve month aggregate plan, the master production schedule is updated weekly to reflect the changing sales demand and also internal problems which require scheduling.

NOTES

2. Bill of materials (BOM): The list of all the materials and their quantities required to manufacture an item is called its bill of materials. This is used for calculating the specific material requirement for a given production schedule during a specific time period. It is also called the product structure file or product tree.

3. Inventory records file: This comprises the item wise inventory records indicating the item as well as the quantities in stock, besides a host of other information with respect to every item in the inventory.

12.5.2 MRP Process

For an accurate MRP system, it is first and foremost essential to have an accurate MPS, accurate bill of materials and accurate inventory records.

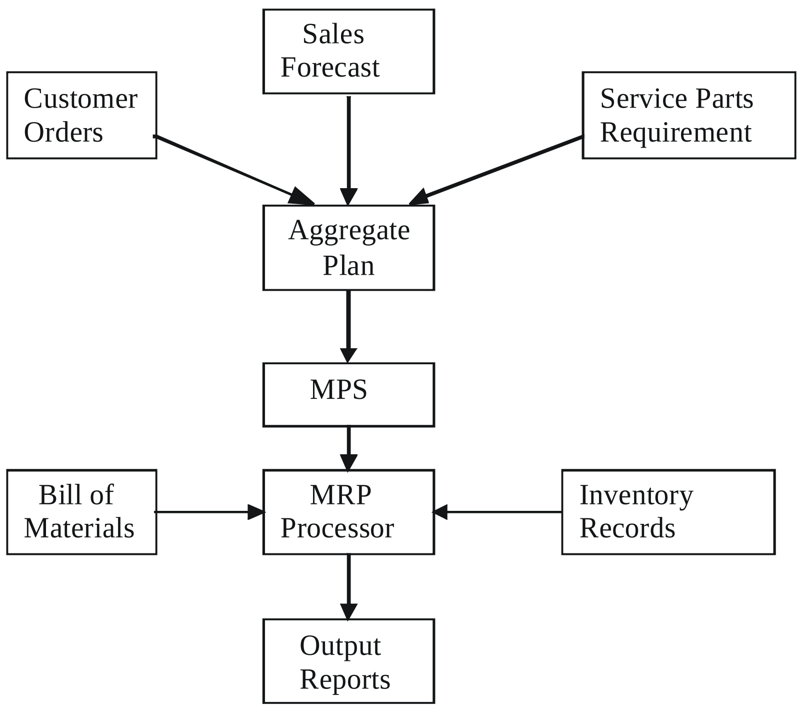


Fig. 12.3 *MRP Process*

The flow chart in Figure 12.3 illustrates the MRP process. The MPS, bill of materials and inventory records are fundamentally used to build the MRP system.

Every item to be manufactured/assembled requires some items of independent demand and some items of dependant demand. The independent demand items are forecasted and specified on MRP. The dependant demand items are calculated based on the bill of materials and the relationship of the products. For instance, suppose 1 unit of product A requires 1 unit of product B and two units of Product C; if 1000 units of Product A have to be manufactured, 1000 units of B and 2000 units of C will be required. Besides calculating the exact requirement, thus, MRP can also reschedule the requirement of B and C if schedule of A is changed.

NOTES

The next issue is the lead time. The time taken to procure the raw materials, component parts, subassemblies and assembling the final product are represented in the form of various levels depending upon the lead time each of them take.

For example,

Level 0 – End product

Level 1 – Assemblies and subassemblies

Level 2 – Component parts

Level 3 – Raw materials

Independent demand items are listed in the MPS at Level 0 in the bill of materials.

The MPS is first exploded to level 1to reflect the demand for assemblies. If there are enough assembles in the inventory to take care of production, it stops there. If not, MRP subtracts the available inventory from the demand to find out how many assemblies need to be ordered. MRP then offsets the assemblies' lead time to find out when the order is to be placed.

The MPS is next exploded to Level 2 to reflect the demand for component parts. If there are enough component parts in the inventory to take care of production, it stops there. If not, MRP subtracts the available inventory from the demand to find out the number of parts that need to be ordered. MRP then offsets the lead time to find out when the order is to be placed.

Similar process is the carried out for Level 3.

The purchase department then takes action to order, defer, expedite or cancel orders. The following example will help illustrate the same.

Example 12.1

Study the table given below.

	Time Period in months					
	1	2	3	4	5	6
Requirement	20		20	20		
Orders placed	20	20			20	20

For Period 1, 20 units are required and ordered. MRP recommends the order for 20 units. Inventory would be zero at the end of Period 1.

In Period 2, there is no requirement but there is an order of 20 units. MRP will recommend deferring the order to Period 3.

In Period 3, there is a requirement of 20 units but no order. If the order is not deferred in Period 2, there will be idle inventory for one period.

In Period 4, there is a requirement of 20 units but no order. However in Period 5, there is an order of 20 units. MRP would therefore recommend expediting or preponing the order to Period 4 so that there is no stockout.

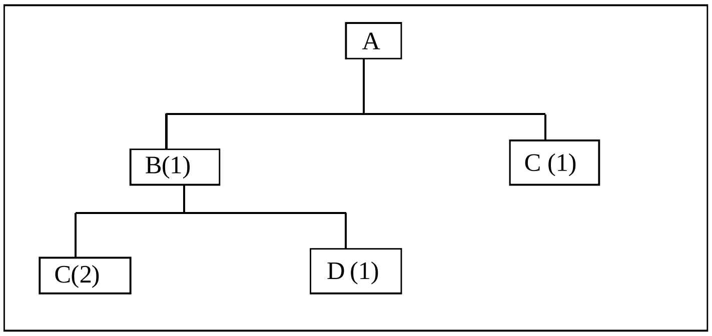
In period 5, there is an order for 20 units but no requirement. So MRP will recommend cancelling the order.

Thus, MRP is a very powerful tool which can adapt to change in requirement by manipulating the purchase orders suitably. It thus helps reduce shortages, improve productivity and minimize inventory.

NOTES

Example 12.2

Product 'A' is made up of one unit of 'B' and one unit of 'C'. Item B is made up of two units of C and one unit of D. Calculate the requirements of items B, C and D.



First the master production schedule for independent demand for product A is developed. Then its bill of materials is exploded to calculate the dependant demand for parts B and C.

Note: The steps have to be followed separately for each item.

Next find out the on-hand inventory and the due dates for receipt of the released orders. Based on this information, MRP will calculate the planned order releases.

Begin with item B. For this item, it is assumed that the order quantity is 10 units and lead time is 2 weeks.

Item	Time periods					
	On hand	1	2	3	4	5

Master Production Schedule

A		10		15		15

Requirements

B		10		15		15

Released Order Due

B				10		

Projected on-hand inventory (Taking into Account the Released Order Due)

B	10	0	0	–5	–5	–20

The problem on hand is that the inventory began with a stock of 10 units. This takes care of the requirement in Period 1. Supply of 10 units received in Period 3 will take care of the requirement in Period 3 but there will still be a shortfall of 5 units. There will be no stock to meet the requirement of Period 5.

The MRP, therefore, will recommend two orders of 10 units to be released so that stock is received in Period 3 as well as Period 5. At the end of Period 3, 5 units will be left behind. Another order of 10 units received in Period 5, will take care of the requirement of Period 5.

Planned Orders Due

B				10		10

Planned Orders Release (if lead time is 2 weeks)

NOTES

B		**10**		**10**		

Having worked out for item B, work out for item C. For C assume that the order quantity is 10 units and lead time is 2 weeks. Inventory available on hand is 25 units.

	Item	Time Periods					
	A	On Hand	1	2	3	4	5
Master Production Schedule	A		10		15		15
Planned Order Release	B		10		10		
Requirement for A	C		10		15		15
Requirement for B	C		20		20		
Total Requirement	**C**		**30**		**35**		**15**
Released Order Due	C		20			20	
Projected On Hand	C	25	15		-20	0	-15
Planned Order Due	C				20		
Planned Orders Release	**C**		**20**				

The problem on hand is that the inventory began with a stock of 25 units. The requirement in period 1is 30 units and a stock of 20 units also arrives. So there is a balance of 15 units.

In Period 3, 35 units are required but the stock is available for 15 units only. So, order should be placed for 20 units such that it is received in Period 3. In Period 4, a stock of 20 units arrives. This will take care of the requirement in period 5 and a stock of 5 units will be left over.

Similarly, one can work out the requirement of item D.

Most firms which use MRP systems run the program once a week. The computer system exports the requirement of materials to all the lower level components and prints out the planned order releases based on the minimum order quantities and lead times specified for each item.

The period between mid–1980s to mid–1990s was characterized by increasing technology and price competition, global and cross-functional business units, total quality concepts, more customer focus and efforts for more and more customer satisfaction. Manufacturers had to face very high pricing pressure caused primarily by increased competition and easy availability of goods globally. Further, competition was based on supply chain excellence. Companies realized that delivering excellent customer service profitably across complex global supply chain required excellent business processes, highly trained people and integrated software systems. All this forced the manufacturers to further evolve the MRP system and integrate it with other business and manufacturing functions. This evolved system is commonly referred to as the manufacturing resource planning (MRP II).

The MRP system studied above had certain drawbacks. They were:

1. It could not take into account variation in capacity.

2. It was unable to convert the operation/production plan into financial terms, hence, financial planning and control was not possible in this system.
3. It was not possible to simulate situations, i.e., if management asked 'what if…' questions, it was not possible to provide answers under this system.

NOTES

Initially, a Capacity Requirements Planning (CRP) module was developed and linked to the original MRP module. With further development in the master production schedule concept, most of the planning activities were integrated into a single planning and scheduling package. This integrated package was called a closed loop MRP system. This system was built around material requirements that included the additional planning functions of operations and sales (production planning, master production scheduling and capacity requirements planning). Once the plans are accepted, its execution begins. These include measurement of input–output (capacity) detailed scheduling and dispatching, reports of anticipated delay from both the plant and the suppliers, etc. The term 'closed loop' signifies that all these elements are included in the total system, and also that feedback is given by the execution functions so that the planning remains valid at all times.

The next step in the evolutionary process is the development of MRP II. This new system simply added two new capabilities to the closed loop MRP system. They were the financial interface and simulation capability. Ollie Wight termed it manufacturing resources planning to reflect the idea that the firm was becoming involved in the program more and more.

The fundamental manufacturing questions are:

- What are we going to make?
- What does it take to make it?
- What do we have?
- What do we have to get?

12.6 CAPACITY REQUIREMENTS PLANNING

As the master schedule is developed, rough-cut capacity planning is used to check the capacity requirements against capacity availability. But rough-cut capacity planning does not take into account lead time offsetting. MRP forms the basis for detailed capacity calculations.

The output of the MRP system indicates what component items will have to be produced and when and this output can, therefore, be converted into the capacities required to produce these items. The explosion of the MPS results in details on machine load or workload projections. The MRP then compares this with the available departmental and work centre capacities to answer such question as relating to overtime work, inter-departmental transfer of work/people, subcontracting of work, starting new shifts, hiring more manpower, etc.

The total capacity requirements placed on a work centre during a given time period is called load. The output of Capacity Requirements Planning (CRP) is usually in the form of load report or load profile which is a graphical representation of the load on each work centre by time period. This report provides visibility into the future and is based on valid order priorities. Hence, it facilitates capacity requirement planning by providing essential inputs for the capacity requirement planning system to function effectively.

12.7 DISTRIBUTION REQUIREMENTS PLANNING

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Finished goods inventory is finally a trade-off between inventory costs and schedule stability once the decisions on the distribution network are firmed up. Therefore, the goal of finished goods inventory is to manage inventory levels so as to bring down costs incurred from holding inventory and from adjustment to the master production schedule (MPS) to prevent stockouts.

As mentioned in the last section, as the number of distribution points increase, there is an increase in the average inventory held by the firm. The firm has little control on the inventory in transit, but safety stock can be reduced if the corresponding uncertainty in supply is reduced. This means that demand variability is a key determinant of safety stock. For achieving a high level of customer service, stock must be held as a buffer against this variability in demand. Therefore, inventory management becomes a struggle to minimize investment in inventory while meeting every customer order on time. This places a premium on the use of accurate demand forecasting techniques.

In real-life applications, demand distribution is seldom known accurately. Customer demand for finished goods is variable and unpredictable. In FMCG, the situation is further complicated by frequent sales promotions which are commonplace. Often, the information flows fails to provide required advance warning of a promotion, which causes further difficulties with a planned build-up of stock. These increase the demand variability and makes prediction more difficult.

It is highly important for companies to increase levels of service without increasing the investment inventory because the inventory amount required for meeting the levels of service is related directly to lead times and variability. Bringing down lead times and supply chain variability is also very important.

The variable demand problem is compounded by the variable lead time which is generally linked with delivery from production. A big cost in production is lost production due to machine resetting and changing products. Consequently, in most production shops, reduced manufacturing costs is achieved by planning long production runs which decrease changeover time. This enhances the variable lead-time associated with delivery from production. Often, sufficient advance warning of scheduled maintenance is not provided by production. Therefore, matching quantities of finished goods becomes difficult. Goods arrive in larger or smaller quantities than requested and in a sequence that may be different from the sales forecast.

In addition, the uncertainty of the future and unpredictability of demand and lead time and the lack of precision in forecasting need to be resolved. This is not only a cost but also a risk to the firm. In order to reduce uncertainty, the organization has to realize that these uncertainties exist and also find means to minimize their impact on the business.

Collaborative Forecasting is a technique for improving the accuracy and reliability in forecasting. An extended benefit of using CPFR is that it reduces the impact of the bull-whip effect and increases the trust and cooperation between members of the distribution chain. The problem still remains: how to optimize this complex system?

The most commonly used method is an extended application of MRP systems. This method is known as Distribution Requirements Planning (DRP). This technique is used for planning of distribution networks. DRP emerged as a major tool during the 1970s. By the 1980s, DRP became a standard approach for planning and controlling the activities of distribution logistics. The concept was extended to embrace all business functions in the supply channel and renamed as distribution resource planning (DRP II). DRP II is widely used not just for inventory and logistics, but a number of other functions required to minimize inventories.

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Distribution resource planning provides a framework to determinine the necessity of replenishing inventory by:

- Relating current position of inventory and demand forecasts to production scheduling
- Matching supply of material to manufacturing and customer demand to supply of product
- Linking market requirements with manufacturing and demand management

The logic of DRP very closely resembles the logic of MRP systems. Distribution networks in the retail business consist of a network of outlets, distribution centres and warehouses. Regional warehouses are get inputs from a national distribution centre and the regional centres provides inventories to the the regional outlets which in turn supplies the distribution chains at the local level. However, the following information are required by DRP:

- Future demand in a certain time period
- Scheduled receipts at the start of a time period
- Requirement of safety stock for a period
- On-hand inventory at the start of a period

By considering each level in the distribution network as a level in a bill of materials, the gross requirements, are first calculated. Orders or forecast demand, or some combination of both are used to arrive at the numbers. If orders are used, the orders placed by the distribution points will generate gross requirements at the different levels in the network, from local to regional and finally national. This structure is captured in DRP for determining finished goods requirement as per Table 12.1.

Table 12.1 **DRP Calculation**

Scheduled receipts:	**1200, periods**
On-hand inventory balance:	**1000**
Lead time:	**3 periods**
Order receipt:	**period due**
Lot size:	**600 unit per pallet**

Periods	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross Requirements	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**
Scheduled Receipts			**1200**					
On Hand	**500**			**200**				
Net Requirements					**300**	**200**	**100**	
Planned Order Receipt					**600**	**600**	**600**	
Planned Order Release		**600**	**600**	**600**				

Scheduled receipts are the goods that the distributor receives from orders already released. On-hand inventory balance constitutes the goods already received and are a part of the inventory. By subtracting scheduled receipts and on-hand inventory from gross requirements, the program determines the net requirements. On the basis of the lot-sizing policy and receiving behaviour of the distributor planned order receipts and capacity planning are made.

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All the nodes in the network including plants, distribution centres (DCs), stock transfer points and warehouses should be defined and the material master record for each node should be set up. In MRP 4 of the material master record, the deployment strategy for each material and also the deployment horizon (push horizon) should be defined. For the push horizon, the number of days for which the system considers the available-to-deploy (ATD) quantity and any additional quantity produced should be entered. The deployment calculation does not consider any quantity produced beyond the push horizon.

A forecast for each DC should be created and transferred to demand management. This system would create independent requirements. After this a DRP run in each DC and in each supplying plant can be performed. The arrangements of quota defined in the network, the stock available, sales orders and independent requirements would be considered by the DRP.

The DRP run in the DCs would create releases for stock transport requisitions in the supplying plants and planned orders for production. These would then be converted to production orders for manufacturing.

Table 12.2 **DRP Key Figures**

Demand Fence (between Day 3 and Day 4)

Day	1	2	3	4	5	6	7
Independent Req'ts	30	40	30	20	10	20	30
Sales Order	35	35	20	10	15	5	5
Demand	35	35	20	20	15	20	30
On Hand (50)	110	95	75	60	70	80	90
In Transit	95	20	∅	∅	∅	∅	∅
Target Stock	110	100	70	60	70	80	90
Safety Stock	10	10	10	10	10	10	10
Replenish Orders	–	–	–	5	25	30	40

Table 12.2 shows some DRP key figures. How these key figures are calculated is given below:

- Independent requirements are calculated for each distribution centre using statistical forecasting. The programme has a tool for this. You can also manually create the independent requirements.
- Sales orders are obtained from the sales force.
- The user defines the demand fence in MRP. The demand fence is represented in terms of days. It indicates the time during which certain types of demand contribute to the demand key figure. Beyond the demand horizon, the highest value of the sales order and the forecast is considered as demand.
- For selecting the types of demand within the demand fence, define a checking group and a checking rule for the demand key figures.
- The on-hand stock is calculated by the system using the initial stock (stock of the previous day) plus the stock in transit of the current day minus the current day's demand.
- The target stock level is calculated by the system by adding the sum of the forecast within the safety time (in this example, three days) and the safety stock for the current day.

- The safety stock is automatically calculated by the system and stored in the material master record.

The replenishment orders are calculated by the system by adding the target stock level and the demand and subtracting the initial stock. As should be apparent, DRP makes possible for the user to set some parameters of inventory control (like a safety stock) and calculate the time-phased requirements of inventories.

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DRP is usually used along with an MRP system, although generally DRP models are more comprehensive than stand-alone MRP models and are capable of scheduling transportation. The rationale behind using DRP is to forecast demand more accurately and then use that information for developing schedules of delivery. Like this, distribution firms by using MRP alongwith other scheduled can bring down inbound inventory.

DRP calculates the future requirements by taking into account the current inventory, adding shipments that are already on the way and subtracting the expected demand. Whenever the projected inventory becomes lower than the desired safety stock level, it calculates the desired shipment date from the plant on the basis of the desired time of arrival.

However, this simple logic of replenishment and shipment of traditional DRP is often not sufficient for the real-world situation. First, DRP ignores costs. Second, limitations of the real world prevent the ideal plan to become a reality. Finally, the distribution problem is much more complicated than reflected in most DRP modules. Due to these limitations and constraints, DRP often produces non-feasible plans. New systems using dynamic distribution logic are being developed to overcome these shortcomings.

Unfortunately, just as in the case of MRP I and MRP II, there are many problems involved with the implementation of DRP systems. The key reason for these failures is the problem of system integration that the implemented systems suffer from and problem of alignment between people, processes and new technology. The level of knowledge and experience available inside the firm prior to implementation is often inadequate. This often results in the organization not being able to realize the anticipated benefits or even to recover the cost of the implementation effort. However, despite these shortcomings, DRP has been a boon to many organizations especially those in the FMCG sector, significantly streamlining operations and reducing inventories and working capital requirements.

12.8 MATERIALS MANAGEMENT CLASSIFICATION SYSTEM

Irrespective of the nature and size of the industry, there are items varying from the smallest to the largest in terms of value, size, complexity and criticality. It is not possible and also feasible to exercise strict management control over all these items. It will only be too much effort with too little benefit. Hence, the principle of management by exception is applied here. The items are classified based on a certain criteria to facilitate selective control. Such control minimizes waste of efforts as well as confusions.

The various ways in which inventory can be classified are as follows:

1. **ABC analysis:** This is the most commonly used method of classification. It is based on the annual consumption value of the items and goes by the principle of ‘vital few, trivial many’. This means that a small number of items account for a major portion of the total expenditure, and there are several items which

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together are many in number but account for a small portion of the annual expenditure.

The actual percentages vary from one firm to another, but it can be taken as a general rule that 10 per cent of the items account for 70 per cent of the cost. They are called the class A items and require maximum attention. Similarly, around 70 per cent of the items account for only 10 per cent of the cost. They are called the class C items and should not be given too much attention. The remaining items are called class B items.

The ABC analysis is also called the Pareto analysis, developed by the Italian economist Vilfredo Pareto. It can be represented as shown in Figure 12.4.

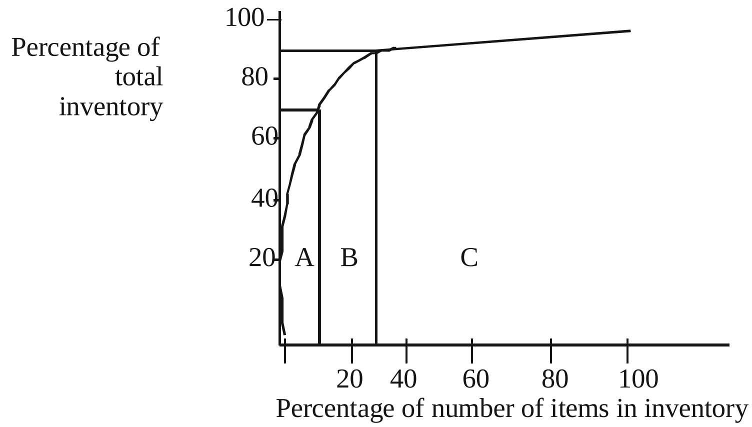

Fig. 12.4 *ABC Analysis*

This analysis is usually carried out annually. Once the items in the inventory have been identified, their usage record for the year is built. Then the items are sorted and ranked in the decreasing order of their consumption value. The value of each item is next expressed as a percentage of the total. By going down the list and successively cumulating the individual percentages for each item, one can determine which items make up the first 70 per cent of inventory investment, the next 20 per cent and the balance 10 per cent. The groups are called A, B and C respectively and the items within the group are called item A, B or C. Separate policies are usually adopted for class A items and class C items. Class C items need to be monitored on a daily basis, decision is taken on class C items based on the objectives of minimizing acquisition cost, maximizing service and reliability, minimizing inventory investment, minimizing indirect costs associated with inventory and utilizing personnel and their time effectively.

2. **XYZ analysis:** This classification is based on the stock value of the items. Items having a very high stock value are classified as ‘X’. Items with least stock value are classified as ‘Z’. The method of arriving at the classification is the same as for ABC classification. Only, instead of taking the annual consumption value into account, the annual stock value for each item should be taken into account. The rest of the procedure remains the same.
3. **VED analysis:** This classification is based on the relative importance of the item in the production process. If certain items are not available they can hold up production and result in high costs of shut down. These items may or may not be priced high but their stockout costs are very high. These items are

called vital items. 'E' stands for 'essential'. Although these items are not very critical to production their stockouts are expensive. 'D' stands for 'desirable.' It is better to avoid stockouts for these items although a stockout for a short period will not affect production.

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4. **FSN analysis:** Items can also be classified as fast moving, slow moving or non-moving based on their pattern of issue from the stores. This denotes how soon a material is consumed after it has been purchased and taken into stock. This classification helps in controlling obsolescence.

   Items which are very fast moving and are used once every week or every month are classified as 'F'. Items which are not consumed even once in say two or three years are classified as non-moving or 'N'. Keeping non-moving items in the inventory is dangerous. They block useful working capital and eat into the profitability of the company. The company should declare them as surplus or obsolete and find alternate uses of the material or else dispose them off, so that it leads to money realization as well as space saving. All items which are neither 'fast' nor 'non-moving' are termed as 'slow moving' items. This classification is again of great importance to companies who need to keep a check on where their money is spent.

5. **PQR classification:** Besides value and criticality of the items, another commonly used method to classify items is based on the shelf life of the item. Shelf life is defined as the useful life of an item, that is, the time period within which the item can display the complete characteristics, for which it is meant. Items having a low shelf life and thus requiring frequent attention are classified as 'P'. Items having the longest shelf life and thus requiring the least attention are classified as 'R'. All the other items which are not 'P' or 'R' fall within 'Q'. The time period in which to define 'P,' 'Q' and 'R' varies from industry to industry. This classification is more relevant in industries producing perishable goods, such as confectionaries, etc.

6. **SDE classification:** This classification is based on the ease of obtaining an item. 'S' stands for scarce. Such items are not easily available in the market and might require source development or else it might be an item which is difficult to manufacture or there are only one or two known manufacturers who have to be given orders several months in advance, and so on. All these require special efforts for procurement. 'D' stands for difficult to obtain and 'E' for easy to obtain. An organization need to concertedly focus on items that are both A as well as S.

7. **GOLF classification:** This classification is based on the nature of the source for an item. 'G' stands for government, O for open market, 'L' for local and 'F' for foreign sources of supply. Items which are channeled through the State Trading Corporations, Minerals and Metals Trading Corporation, etc., come under the 'G' category. They require special procedures for procurement and as such common procedures for inventory management may not be fully applicable to them. The transactions require more paperwork and lead times are longer. For 'O' items, there are a number of suppliers. Quality and availability is good. Most big organizations depend on the local market only for emergency supplies and low value procurement. For 'F' the source of supply is abroad, this involves considerable paperwork and lead time is high.

8. **SOS classification:** This classification is based on the the time of availability for an item. 'S' stands for seasonal and 'OS' for off-seasonal. This is more

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relevant in case of items which are derived from nature, such as jute, cotton, etc., which are available more during their harvest time and less available during the monsoons when it rains. They require separate purchasing and stocking strategies. The inventory management system will have to balance out between the stocking cost and lower prices at which it will be available. 'OS' items are ordinary items which are not seasonal and can be subject to any other classification for selective control.

9. **HML classification:** This classification is based on the unit price of material. 'H' stands for high, i.e., high price per unit of the item, 'M' stands for medium and 'L' for low unit price of the item. This classification is particularly relevant when it comes to deciding the procedure to be followed for procurement.

12.9 PURCHASE MANAGEMENT

Purchasing is the procuring of goods as per the need — either for further sale, use or storage — against payment of an optimum price. Purchase only pertains to goods and not services because services are hired. Purchase leads to possession and services cannot be possessed.

Purchasing is an integral part of 'operations management'. In business houses, a purchase cell, which is the part of marketing department, specializes in the techniques of procurement and makes the required goods available as and when they are needed.

Normally, a purchase order or supply order is issued to a source, also known as vendor. Purchases are made from reliable sources after ascertaining the right price, which may not necessarily be the lowest price, as the quality of goods and the reliability of the vendor are important criteria. The key is in buying the right quantity and quality of goods at the right time from the right vendors.

12.9.1 Meaning of Purchase Management

Purchase management is the technique of buying the right goods at the optimum price at the right time and from reliable vendors. It is a procedure for procurement of goods or services on cost-effective terms. The management must develop a reliable system for creating a flow of supplies. The purchasing must be done on the basis of need, at the time when the goods are required in the quantity that is necessary. Thus, the purchase procedure is a defined method of buying goods or hiring services to make them available when they are required. Goods may be purchased and kept in storage for future requirement, keeping in mind possible shortage conditions in the future.

12.9.2 Objectives of Purchase Management

The main objective of purchase management is to ensure availability of required goods or services, as and when they are needed by the organization. This is to maintain a proper flow of supplies of goods as per the specifications and on a cost effective basis. The objectives are aimed at achieving the following:

- **Right stores:** The acquiring of goods as per defined specifications.
- **Right quantity:** The procurement must be restricted to the quantity required to avoid creating surplus or deficiencies.
- **Right quality:** The quality specifications and quality assurance should be of high standards. The stores acquired should be inspected at the time of receipt.

Check Your Progress

1. What is a danger warning level?
2. State two parameters that influence the quantity of safety stock.
3. What is demand management?

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- **Right time:** The purchase should be done when the stores are required. Under certain conditions, the goods may be purchased before time and kept in storage for use in future, when shortage of supply is anticipated.
- **Right price:** Purchases are always made on the principle of *optimum price* and *cost-effectiveness*. The optimum price is the combination of cost and quality. Quality cannot be sacrificed over minimum price.
- **Right sources:** Reliable sources of procurement must be established to maintain the flow of supplies.
- **Alternate sources:** Multi-supply resources must be established so that if one vendor fails, a suitable alternative is available.

12.9.3 Principles of Purchase Management

Purchase management must develop a system of procurement with least lead time. The purchase cell is the part of marketing department that works as an integral unit of the organization and contributes by ensuring savings in procurement, being cost effective, and avoiding both stockouts and overstocking.

- **Cost-effectiveness:** Procurement should be done on optimum costs combining reasonable prices with high quality of goods.
- **Least lead time:** The time between the placing of order and receiving the goods, also known as lead time, should be as little as possible. Many companies have achieved zero lead time by applying just in time (JIT) techniques.
- **Vendor development:** A panel of reliable vendors should be maintained at all times, keeping in mind possible alternative sources of supply.
- **Quality:** Quality standards are never compromised.
- **Specifications of goods:** The goods received must be as per given specifications, duly inspected before clearing the receipt of stores.
- **Stockout:** The flow of the supply-system should ensure that no stockout is allowed to take place.
- **Overstocking:** Overstocking should also not be encouraged it locks up wealth and eats away from the profit margins.
- **Centralized purchases:** Centralizing purchases has many benefits over a de-centralized system as it ensures competitiveness, cost-effectiveness and a vast vendor-base.

12.9.4 Purchase Procedure

A defined uniform purchase procedure is essential for purchase management. The purchase-procedure passes through the following stages:

- **Forecasting:** Depending upon past experience, the forecasting report is prepared much in advance. Forecasts can be based either on estimates given by manufacturers or surveys by the marketing department.
- **Requisition of requirements:** In any manufacturing unit, the production department floats the requisition for spares or other materials required by a certain date. The materials department consolidates the requirement and intimates the purchase cell to procure the stores required by a certain date.

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- **Tender enquiry:** Depending upon the details given, the purchase cell prepares tender enquiries and asks for quotations from listed vendors by a certain date.
- **Receipt of quotations:** The sealed quotations are opened by the designated authority in the presence of the vendors, on the date fixed. The purchase decision is taken after negotiations.
- **Comparative statement:** The comparative statement of quotations received is prepared and signed by the designated authority for assessment of pricing.
- **Supply order:** The supply order for stores as per the specifications and quantity required is placed for delivery by certain date.
- **Receipt of stores:** Correct stores are counted, weighed, measured and inspected before receipt is issued to the vendors.
- **Payment:** As per the laid down schedule, the payment is released to complete the transaction.

12.9.5 Negotiations

Negotiations are carried out as per the policy of the company with the lowest quoting vendor, called L-1, or sometimes with L-2 as well, to ensure that the stores are bought at the lowest market rates while not compromising with the quality. The negotiations are the part of the purchase procedure and a contract agreement is prepared when the negotiations are over. Effective negotiation is an art, enabling the purchase of quality goods at optimum cost. The negotiations are based on the following principles:

- **Prevalent rates:** Successful negotiation skills can be acquired by purchase managers either by experience or learning through studies to achieve lowest buying costs of required quality.
- **Vendor reliability:** The reliability of vendors is kept in mind while negotiations are carried out.
- **Warranty and guaranty:** Better and longer guaranty or warranty terms may be considered a bargain over pricing.
- **Payment schedule:** Delayed acceptance, payment schedule without interest may be considered a negotiation factor at the time of financial difficulties.
- **Technical assistance:** The longer maintenance of equipment by the vendor may also be counted as a bargain.
- **Long-term relationship:** Long-term relationships may be established with reliable vendors, who would willingly offer discounts.

12.10 STORES MANAGEMENT

A store or warehouse is a static unit in the material and product pipeline, necessary to match products in a timing sense with consumers', demand for storage of products. These two words, store or warehouse, are used interchangeably in management literature.

Many consider warehouses 'a necessary evil' that add costs to the distribution process. However, in the broader logistical spectrum, stores management plays a vital role to group products into assortments desired by customers.

A store is a godown or storage space, which a firm uses for storing or holding raw materials, semi-finished or finished goods, for different periods of time. It helps in the creation of time utility for raw materials, industrial goods and finished products. The basic nature of raw materials, parts and finished goods flowing through and between vast networks of facilities, makes stores management a labour-intensive process. Productivity has been an issue in stores management.

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The typical store receives merchandise by rail, road, car or truck. The items are moved to a storage area within the warehouse and piled in stacks. When customer orders are received, products are handpicked for placement on wagons and transported to the shipping area, where the merchandise is assembled and loaded onto delivery trucks. The description of the operations of a traditional store also explains the reasons for low labour productivity. It is low because few, if any, skills are required to perform many of the manual tasks.

However, despite this limitation, stores management has developed into a strategic tool with state-of-the-art systems capable of providing necessary manufacturing and retail support. Efficient stores management leads to reduced cost of material and parts storage and handling and optimized production for manufacturers producing products at multiple locations. A central store is used to maintain a basic stock of parts, which reduces the need of maintaining inventory at every assembly plant. With the use of consolidated shipments, products are purchased and sent to the supply warehouse which are distributed to the manufacturing plants when required. When fully integrated, the store is an important extension of manufacturing.

Stores management has become an integral part of JIT and stockless production strategies. The JIT concept reduces work-in-process inventory, but its success is based on the support of a highly dependable delivery system. Such logistical support is possible only through the use of strategically located warehouses.

On the outbound side of manufacturing, stores or warehouses also create the possibility of direct customer shipment of mixed products. The capability to provide factory-direct mixed product shipments enhances service capability of the marketing organization. As the level of competition in the marketplace increases, manufacturers capable of rapidly providing direct mixed shipments gain a competitive advantage.

Similarly, as the cost to retail stores for transporting small shipments makes direct ordering prohibitive, manufacturers and wholesalers have a need to utilize stores or warehouses to provide timely and economical inventory assortments to the retailers. At the wholesale level of the channel of distribution, the warehouse is a support unit for retailing.

Market-oriented stores management enables a firm in providing shorter lead times to the customers. This warehousing function is becoming more important, as companies and industries are utilizing customer services as dynamic, value-adding, competitive tools.

For the customer, direct mixed shipments have two specific advantages. First, the logistical cost is reduced, because of the ability to deliver full product assortment while also taking advantage of the benefits of consolidated transportation. Second, inventory of slow-moving products can be reduced, because they can be received in small quantities as part of consolidated shipments.

Technology has had a great impact on the quality of service, costs and operations of warehousing and improved the flexibility of stores management. Technology-based improvements, especially information technology, make it possible to respond to growing customer demands in terms of product and shipment profiles. With advanced information technology, warehouse operators can quickly react to changes in the market conditions.

Information technology also provides the resources to measure performance under a wide range of operational conditions. In the area of productivity, which is one of the areas of concern in stores management, technology has been used to improve configuration of stores systems, handling equipment performance and improved storage techniques.

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Strategic warehousing logistics planning has become a means to competitive advantage. It enables the organization in aligning the operations with the general business objectives. Such a network has objectives like increasing the speed of the product supply and thus speeding up the flow of cash. It also ensures a high growth of revenue for the companies which are a part of the chain. It increases the loyalty of customers through commitment and competence. It helps in keeping costs as low as possible, while providing excellent customer service.

12.11 ECONOMIC BENEFITS AND SERVICE BENEFITS OF STORES MANAGEMENT

The supporting rationale of stores management is to improve in the time and place capability of the total logistical system, both in terms of economic benefits and service. For example, including a warehouse or store in a logistical system for servicing a particular market segment may increase cost. These costs must be exceeded by the benefits of increased market share, revenue and gross margin to make the decision acceptable.

From a conceptual point of view a warehouse should not be a part of a logistical system unless it is fully justifies the cost-benefit basis. Some major benefits that can accrue from warehousing are discussed below.

12.11.1 Economic Benefits

Economic benefits of stores management can be quantified by the return on investment reflected in the direct cost-to-cost trade-off. For example, if including a warehouse to a logistical system reduces the overall cost of transportation by an amount thats exceeds the fixed and variable cost of the warehouse, the warehouse is economically justified. This means that the total costs have been reduced. Cost reductions are attainable through four basic economic benefits:

- Consolidation
- Break-bulk and cross-dock
- Processing/postponement
- Stockpiling

Consolidation: Shipment consolidation is when a warehouse gets and consolidates materials for a particular customer on a single transportation shipment. The benefit is getting the lowest possible rate of transportation.

The key benefit of consolidation is the combination of the logistical flow of many small shipments to a particular market area. By using such a program, the manufacturer can optimize the total cost of distribution. Figure 12.5 shows the consolidation warehouse.

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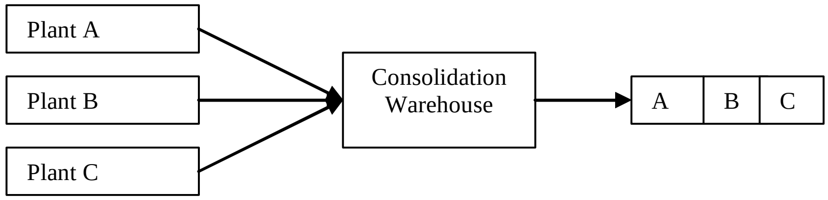

Fig. 12.5 *A Consolidation Warehouse*

Break-bulk and cross-dock: In break-bulk and cross-dock warehouse operations, there is no storage. A break-bulk operation gets combined customer orders from manufacturers, sorts or splits individual orders and delivers them to individual customers. Long-distance transportation movement is consolidated, lowering transport costs. Figure 12.6 illustrates the break-bulk operation.

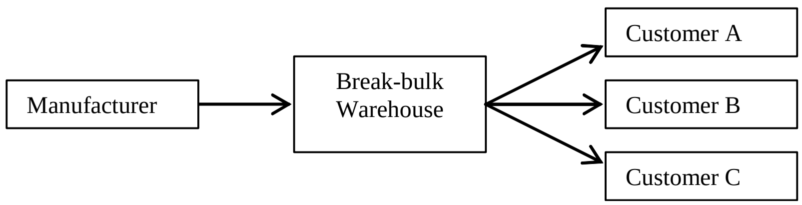

Fig. 12.6 *Break-bulk Operation*

A cross-dock facility is similar to a break-bulk operation except that its multiple manufacturers are involved in it. In this case, truckloads of product come from several manufacturers. The products are received and sorted by customers moved 'across the dock' for loading onto the truck to reach the appropriate customer. The truck is filled with mixed product from several manufacturers. Cross-dock operations are used extensively by retail chains for replenishing fast-moving store inventories.

Cross docking provides cost savings as full trucks move from the manufacturer's end to the warehouse and from the warehouse to the retailers. There is also reduced handling cost since products are not stored. Figure 12.7 shows the cross-docking warehouse operations.

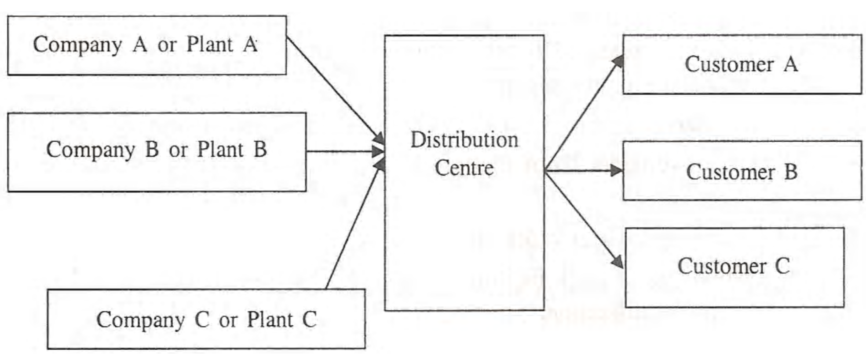

Fig. 12.7 *Cross-docking Warehouse Operations*

Processing/Postponement: Stores can also be used for postponing or delaying production. For example, a warehouse with the facility of packaging or labelling postpones final production until the actual demand is known. When it receives a specific customer order the warehouse can finish the final processing and finalize the packaging.

Two economic benefits are incurred from processing and postponement. First is minimization of risk as final packaging happens only when an order is received. Second, the total inventory level can be brought down by the basic product for a variety of labelling and packaging configurations.

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Stockpiling: In case of seasonal products like agricultural commodities, which are harvested at particular times, but consumed throughout the year or products like sarees, which are manufactured throughout the year, but sold mainly during festival seasons, such products require warehouse stockpiling. An inventory buffer is provided by stockpiling and it allows efficiencies of production within the limitations imposed by material sources and consumer behaviour while at the same time, supporting marketing requirements.

12.11.2 Service Benefits

Stores management enhances the time and place capability of the total logistical system. However, the cost-benefit basis of service is often difficult to quantify. Conceptually if the net effect of service contributes to an increase in profitability, it will be a service-justified warehouse. But, at the level of operation, the problem is the way of measuring the direct revenue impact.

The following are the basic benefits that can be achieved through warehousing from a service point of view:

- Spot stock
- Assortment
- Mixing
- Production support
- Market presence

Spot stock: Utilizing warehouse facilities for stock spotting takes place when a specified amount of product line of a firm is placed or 'spot stocked' in a warehouse for filling orders of customers during a critical marketing period in a variety of markets, which allows manufacturers with limited or highly seasonal product lines to substantially reduce delivery times to strategic markets.

For example, stock spotting is commonly used in physical distribution of agricultural products to farmers during the growing season. At the end of the season, the outstanding inventory is shifted to a central warehouse.

Distribution assortment: A distribution warehouse is used to stock various kinds of products anticipating orders from customers. It may represent multiple products from the manufacturer or special assortments of products as specified by customers. For example, a manufacturer supplying JIT components would stock products, so that it could be offered to the customer as and when required.

Distribution warehouses improve service by having inventory at hand to supply the principal products and also allow larger shipment quantities, which in turn reduce transportation cost. Figure 12.8 shows the distributed assortment warehouse.

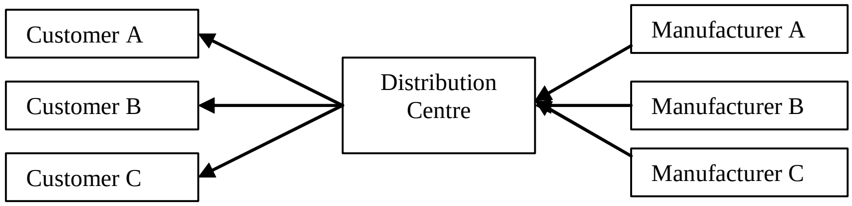

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Fig. 12.8 *Distribution Assortment Warehouse*

Mixing: Warehouse mixing is similar to the consolidation process. In mixing, truckloads of products are shifted from the manufacturing plants to the warehouses. When it arrives at the mixing warehouse, the products are unloaded and the required combination of each product for various customers or markets is selected.

In-transit mixing brings economies when plants are geographically separated, reducing the overall transportation charges and warehouse requirements. From the service point of view, warehouses that provide in-transit mixing have the net effect of reduced overall product storage and improved customer service as the inventory is sorted to precise customer specifications.

Production support: Production support warehousing meets the actual requirements of raw material, subassemblies and assemblies required for production in an efficient manner. It provides for safety stocks on items purchased from outside vendors, protecting against long lead time or significant variations in usage.

The different types of warehousing could be raw materials stores, processed or semi-finished materials store, finished goods store, yard store, and so on. The economics is reflected in the ability of providing the most economical total-cost solution by supplying or 'feeding' processed materials, components and subassemblies into the assembly plant in an efficient and timely manner.

Market presence: The major advantage of local warehouses is that they can be more responsive to the needs of customers and can offer faster delivery than more distant warehouses. As a result, a local warehouse increases the speed of delivery. In many cases, especially for FMCG products, this can result in increased market share and increased profitability.

12.12 WAREHOUSING STRATEGIES

Warehouses represent one part of a firm's overall effort to gain time and place utility. A warehouse should be established if it can render either service or cost advantages. The formulation of any warehousing strategy largely depends on the overall corporate objectives with regard to growth of the company expected to be achieved in future in general and logistical objectives in particular. Some of the objectives for the warehousing decisions may be as follows:

1. Level of availability of products or services to the customer
2. Level of availability and support for manufacturing
3. Degree of customer service to be offered/desired
4. Minimization of total distribution costs

Using a traditional classification, warehousing strategies can be divided on the basis of locational decisions. Warehousing can be:

- Market positioned
- Manufacturing positioned
- Intermediately positioned

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Market-positioned warehouse: This is typically positioned near the key customer locations to provide inventory replenishment to customers. The geographic size of a market area served from a market-positioned warehouse depends on the desired speed of delivery, size of average order and cost per unit of local delivery. The logic behind this decision is to take advantage of long-haul inbound transport consolidation from manufacturing points with relatively short secondary movement to customers. The service capability gets maximized and at the same time, it is also the lowest cost basis of providing logistical support in a dispersed market.

Market-positioned warehouses are operated by retailers, manufacturers and wholesalers. They may also serve as locations to assemble products for onward delivery to the customer. For example, Hewlett-Packard (HP) India utilizes warehouse facilities of Airfreight Ltd (AFL) in different parts of the country to store basic components like motherboards and RAM for their PCs. Once an order is placed, it immediately notifies the warehouse nearest to the customer, which assembles and delivers the final product.

A market-positioned warehouse may also store products from different origins and various suppliers. This strategy is used by retailers. As the demand for any specific product for a retailer is small in comparison with the total warehouse throughput volume, a retailer may elect to establish a warehouse to maintain rapid replenishment of a large inventory assortment at low logistical cost.

Other examples of market-positioned distribution warehouses are found in manufacturing logistical support, where components and parts are sequenced to enable JIT strategies. Location of a warehouse close to the customer is justified as the lowest cost way to meet the stringent delivery requirements that such systems demand.

Manufacturing-positioned warehouse: This type of warehouse is typically located close to the production plants and serves as an assembly and consolidation point for items being produced. Such warehouses facilitate shipment of product assortments to customers. Items are transferred from specialized plants, where they are produced, to the warehouse, from which full-line assortments are shipped to customers. This allows mixed-product shipments to customers at consolidated transport rates.

The consolidation enhances the ability of the manufacturer to provide superior service across a full product assortment. A manufacturer, who can offer a combination of all products sold on a single invoice at consolidated transportation rates, can gain competitive advantage over rivals.

This warehousing strategy is common to many clearing agents. DHL and Batliboi Impex, for example, consolidate consignments for export to give the customers the benefit on air or sea freight. Consolidation of cargo also helps to save ground rent or demurrage on project cargo, wherein the cargo can be stored in a warehouse and after consolidation can be moved to the port for filling into containers.

Intermediately positioned warehouses: Warehouses located between customers and manufacturing plants are intermediately positioned. These are similar to manufacturing-positioned warehouses and provide single shipments of broad inventory assortments at a reduced logistics cost. When products from two or more plants are sold to a single customer, an intermediate consolidation and assortment warehouse may be the least-total-cost logistics solution.

In the steel industry, SAIL steel plants maintain stockyards that serve consolidators for a variety of different steel components. Products from their plants at Bhillia, Durgapur and Rourkela are sent to the stockyards. Customers are offered full assortments of products on a single invoice and in one transportation vehicle.

12.12.1 Owner-operated or Private Warehousing Facilities

Once the basic strategy of the firm has been decided upon, it has the option of utilizing a combination of owner-operated and private warehousing facilities. Most warehouses seldom have full utilization throughout the year. As a planning rule, a warehouse designed for full-capacity utilization will in fact be fully utilized between 75 and 85 per cent of the time. For example, the owned capacity godowns of CWC have an average utilization of 87 per cent, while the average utilization of the hired capacity godowns is only 78 per cent. Therefore, from 15 to 25 per cent of the time, the space needed to meet peak requirements is not utilized.

A private facility may be used to handle peak seasons, while owner-operated facilities may cover basic year-round requirements. The use of warehouse combinations is dependant on the warehousing strategy of the firm.

Another reason for combined warehousing may result from market requirements. Most firms in India, due to the dispersed nature of the market, demographics and volume, do not have a formal distribution network beyond eighty largest towns in the country. In such a case, firms may find private warehousing as the least-cost option and justified at specific locations beyond their own network. The ultimate objective of system design is to determine whatever combination of warehouse strategies that most economically meets customer service objectives.

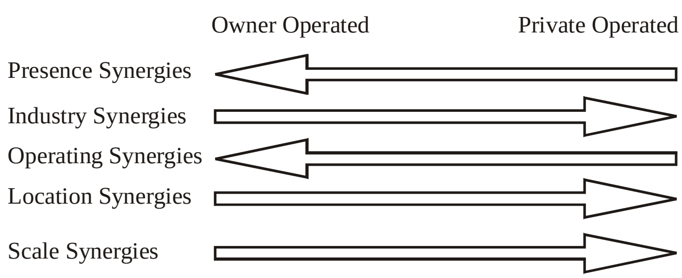

Fig. 12.9 *Qualitative Factors influencing Warehousing Strategies*

A number of qualitative factors are also likely to influence the decision, as shown in Figure 12.9. Across the top, the figure presents a strategy continuum, ranging from owner-operated to public warehousing facilities.

Qualitative considerations, listed on the vertical dimension of the figure are:

(1) Presence synergies
(2) Industry synergies
(3) Operating flexibility
(4) Location flexibility
(5) Scale economies

Presence synergies: It signifies to the marketing benefits of having inventories situated near the market owned by the firm. Customers generally feel comfortable if suppliers have inventories in nearby locations. Products benefitting from local presence should be served from owner-owned facilities.

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Industry synergies: It signifies the operating benefits of using warehouses, which also cater to other firms serving the same industry. For example, firms dealing in grocery often get huge benefits, if they share the facilities of public warehousing with other suppliers serving the same industry. This allows consolidated loads from multiple suppliers, reducing transportation cost. Private warehousing enhances the potential for industry synergy.

Operating flexibility: It signifies the ability to have flexible policies and procedures for meeting the needs of the products and customers. Since owner-operated warehouses are controlled by the firm, they usually provide more operating flexibility. On the contrary private warehouses can often afford to employ technologies that give them an edge on policies and procedures across its clientele. While one would think that owner-operated warehouses can offer more flexibility in operation, there are several private warehouses, especially 3PL operators, who demonstrate significant flexibility and responsiveness.

Location flexibility: It signifies the ability of quickly adjusting the location and number of warehouses according to the demand or seasonal changes. For example, demand for fertilizers and pesticides requires warehouses at mandis that allow easy customer pickup. Apart from the growing season, however, these local warehouses are underutilized. In such cases, it is often economical to use private and public warehouses, which offer the location flexibility under these conditions.

Scale economies: Private and public warehouses offer benefits of scale economies, since they can design operations and facilities for meeting the needs of multiple clients. Some of the better private warehouse firms are also expanding their operations to encompass a network of warehouses located in key markets. They provide an integrated service, which includes all the functions required to service a firm's customers, i.e., transportation, order processing, inventory control, warehousing and selected administrative matters. They are able to do so economically because of technology and scale economies.

Centralized stores show scale economies as they can reduce material handling and storage cost through the application of advanced technologies. With increasing volumes, warehouses usually have greater opportunities of achieving scale economies, because they can spread the fixed cost of technology over larger volumes. Additionally, capital investment in information technology and mechanized or automated equipment can bring down direct variable cost.

A centralized warehouse is more economical and easier to control in comparison to decentralized stores at various production centres. However, the decision depends on the nature of business, size and feasibility of operation of the individual business. The advantages of centralized stores are as follows:

(a) Less stock records
(b) Lower stock level and less investment
(c) Less expensive to administer
(d) Better supervision and control
(e) Better inventory control
(f) Bulk buying at lower cost
(g) Better security arrangements

The disadvantages of centralized control are increase in material handling, transportation cost, inconvenience and delay. Besides, the risk of loss because of flood fire, flood, etc., is higher. Any problem in the transportation system may disrupt the movement of materials with a resultant production loss avoid. To these difficulties, sub-stores should be there in addition to central stores. While this type of operation has some advantages, it also has some disadvantages as shown in Table 12.3.

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Table 12.3 **Centralized vs Decentralized Warehouses**

Centralized Warehouse Strengths	**Decentralized Warehouse Strengths**
Average inventory is small as compared to a decentralized facility.	Maximizes market coverage.
Centralized control of inventory. Safety stock can be reduced due to storing of goods at one/few locations.	Maximization of customer services creates a high level of loyalty and goodwill.
Demand variations in different market segments can be met at a short notice.	Transportation cost will be lower in case of part load shipments directly from the plant.
More amenable to capital investment in mechanized or automated equipment and information technology, which can reduce direct variable cost.	Better control over market and better coverage.
Centralized Warehouse Weakness	**Decentralized Warehouse Weakness**
Distant market's demand cannot be met in short notice as transportation cost may be excessive.	Larger inventory investment
Loss of customer service.	Higher investments in warehousing.
Poor market coverage and control.	Demand variations in different market segments can result in higher warehousing costs.

12.13 SUMMARY

This unit familiarized you with the concept of inventory management. Inventory is an organization's working capital blocked in the form of materials. Every company fixes certain levels for holding inventory. These are called stock levels. The various stock levels like reorder level, buffer stock level, stockout level and safety stock level have been discussed in this unit. Inventory items are broadly classified as independent demand items and dependent demand items. In this unit, you have learned how dependent and independent demands are managed. It also dealt with materials requirement planning (MRP), capacity requirements planning (CRP) and distribution requirements planning (DRP). You also learned the various ways of classifying inventories, such as ABC analysis, VED analysis, PQR classification and HML classification.

Further, you have learned about the just-in-time (JIT) system. JIT is a management philosophy that strives towards the elimination of sources of manufacturing waste by producing the right item in the right place at the right time. This unit also familiarized you with the concepts of purchase management and stores management. Proper stores management can reap various economic and service benefits. Finally, you have learned about the various warehousing strategies.

Check Your Progress

4. What are the benefits of warehousing from the service point of view?
5. State any three advantages of centralized warehousing?

12.14 KEY TERMS

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- **Inventory:** An organization's blocked working capital in the form of materials.
- **Reorder level:** The point when the stocks are just sufficient to meet demands during one normal lead time without dipping below the minimum level or into safety stocks.
- **Lead time:** The time that must be allowed to complete a job from start to finish.
- **Bill of materials:** The list of all the materials and their quantities required to manufacture an item.
- **Stockout:** The condition when required stores are not available in stock at the time needed.
- **Overstocking:** The condition when surplus stores that are not needed are lying in stock.

12.15 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Danger warning level is the level at which stocks are just sufficient to meet the demands during one normal lead time without getting totally exhausted and resulting in stockouts.
2. Two parameters that affect the quantity of safety stock are nature of the item and stockout cost.
3. Demand management describes the process of influencing the volume or consumption of the product or service through management decisions.
4. The benefits that can be achieved through warehousing from a service point of view are spot stock, assortment, mixing, production support and market presence.
5. Three advantages of centralized warehousing are the maintenance of less stock records, a lower stock level and less investment and being less expensive to administer.

12.16 QUESTIONS AND EXERCISES

1. What are the disadvantages of holding a large inventory?
2. Explain the factors influencing the determination of safety stock.
3. What is lead time?
4. Write a short note on capacity requirements planning.
5. How does DRP work?
6. Write short notes on any two of the following:
   (a) ABC analysis (b) FSN analysis
   (c) GOLF classification (d) SOS classification
7. Describe the MRP process.
8. Explain the various ways of classifying inventory.
9. Explain the purchase procedure in a large company.
10. What are the economic benefits of stores management?

12.17 FURTHER READING

Bedi, Kanishka. *Production and Operations Management*. New Delhi: Oxford University Press, 2007.

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