PRODUCTION AND OPERATIONS MANAGEMENT

DIRECTORATE OF DISTANCE EDUCATION

MBA
Paper 3.3

ALAGAPPA UNIVERSITY
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SYLLABI-BOOK MAPPING TABLE

Production and Operations Management

Syllabi	Mapping in Book
UNIT 1 **Introduction to Production and Operation Functions:** Functions of Production Management- Relationship between production and other functions -Types of Production or Manufacturing systems- Job and Mass production- industrial engineering- Manufacturing engineering- operations research- Toyota Production System- CAD and CAM- Automation in Production.	**Unit 1:** Introduction to Production and Operation Functions **(Pages 3-23)**
UNIT 2 **Capacity and Facility Planning:** Importance of capacity planning- Capacity measurement - Capacity Requirement Planning (CRP) process for manufacturing and service industry- Facility Planning - Location of facilities - Location flexibility - Facility design process and techniques - Location break even analysis.	**Unit 2:** Capacity and Facility Planning **(Pages 25-39)**
UNIT 3 **Production Process Planning:** Characteristic of production process systems - Process selection with PLC phases- Process simulation tools- Work Study - Significance - Methods, evolution of normal/ standard time - Job design and rating.	**Unit 3:** Production Process Planning **(Pages 41-68)**
UNIT 4 **Plant Layout:** Importance and function - Objectives - Work Flow patterns - Factors for good layout design - REL (Relationship) Chart - Assembly line balancing- Production Planning Control Functions - Planning phase- Action phase- Control phase - Mixed model line balancing- Aggregate production planning - Plant design optimization-Forecasting methods.	**Unit 4:** Plant Layout **(Pages 69-113)**
UNIT 5 **Material Requirement Planning (MRP) and Control:** MRP concept and process - Inventory control systems and techniques - JIT and Lean manufacturing- Embedded JIT and MRP - Network techniques.	**Unit 5:** Material Requirement Planning (MRP) and Control **(Pages 115-140)**
UNIT 6 **Quality Management:** Preventive Vs Breakdown maintenance for Quality - Statistical Quality Control: Control charts and Acceptance sampling procedures -Total Quality Management- 6 Sigma approach and Zero Defect Manufacturing.	**Unit 6:** Quality Management **(Pages 141-210)**

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INTRODUCTION

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Production and Operations Management originated at the time of the Industrial Revolution. However, it gained importance in the late 1950s when scholars realized the need to analyse production operations as a system in its own right. In recent times, 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 control of the resources of an organization in a manner that will facilitate the production process. In simple words, 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 business functions such as production, design and product performance operate smoothly in a manner that is not only efficient but also effective.

Operations management concerns itself with the production of quality goods and services, and ensures that business operations such as production function, design and product performance are executed efficiently. Production and operations management has tremendous potential and is gradually gaining a lot of prominence amongst all functional areas of management, irrespective of the size of the business. Firms gain an edge in numerous ways, for instance in terms of better quality products, reduced wastes, more inventory turns, better product designs, greater flexibility, etc., to name a few.

This book, *Production and Operations Management*, has been written keeping in view the requirements of management students of distance learning programmes. The book has several distinctive features and chief among them are as follows:

- Detailed coverage of the course material
- Segregating subject matter into easy-to-understand units
- Clear explanation of concepts along with illustrative examples

The text follows the SIM or self-instructional mode format wherein each Unit begins with an Introduction to the topic of the unit, followed by an outline of the Unit Objectives. The text is presented in a simple yet structured manner embedded with Key Terms and 'Check Your Progress' questions to test the understanding of the students. A Summary and a set of Questions and Exercises are also provided at the end of each unit for effective recapitulation.

UNIT 1 INTRODUCTION TO PRODUCTION AND OPERATION FUNCTIONS

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Structure

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1.0 INTRODUCTION

The process of production/operations management is aimed at combining and transforming different assets used in the production/operations subsystem of the organization into value added product/services, in a synchronized way according to the rules and regulations of the organization. Hence, it is that part of an organization, which is associated with the conversion of a variety of inputs into the requisite (products/services) having the necessary quality levels.

The combination of interconnected management actions, which are involved in manufacturing specific goods, is known as production management. If the same theory is stretched to services management, then the equivalent set of management activities are known as operations management.

1.1 UNIT OBJECTIVES

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

- Define the functions of production management
- Classify the types of production or manufacturing systems
- Explain the significance of industrial engineering, manufacturing engineering and operations research
- Discuss automation in production

Operations Management: The management of all activities directly related to the production of goods and services

1.2 FUNCTIONS OF PRODUCTION 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 a 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 operations'.

According to Sherin Siegel 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 that 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 rendering 'services'. This is what is meant by production and operations management (POM).

POM 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.

1.2.1 The Production Process

The production and operations of goods and services involve the conversion of input into output through a transformation process as shown in Figure 1.1.

Fig. 1.1 *Conversion of Input into Output*

1. **Input**: This includes the six Ms, i.e., man, machine, materials, money, method and management.
2. **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 sold to a customer. This value addition can be done in any of the following ways:

(*i*) **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.

(*ii*) **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.

(*iii*) **Storage:** This refers to preserving the goods in a protected environment so that these 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.

(*iv*) **Output:** Output can be in the form of either goods or services, or a combination of both. The major differences between goods and services are listed in Table 1.1.

Table 1.1 *Major Differences between Goods and Services*

Goods	Services
Goods are tangible; they have physical parameters.	Services are intangible. They are just ideas, concepts or information.
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.
They are produced in a factory environment, usually away from the customer.	Services are produced in a market environment in collaboration with the customer.
Goods are mainly standardized.	Services are often customized.
Quality is inherent in the product.	Quality is inherent in the process since it is a function of people.

As the complexities of organizations 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 the transformation process.

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

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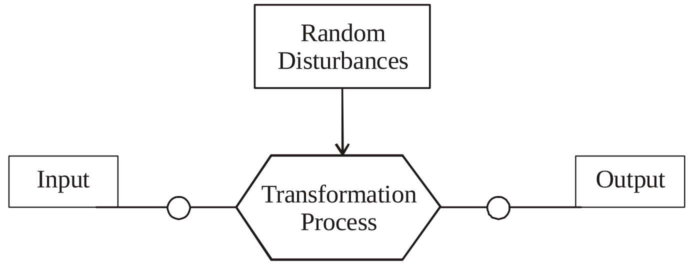

Fig. 1.2 *The Cycle of Production and Operations Management*

1.2.2 Objectives and Scope of Production Management

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:

1. **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:

   (*i*) Quality of the product as per acceptable standards

   (*ii*) Easy maintenance and reliability of the product

   (*iii*) Functionality of the product as offered by the seller

2. **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.

3. **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 operations 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.

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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.
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 and 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 and methods to ensure safety at workplace etc.

1.2.3 Production: Relationship with Other Functions

Production is the primary function of an organization. All other divisions or activities of an organization exist only if production exists. A business organization cannot exist if it does not have anything to produce or sell.

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

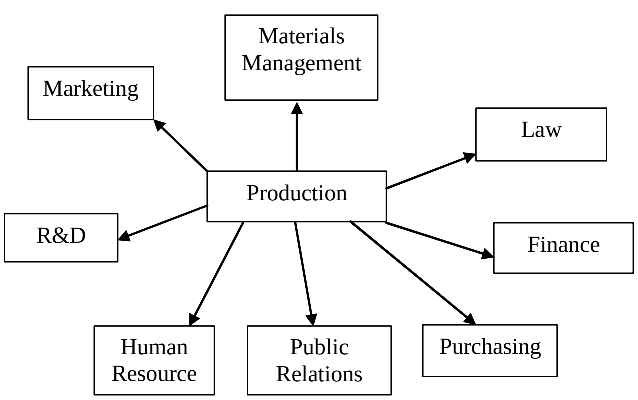

Fig. 1.3 *Departments of an Organization*

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- 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 that produces the goods and services. It plays a vital role in achieving a firm's strategic goals. 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 can say that production is the heart of an organization.

1.3 TYPES OF PRODUCTION OR MANUFACTURING 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. 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 1.4.

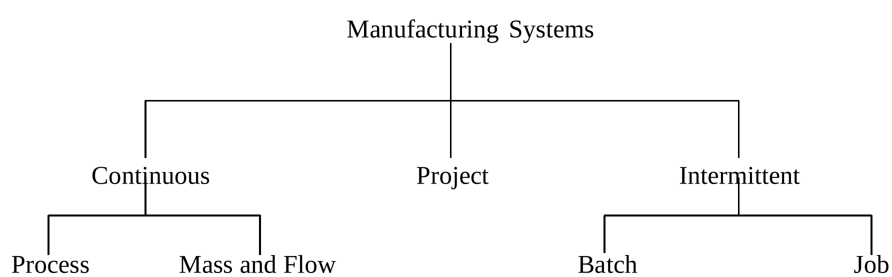

Fig. 1.4 *Classification of Manufacturing Systems*

Let us now learn about each of these systems.

1. Continuous Production System

It involves 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.

(i) **Process production:** The name is derived from the way materials move through the process. This system is used for manufacturing items for which

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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).

(ii) **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.

Characteristics of continuous production system

(i) Standard products are manufactured, which have large demand throughout the year. Production is usually 'made to stock'.

(ii) Standardized inputs and standardized sequence of operations, machine tools and equipment are used.

(iii) Division of labour is efficient and less supervision is required since the same or similar products are always produced.

(iv) Inventories are low and material handling can be streamlined. It will be lower than intermittent manufacturing system.

(v) There is a balanced flow of work. This will result in small work in progress.

Advantages of continuous production system

(i) Reduced labour cost because highly skilled workers are not generally required. Also, division of labour and job rotation is possible.

(ii) Once systems are set, strict supervision is not required since system takes care of itself.

(iii) High volumes of production, so cost is low.

(iv) Low inventories and reduced material handling.

(v) Minimum wastage seen as products are standardized.

(vi) Possible to use all the techniques of production control, material control/inventory, maintenance systems, etc.

Disadvantages of continuous production system

(i) Strict maintenance is necessary to avoid production hold-ups.

(ii) Adjusting to fluctuating demand is difficult as it takes time and capital investment.

(iii) Huge capital investment.

(iv) 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

(b) Mass or flow production.

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.

The two types of intermittent production systems are:

1. Job production
2. Batch production.

Job production: The production of a wide variety of products in relatively low quantities

1. **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.

2. **Batch production**: Here, items are processed in lots or batches and a new batch is undertaken for production only when the production of 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.

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.

Continuous and intermittent production systems—comparison

Continuous production

1. There is continuous flow of raw material.
2. It is 'made to stock'.
3. It is not flexible—change in the 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.

Intermitten production

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.

3. 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.

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Check Your Progress

1. How does the Association of Operations Management (APICS) define operations management?
2. Which is the primary function of an organization?
3. What is batch production?

1.4 INDUSTRIAL ENGINEERING, MANUFACTURING ENGINEERING AND OPERATIONS RESEARCH

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Operations Research: A discipline dealing with the application of advanced analytical tehniques to facilitate better and faster decision-making in business organizations

Operations research is a discipline dealing with the application of advanced analytical tehniques to facilitate better and faster decision-making in business organizations. Not surprisingly, it is also referred to as management science or decision science. So how exactly is it related to manufacturing and industrial engineering? This section will tell you how.

Using techniques such as mathematical modelling and optimization and statistical analysis, operations research comes up with optimal or near-optimal solutions to complicated decision-making problems.

Owing to its focus on human-technology interaction and practical applications, the discipline of operations research has a lot in common with industrial engineering, organization science and even psychology.

The role of Operations Research or OR, in the public as well as the private sectors is rapidly increasing. In general, OR addresses several issues related to inventory, production, transportation and communication. Therefore, it is indispensable in management. It facilitates the management of computer operations, risks, revenue, financial assets, etc.

In the public sector, OR is used in making important decisions related to healthcare, energy policy, water resources, defense and urban systems. It is an analytical technique of problem solving and decision-making that useful in the efficient management of organizations.

Industrial engineering is that branch of engineering that focusses on optimizing complex processes or systems. It is aimed at developing, improving, implementing and evaluating integrated systems comprising not just people, information, money, knowledge and equipment but energy, materials, analysis and synthesis. It also integrates mathematical, physical and social sciences with engineering principles and techniques for evaluation of the results or outcomes of such systems or processes.

While its basic concepts are similar to business-related disciplines like operations management, the engineering side focusses on mathematical proficiency and quantitative techniques.

Depending on the subdisciplines involved, industrial engineering may also be referred to as manufactuirng engineering, operations research, systems engineering or safety engineering. If the subspecialty in question is healthcare, those involved, such as health management engineers and health systems engineers could also be referred to as industrial engineers.

1.4.1 The Toyota Production System

TPS, short for the Toyota Production System, as the name suggests, was developed by Toyota and encapsulates its management philosophy and practices.

This system organizes manufacturing, logistics and interaction with suppliers, for Toyota. Originally known as 'just-in-time' production, it is based on the approach created by Sakichi Toyoda, the founder of Toyota along with his son and an engineer.

The TPS system is aimed at eliminating inconsistency, overburden and waste, that is, mura, muri and muda respectively.

The seven kinds of waste that the system addresses are related to:

1. overproduction
2. transportation
3. processing
4. stock at hand
5. movement
6. defective products

According to the system, reduction of inconsistency or overburden triggers several initiatives which drive out waste without specifically focussing on its reduction. Adoption of this system has made Toyota a leader in the automotive manufacturing and production industry.

The system is based on the way things work in a supermarket. A customer in a supermarket picks up what he wants in the desired quantity and pays for it. The store ensures that the shelf is restocked with sufficient amounts of new products to occupy the shelves. Similarly, a work-center requiring parts would go to a 'store shelf' (the inventory storage point) for the particular part and 'buy' (withdraw) the quantity it needs, and again the 'shelf' would be 'restocked' by the work-center that produced the part. It will make just enough to replace the volume withdrawn.

The primary outcome of the system is that only minimal inventory is required. Waste is intelligently eliminated. The main principles of the Toyota Way that forms the foundation for TPS are:

- Form a long-term vision and keep that in mind while meeting challenges
- Improve business operations on a continuous basis, always striving for innovation and evolution
- Get to the root of the issues and get all the facts correct before making decisions
- Respect and understand people you work and interact with
- Maximize individual performance and encourage teamwork
- Ensure personal involvement to understand matters

1.4.2 Operation Standards

Management must establish goals for evaluating the employee's performance. These goals are translated into standards. A production and operations standard is used for measuring or judging the output. The standard can be set for quality, quantity, cost, or any other attribute of output, and is the basis for control.

Standards at various levels in the organization

The standards at the various levels in the organization are:

- Individual standards
- Departmental standards
- Plant standards

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Individual standards

The terms standard and labour standard are often used in operations management. A labour standard is the output expected from an average worker under average working conditions for a given period of time. A standard for workers at the lowest level within the organization is expressed in terms of the time allowed per unit of output or output required per unit of time. For example, a candy making operation, in which coconut is sprinkled on soft chocolate, might have a standard of .01 minutes per piece or 100 pieces per minute.

Departmental standards

Several workers may perform as a unit or team. Every team may have a specific standard for the team's output. By adding all the individual and team standards together, managers can set department standards for quality, quantity, costs and delivery dates.

Plant standards

In the organization, a specified volume of goods and services must be produced. Labour and materials must be maintained, and at the same time their costs must be controlled. There is a greater need for accurate cost systems for labour, materials and overheads. The quality levels of the products must also be maintained.

Uses of operations standards

As a basis for making operating decisions, labour time standards are used to evaluate the performance of the workers; these standards also help in planning and controlling operations. The various uses of the standards are:

- Evaluating the performance of an individual
- Evaluating the performance of the various departments in an organization
- Evaluating process design, and work methods
- Calculating standard costs

Standard costs are computed in accounting as follows:

Standard cost = Standard usage * Standard labour rate

The standard usage is the industrial engineering established for the labour time standard. The standard labour rate is the accepted wage rate for the labour force that will be performing the work. If the standard usage and labour standard are incorrectly established, then the standard cost will show an error.

1.4.3 Industrial Engineering

Meaning and nature

Industrial engineering refers to the mechanism that deals with the designing, progress, enhancement, operation and estimation of the assembled structure of people, knowledge, tools, energy, material and process.

The reports acquired from such structure are predicted and analysed by industrial engineering using the engineering analysis theory along with the principles of mathematical, physical and social sciences. An industrial engineer works mostly for manufacturing a product with the purpose of reducing wastage of time, money, materials, energy and other resources. He designs plans and not machinery. Industrial Engineering is also identified as Operations Management, Production Engineering, Manufacturing Engineering, etc.

Applications

Most industrial engineers work in a manufacturing environment. Other industrial engineers might work in service environments as well. Industrial engineers thus cover a variety of fields where they usually work as:

- Plant Engineers
- Manufacturing Engineers
- Quality Engineers
- Process Engineers
- Methods Improvement
- Health Systems Engineers

1.4.4 Functions of Industrial Engineers

The basic functions of the industrial engineer are concerned with the following industry-related activities:

- Quality Control
- Manufacturing Processes
- Plant Layout/Material Handling
- Engineering Economy/Cost Estimating
- Time Studies/ Labour Cost
- Human Factors/ Safety
- Simulation/ Statistics

The duties and responsibilities of the industrial engineer vary greatly according to his field of endeavour. On the basis of the mentioned general activities, the basic functions and expertise of the industrial engineer can be classified into three categories of proficiency:

- Functions as per Product
- Functions as per Process
- Generic Functions

Functions as per product

Following are the functions of the industrial engineer as per product:

- In this category, the industrial engineer has to perform the following functions related to a specific product of his organization:
- Investigating the complete product design to decide about the steps involved in the whole process or operations. This calls for the knowledge of the in-house facilities.

- Determining the mechanism used for the manufacturing or assembling of the product(s) at each operation. This includes the concerned machinery, tooling, jigs and fixtures and safety equipments, which need to be constructed. The industrial engineer may be required to collect information about quality procedures and constraints such as ISO 9000 in the organization. This demands expertise in Health and Safety responsibilities and Quality policies.
- Estimating the time essential to execute the specified method, with due consideration to the operator's skills. This is used to rate the operation executed, to allow balancing of assembly, machining flow lines and the assessment of the manufacturing capacity required. This technique is known as Work Study.
- Defining the maintenance, handling and delivery methods and the equipment necessary for components and finished product. This ought to help in eliminating any possible damage.

Generic functions (medium term)

Following are the generic functions of the industrial engineer

- Determining the maintenance plan for the particular process.
- Surveying the variety of products involved in the process, then examining the possibilities of improvement in the process through a restructuring of the current facilities or by purchasing better equipments. This may call for the outsourcing of that process which in turn requires know-how of design techniques and of investment analysis.
- Revising the individual products involved in the process to recognize the cost that process adds, or to standardize the components, tooling or methods used.

  Functions as per Generically (long term)

  Following are the functions of the industrial engineer as per generically:

- Evaluating the flow of products through the facilities of the factory to assess the overall efficiency, and assessing whether the most important products have the priority of the most efficient process or machine or not
- Training new workers in the techniques essential for operating machines or assembling processes
- Planning projects to attain timely introduction of new products and processes

1.4.5 Techniques of Industrial Engineering

Following are the techniques that can be used in industrial engineering:

Quality assurance/quality control

Quality control is a series of activities performed to ascertain that no defective products or services are produced, and that the product design meets performance requirements.

Quality assurance covers all activities like designing, developing, producing, installing, servicing and documenting. 'Quality is free' is a universal dictum. It costs nothing to produce a commodity that works permanently, every time it comes off the assembly line. This necessitates a genuine effort on the part of the industrial engineer and also helps to reduce the cost of waste and rework.

Quality Control: A series of activities performed to ascertain that no defective products or services are produced, and that the product design meets performance requirements

Statistical process control usually progresses by a random testing of a fraction of the finished product. Testing every unit of the product is generally prevented, in consideration with the cost and time restrictions, and the possibility of product destruction. The variances of critical tolerances are constantly traced, and manufacturing processes are reformed before any bad parts are produced.

Another related technique is to operate samples of products until they fail. Then the resultant data is used to design improvements in the engineering and manufacturing processes. Sometimes very simple changes in the product can drastically improve the product service, such as changing to mould-resistant paint, or adding lock-washed placement to the training for new assembly personnel.

Many organizations utilize the statistical process control to bring the organization to 'Six Sigma' levels of quality. In a six-sigma organization, every item that creates customer value is controlled, to ensure that the total number of failures in a normal distribution of customers(setting a standard for failure of fewer than four parts in one million) are beyond this level. Examples of the items often controlled include; clerical tasks such as order entry and conventional manufacturing processes.

Producibility

Quite often, finished products have unnecessary precision, product operations or parts. Simple redesign can exclude these, thereby lowering production costs and increasing manufacturability, reliability and profits.

For example, some liquid-fuel motors are purposely designed to allow ugly (though leak-free) welding, to eliminate grinding and finishing functions that do not ensure better functioning of the motor.

Another producibility technique is 'near net shape forming'. The name denotes that the introductory production of the item greatly resembles the final (net) shape. Thus an optimum construction process can remove a number of low precision machining or drilling steps.

For example: 1) Precision transfer stamping can facilitate quicker production of numerous high-quality parts from generic rolls of steel and aluminium. 2) Die casting is used to produce metal parts from aluminium or sturdy tin alloys (they are often about as strong as mild steels). 3) Plastic injection moulding is a powerful technique, especially if the special properties of the part are supplemented with inserts of brass or steel.

With the rapid development of computer technology, digital signal processing software is beginning to replace many analog electronic circuits for audio and sometimes radio frequency processing.

In some printed circuit boards (attached inside the CPU), the conductors are so designed that they act as delay lines, resistors and inductors to reduce the parts count. A significant recent innovation was to remove the leads of 'surface mounted' components. At one stroke, this removed the need to drill holes in a printed circuit board, as well as clip off the leads after soldering.

Producibility is being considered frequently today in the initial stages of product design. This is a process referred to as 'design for manufacturability'. It is much advisable and money-saving procedure to consider the changes during the initial stages of design itself, rather than redesigning the products after their initial design is complete.

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To the industrial engineer, the initial designing of the product is thus of vital importance and he commands better knowledge of the market value and demands of the product.

Motion economy

In this technique, industrial engineers study the way workers perform their jobs. For example, in the case of a circuit board, they study how the workers or operators pick up the electronic components to be placed on the board and in which order these components are placed on the board.

Another example is that of chemical testing records. The industrial engineer studies the sequence of activities involved in chemical mixing records procedure and accordingly provides necessary steps required for testing. The aim is to save the time involved in performing a certain task and redistributing work so as to reduce the number of workers required for a given task.

Frederick Winslow Taylor and Frank and Lillian Gilbreths did much of the pioneering work in 'Motion Economy'. Taylor's work tried to study and understand the causes behind the fatigue of the workers in a coalmine, and also the ways to acquire greater productivity from the workers without additional man-hours. The Gilbreths devised a system to categorize all movements into sub-groups known as therbligs (Gilbreths spelled backwards).

Today industrial engineers often perform time studies or work sampling to understand the typical role of a worker.

1.5 AUTOMATION IN PRODUCTION

Automation means replacing human labour with machines.

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.

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" × 8", 300 pieces of 6" × 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.

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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.

Computer-Aided Manufacturing (CAM)

CAM: Computer control of the manufacturing process, such as determining tool movements and cutting speeds

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.

Flexible Manufacturing System (FMS)

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.

CIMS: The complete integration of CAD, CAM and FMS

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.

Robot: A programmable machine designed to handle materials or tools in the performance of a variety of tasks

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.

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!

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.

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.

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Check Your Progress

4. Fill in the blanks with appropriate words.
   (a) _________ _________ is that branch of engineering that focuses on optimizing complex processes or systems.
   (b) Management must establish goals for evaluating the employee's __________.
   (c) ______ assurance covers all activities like designing, developing, producing, installing, servicing and documenting.
   (d) ________ is being considered frequently today in the initial stages of product design.
5. State whether the following statements are true or false.
   (a) Statistical process control usually progresses by a consecutive testing of a fraction of the finished product.
   (b) Automation and advanced technology began in the 1950s with the development of numerically controlled (N/C) machine tools.
   (c) CAD involves computer control of the manufacturing process, such as determining tool movements and cutting speeds.
   (d) An FMS consists of two or more computer-controlled machines linked by handling devices such as robots and transport systems.

Automation in materials handling

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.

1.6 SUMMARY

- Production management comprises the processes of planning, structuring, guiding and managing the activities of the production function. It brings together and alters different resources used in the production subsystem of an organization into value-added product in a step-by-step way, according to the policies of the organization.
- The production process is associated with converting an array of inputs into outputs that are in demand in the market.
- Companies depend upon various types of manufacturing systems to produce its yield ranging from consumer goods to high-tech electronics.
- Three major systems of manufacturing processes are:
  - o Continuous production system
  - o Intermittent production system
  - o Project process
- Continuous production is a technique used for manufacturing, producing, or processing goods without disturbance.
- In intermittent production system, the cycle of production of short and comprises frequent change of machines for making various products.
- A project process is one in which there is a very high degree of customization and the job is undertaken to meet specific requirements.
- Industrial engineering is a division of engineering that is associated with the development of complicated procedures or systems.
- Manufacturing engineering generally relates to various practices of manufacturing; research and development of tools, series of activities, machinery and apparatus.
- Operations research refers to the application of scientific philosophy to business management, through a quantitative base for intricate decisions.

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- Automation of production is a process in the optimization of mechanical production in which management and keeping tabs on functions that were earlier performed by humans is transferred to automated devices.

1.7 ANSWERS TO 'CHECK YOUR PROGRESS'

1. 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'.
2. Production is the primary function of an organization. All other divisions or activities of an organization exist only if production exists. A business organization cannot exist if it does not have anything to produce or sell.
3. Here, items are processed in lots or batches and a new batch is undertaken for production only when the production of all items of a batch is complete.
4. (a) Industrial engineering
   (b) performance
   (c) Quality
   (d) Producibility
5. (a) False
   (b) True
   (c) False
   (d) True

1.8 QUESTIONS AND EXERCISES

Short-Answer Questions

1. How can value-addition be done in a transformation process?
2. What is the relationship of production with other departments of an organization?
3. What are the advantages and disadvantages of intermittent production system?
4. Give a detailed account of the various techniques of industrial engineering.
5. State the standards at various levels in an organization.
6. Define FMS.

Long-Answer Questions

1. Write a note on the functions and objectives of production management.
2. Discuss the various types of production or manufacturing systems.
3. Explain the features of industrial engineering, manufacturing engineering and operations research.
4. Compare and contrast the continuous and intermittent production system.
5. List and explain the various computer-aided systems used in production.

UNIT 2 CAPACITY AND FACILITY PLANNING

NOTES

Structure

2.0 Introduction
2.1 Unit Objectives
2.2 Importance of Capacity Planning
2.2.1 Methods to Modify Capacity
2.2.2 Capacity Measurement
2.2.3 Capacity Requirement Planning (CRP)
2.3 Facility Planning: Location of Facilities
2.3.1 Locating Foreign Operations Facilities
2.3.2 Location Flexibility
2.3.3 Location Decision Process
2.3.4 Location Decision for Warehouses
2.3.5 Facility Design Process and Techniques
2.3.6 Location Break-Even Analysis
2.4 Summary
2.5 Answers to 'Check Your Progress'
2.6 Questions and Exercises

2.0 INTRODUCTION

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. Capacity planning includes methods to modify capacity, needs, objectives, types and activities.

Machinery needs regular maintenance to retain efficiency levels. In this unit, you will learn about capacity planning including methods to modify capacity, needs, objectives, types and activities.

Capacity requirement planning is a technique of accounting method that is used in the determination of the existing productive capacity of a firm. Capacity requirement planning begins by assessing the agenda of production that has been designed by the company. Then it examines the company's authentic productive capacity and compares both, the planned and the actual productive capacities to find out whether the targets can be met with the existing production capacity.

Facility planning includes activities like planning and securing facilities site, facilities blueprint, facilities plan, or plant layout.

2.1 UNIT OBJECTIVES

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

- Explain the importance of capacity planning
- List the methods to modify capacity
- Define the capacity requirement planning process
- Discuss the significance of facility planning and its salient features

2.2 IMPORTANCE OF CAPACITY PLANNING

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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

- it is starting a new manufacturing unit.
- it is increasing volumes of an existing manufacturing unit.
- when new products are being introduced.
- when there is a change in demand - addition, deletion of products.

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.

2.2.1 Methods to Modify Capacity

Strategies to modify the capacity can be broadly classified into short term and long term.

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. ***Multi-skilling:*** 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.

Long-term methods

These methods take a long time to modify capacity. They can be of two types –

1. Capacity expansion
2. Capacity contraction

1. ***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.
2. ***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 50 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:

$$\text{Rated Capacity} = \frac{168 \times 50 \times 0.9}{4} = 1{,}890 \text{ tons/week}$$

2.2.2 Capacity Measurement

Capacity of a plant is expressed as the rate of output viz., units per day or per week or per month, tones per month, gallons per hour, labour hours/day, etc. But for organizations whose product lines are more diverse, it is difficult to find a common unit of output. More appropriate measure of capacity for such firms is to express the capacity in terms of money value of output per period of time (day, week or month). As a substitute, capacity can be expressed in terms of input. A legal office may express capacity in terms of the number of attorneys employed per year. A custom job shop or an auto repair shop may express capacity in terms of available labor hours and / or machine hours per week, month, or year.

Therefore, it can be stated that capacity is measured in terms of inputs or outputs of the conversion process. It must be remembered that since capacity is defined along with the constraints, the capacity measurements becomes subjective, as different interpretations of the terms are made by different people in the organization. For example, if the capacity is measured on the sale of products in rupees to dollars, the forex fluctuations will result in different results on capacity. Details of the industries and the capacity measurements are given in Table 2.1.

Table 2.1 *Examples of Commonly used measured of Capacity*

Type of business	***Measurement of capacity***	
	Resource available	***output***
Education	Faculty, Infrastructure	Number of Students Year
Automobile	Man-Machine hours	Number of cars/shift
Agriculture	Acres Cows	Tone of Grains/Year Litres of Milk/day
Steel Mill	Furance Size	Tons / Shift
Theatre	Number of Seats	Number of Tickets sold/day
Restaurant	Number of Tables	Number of meals sold/day
Oil Refining	Size of Refinery	Fuel oil/day

In service organizations, the capacity is measured in terms of homogeneous or heterogeneous service. For example, in the case of Insurance companies, the service offered is homogenous, i.e., it is based on the number of policies serviced per year. Banks and Transport companies offer heterogeneous services. Their offer is restricted by the availability of limited resources under their possession. For example, in banks, it is measured by the man hours available per week; and in case of transport companies, it is tonnage per kilometer.

2.2.3 Capacity Requirement Planning (CRP)

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Various ways to meet the capacity requirements of a product by the organization are:

- **Overtime**: The organization can fulfil its capacity by increasing the working hours of the employees. In this way, the organization reduces the extra cost of hiring additional number of employees for achieving its target.
- **Casual labour**: These are the labourers who are considered as permanent but work only when there are less number of full-time labourers. Casual labourers do not enjoy the benefits provided to the full- time labourers.
- **Inventory**: During the period of slack demand, the inventory of the finished goods can be stored so that it can be used when there is a high demand for the goods. In this way, the organization does not have to bear the extra cost of hiring additional or casual labourers.
- **Cross-training**: The organization can create some flexibility in its working environment by employing cross-trained employees who have the ability to perform any given operation of the organization.

CRP in service organizations depends on future demands to determine the available capacity, ability to translate prediction into physical capacity requirement, develop alternate capacity plans for matching required and available capacities, analyse the economic effects of alternate capacity plans, analyse the risk and other Strategic consequences of alternate plans.

2.3 FACILITY PLANNING: LOCATION OF FACILITIES

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.

1. 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,
     - (a) Locating buyers for used equipment will be difficult.
     - (b) 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:
     - (a) huge expenditure in shifting machinery, equipment, manpower, etc.
     - (b) time and added costs for taking new land lease/outright purchase, registration, etc.
   - (iii) If the company continues its operation at the wrong location
     - (a) It may accumulate losses.
     - (b) Competitors with better locations will have an edge.
     - (c) The company will lose market share/customer goodwill.

Check Your Progress

1. What is capacity planning?
2. Name the short-term methods to vary capacity.
3. Name the long-term methods to vary capacity.

2. Location facility is an issue for consideration either for
   Starting a new facility or for
   Starting additional facility
3. Additional or multiple facilities can be desired due to the following reasons –
   (i) Separate facilities for different products/services – e.g., 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 –e.g., LPG filling plants across the country to serve different locations.
   (iii) Separate facilities for different processes – e.g., Separate facilities to make pizza base.

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.

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.

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.

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.

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.

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.

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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. 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.

7. Environmental and Community Considerations

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.

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.

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.

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.

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.

2.3.1 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.

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.

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.

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.

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.

5. Share Prices and Goodwill

The market value of the firm may soar as international operations are deemed prestigious by investors.

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.

2.3.2 Location Flexibility

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There are certain factors based on location, which affect the productivity and profitability.

- Availability of Raw Material as inputs: Nearness to the place of the raw material will give advantage on the transportation cost, so that overall profitability can be improved. When the raw material is heavy or is consumed in bulk, then plant location has to be nearer to the raw material site.
- Nearness to Markets: It reduced the cost of transportation as well as the chances of the finished products getting damaged and spoiled on the way, especially the perishable products. Moreover, a plant being near to the market can capture a big market share and render quick service to the customers.
- Transport Facilities: Depending upon the size of raw material and finished goods, a suitable method of transportation like roads, rail, water or air is selected and accordingly the plant location is decided.
- Availability of Labour: Stable and reasonable labour force, governs the plant location to a major extent.
- Availability of Fuel and Power: The main sources of energy are electrical power, coal, oil, etc. In the case of power intensive industries like steel manufacturing units or continuous process industries like petrochemical and cement, the availability of fuel and power will be one of the major deciding factories in plant location.
- Climate: Depending on the type of industry and the products that are being manufactured, this is a different factor. For instance, in the case of textile mills climatic conditions with adequate humidity is a basic essential criterion. That is the reason many textile mills have been put up in Bombay, Coimbatore region.
- Water In industries like textile dying, paper or chemicals, the requirements of good quality water is one of the basic requirement for plant location. The water is required for processing or for effluent rejection into the rivers or specifically for waste disposal.
- Government Policies: The central and state governments may declare many talks as backward and give numerous concessions like tax holiday, uninterrupted power supply, capital subsidy, easy availability of loans, etc. for balanced development of regions in the country.
- Land: Topography, area, the shape of the site, cost, drain age and other facilities, the probability of floods and earthquakes will influence the selection of the location.
- Community Attitude: Industries like matches, crackers, hosiery and leather have flourished because of the positive and accepting attitude of the community.
- Housing facilities
- Security
- Existence of other infrastructure and service facilities like hospital marketing centres, schools, banks, post offices, clubs.

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2.3.3 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.

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.

Example 3

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		*Location Rating*		
		Factor 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.

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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.

Example 4

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 ₹ 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

(a) 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 = ₹ 150,000.

Qty	1000	2000	3000	4000	5000	6000	7000	8000
VC	75000	15000	225000	300000	375000	450000	525000	600000

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Check Your Progress

4. Fill in the blanks with appropriate words.
   (a) Companies ____ manpower during periods of high demand and lay off during periods of low demand.
   (b) When the plant is located near the customers/markets, the cost of transportation is low. This reduces the _______ cost.
   (c) __________ and Daman and Diu are declared 'no sales tax regions'.
   (d) _____ cost includes capital expenditure land, building manufacturing and equipment.
5. State whether the following statements are true or false.
   (a) The capacity of a company depends on the buyers and the sellers.
   (b) In the Chipko Movement, started by S.L Bahuguna, the locals embraced a tree each.
   (c) Fixed cost includes raw material, labour, etc., which are directly involved in the production process and are proportional to the volume of production.
   (d) Capacity is usually specified in terms of available hours, either for machines or labour.

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.

2.3.4 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.

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 out of stock 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 in Figure 2.1.

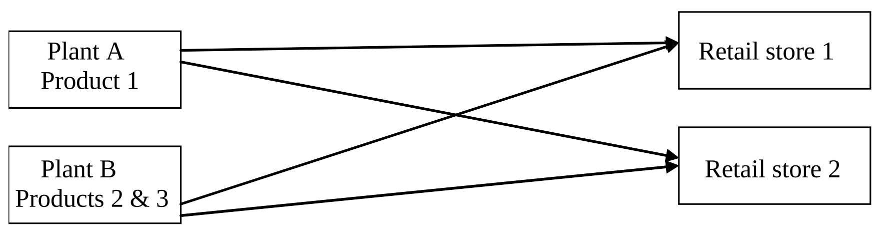

Fig. 2.1 *Distribution System*

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.

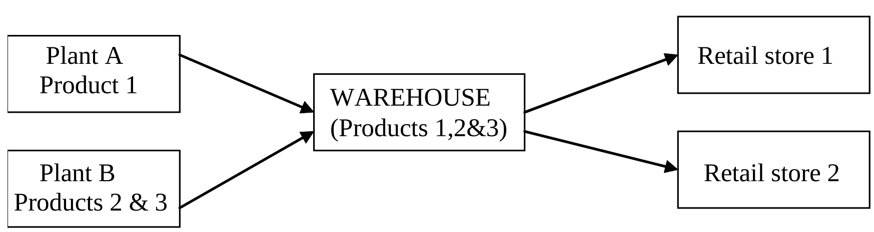

Fig. 2.2 *Warehouse Distribution*

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:

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- 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.

2.3.5 Facility Design Process and Techniques

The facility design process consists of the following 5 steps:

1. Defining the location objectives and associated constraints
2. Identifying the relevant decision criteria, which may be Quantitative or Qualitative
3. Relating the objectives to the criteria using appropriate models like
   - Economics cost models
   - Break Even analysis
   - Linear Programming
   - Qualitative Factor Analysis
4. Doing research to generate relevant data and use the models to evaluate the alternatives.
5. Selecting the location that satisfies the criteria.

Techniques used for facility location:

The following factors are observed

a. Industry Precedence – Succeedence Technique
   - The basic assumption is that if the location is best for many companies in the same industry, then it holds good for a new company too. There is no need for conducting detailed location study since the locations choice is subject to the 'Principle of Precedence'.

b. Preferential Factor
   - The decision is dictated by personal factor, individual preference

c. Dominant Factor
   - This depends on the availability of raw material, for example Cement, Oil exploration, Mining industries. And to existence of good infrastructure and skilled personnel

Now, for evaluating qualitative factors, the techniques used are Factor Ranking and Factor Weight Rating.

2.3.6 Location Break-Even Analysis

The economic comparison of location alternatives is facilitated by the use of Cost-Volume-Profit analysis which is also known as 'Location Break-even Analysis'. The graphical approach will help you to understand the concept as it provides an indication of the ranger over which one of the alternatives is superior to the others.

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Fixed Cost: Capital expenditure land, building manufacturing and equipment

Variable Cost: Raw material, labour, etc., which are directly involved in the production process and are proportional to the volume of production

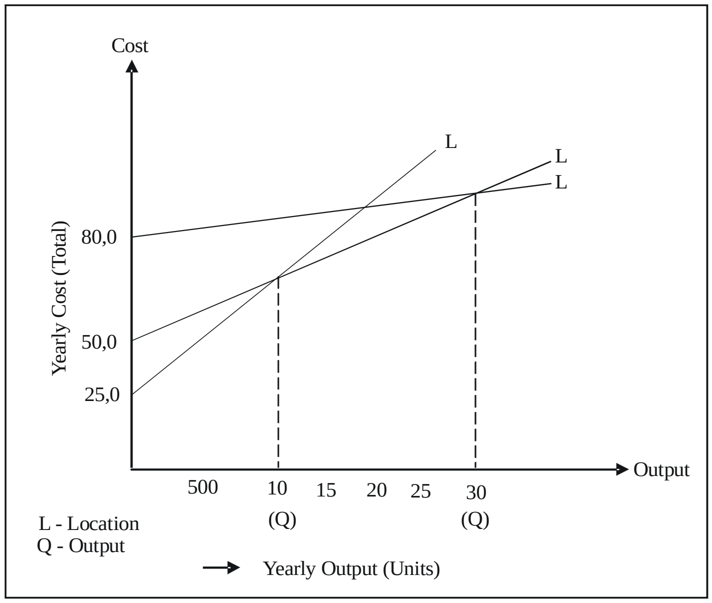

Fig. 2.3 *Location Break Even Analysis*

The procedure for the location break even analysis involves the following steps.

(i) Determining the **fixed cost** and **variable costs** associated with each location alternative.

(ii) Plotting the total cost lines for all location alternatives on the same graph.

(iii) Determining the location that has the lowest total cost for the expected level of output.

In the case of urban location, the initial fixed is very high and the variable cost is comparatively low. In the case of rural location, the initial cost is low but there is an increase in the slope, which is due to the high variable cost. The semi-urban location cost will be somewhere in between.

Hence, if the volume (i.e. annual output) is low, then we can select the rural locations for the purpose of establishing the factory. If the volume lies beyond a point, we can choose the urban centre for locating the plant. If the annual output lies between, it is better to locate the factory in a semi-urban area so as to reap the maximum benefits.

2.4 SUMMARY

- Capacity planning is the process of establishing the capacity needed to produce, by an organization for fulfilling the fluctuating demands of its customers. With reference to capacity planning, 'capacity' is the greatest amount of work that an organization can perform in a specific time.
- The most significant purpose of capacity planning is to bring down cost and increase productivity.
- Facility planning establishes the manner in which an activity's tangible fixed assets offer optimum support to achieve the activity's objective. This comprises activities like facilities location, facilities design, facilities layout, etc.

- The location of a facility means the way it is placed with reference to customers, sellers and other interfaces. In addition, the location also includes its location and adaptation on a particular piece of land.

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2.5 ANSWERS TO 'CHECK YOUR PROGRESS'

1. 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.
2. Short-term methods to vary capacity are: inventories, labour, process redesign, subcontracting and maintenance.
3. The long-term methods to vary capacity are: capacity expansion and capacity contraction.
4. (a) hire

   (b) product

   (c) Pondicherry

   (d) Fixed
5. (a) False

   (b) True

   (c) False

   (d) True

2.6 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What factors affect capacity planning?
2. Write the long-term methods to modify capacity.
3. What are the basic amenities that determine the decisions regarding choice of location?
4. Define the break-even volume.
5. Give some common productivity measures that can be used to evaluate customer service.

Long-Answer Questions

1. Explain the significance of capacity planning.
2. Write a note on capacity requirement planning process for manufacturing and service industry.
3. Discuss the factors that affect decisions regarding choice of location of facilities.
4. List and define the factors that should be considered while locating foreign operations facilities.
5. Explain the location-decision process. With the help of an example, demonstrate the process of arriving at the best location using the factor and location rating methods.

UNIT 3 PRODUCTION PROCESS PLANNING

NOTES

Structure

3.0 Introduction
3.1 Unit Objectives
3.2 Process — Design, Selection and Classification
 3.2.1 Classification of Process on the basis of Number of Steps
 3.2.2 On the Basis of 'Made to Stock' or 'Made to Order'
3.3 Process Design and Selection
 3.3.1 Parameters of Process Design and Process Selection
 3.3.2 Competitive Priorities
 3.3.3 Adoption of Appropriate Technology as per Market Requirements
 3.3.4 Process Design
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3.5 Work Study: Definition and Significance
 3.5.1 Objectives of Work Study
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3.8 Summary
3.9 Answers to 'Check Your Progress'
3.10 Questions and Exercises

3.0 INTRODUCTION

At its core, production process planning is the lifeline of any production process. It is aimed at minimizing production time and expenses, proficiently systematize the use of resources and make best use of efficiency in offices.

Production process planning comprises of an array of production basics, ranging from the routine activities of employees to the capability to comprehend precise distribution times for the customer. With an effectual production process planning at its core, any type of production process has the potential to make use of its full capability.

The association between process design and production is that of planning and execution. Process selection choices decide the nature of productive to be used and the suitable duration of that process.

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.

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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.

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. This unit defines work study, states its objectives and the techniques of measuring work/output.

3.1 UNIT OBJECTIVES

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

- Discuss the design, selection and classification of processes
- Explain process design and selection
- Define work study and explain its significance
- Evaluate the methods and evolution of standard normal time
- Assess the concept of job design

3.2 PROCESS — DESIGN, SELECTION AND CLASSIFICATION

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.

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

3.2.1 Classification of Process 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.

1. Single Stage Process

A single 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 3.1)

INPUT → PROCESS → OUTPUT

Fig. 3.1 *Single Stage Process*

2. 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. (refer Figure 3.2)

INPUT → STAGE-1 → STAGE-2 → STAGE-3 → OUTPUT

Fig. 3.2 *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:

Stage 1 → Stage 2

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.

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Buffering: The storage activity between two successive stages

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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 3.3.

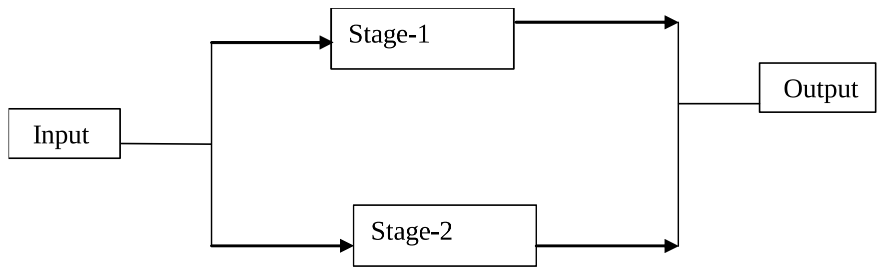

Fig. 3.3(a) *Simultaneous Activity*

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

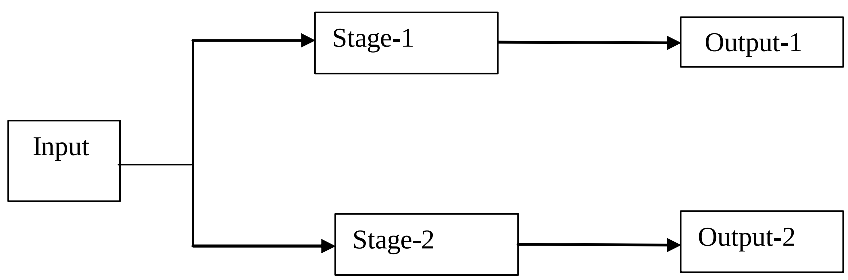

Fig. 3.3(b) *Simultaneous Activity*

3.2.2 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'.

1. 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.
2. 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 as 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

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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.

3.3 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.

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.

3.3.1 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.

3.3.2 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:

1. Cost
2. Time
3. Quality
4. Flexibility

Let us understand each of these in detail.

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1. **Cost**

   Lowering costs will increase demand and sales while increasing cost will improve profits (as profit addition becomes possible) 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.

2. **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 –

   (i) **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!

   (ii) **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.

3. **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.

   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.

4. **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.

   (i) **Volume flexibility:** Volume flexibility is most common and involves acceleration or deceleration of 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.

   (ii) **Variety flexibility:** 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.

   (iii) **Customization:** 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.

3.3.3 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

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Consistent Quality: The ability of a firm to produce the same set of goods consistently, meeting the prescribed specifications every time

Flexibility: The ability of a firm to react to the customers' changing needs quickly and efficiently

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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.

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.

3.3.4 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.

3.3.5 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-

1. Technical
2. 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

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Process Design: The selection of inputs, resources, workflows and methods needed to transform inputs to outputs

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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?

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.

3.4 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 3.4).

1. Volume
2. Product design
3. Process

Check Your Progress

1. What is a single stage process?
2. What are the four major competitive priorities of any firm?
3. What are the parameters of a product-process matrix?

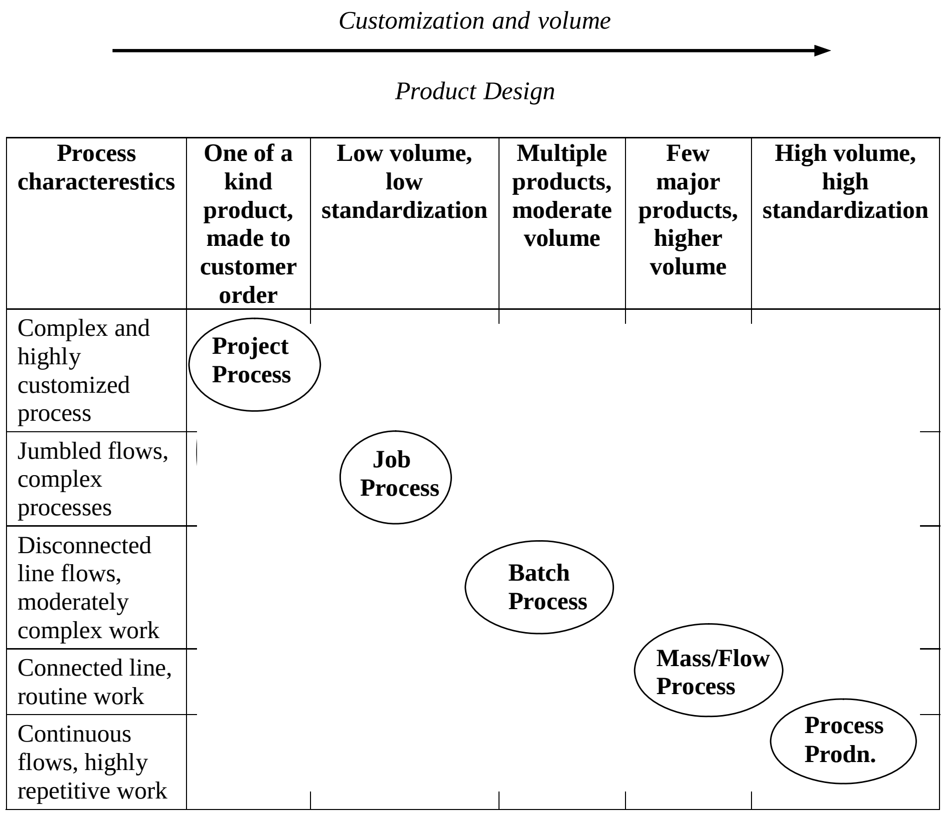

Fig. 3.4 *Product-Process Matrix*

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.

3.4.1 Process Selection With PLC Phases

Since fixed and variable costs tend to differ from one production process to another, economic analysis is used for comparing alternative processing plans for the production of products. When deciding among the types of production process in organizations, it is important to consider the cost of each alternative. Capital costs are fixed charges

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that occur every month. The fixed costs are greater when the initial cost of equipment, buildings and other fixed assets are high. The variable costs – the costs which vary with the volume of products produced in each month are also different for different forms of production processing systems. The amount of capital required for each type of process design tends to be different.

Automated assembly line has the highest fixed cost as it consists of expensive robotics, computer controls and fixed-position material-handling equipments. On the other hand, the variable costs, (labour, material and variable overhead) for the automated assembly line is the least.

The fixed costs and variable costs of cellular manufacturing are intermediate and for the job shop, the fixed costs are very low and the variable costs are very high.

Hence, if capital availability is not a factor and annual production costs (sum of fixed costs and variable costs) are the predominant factors, the preferred process design depends on the production volume of the product.

3.4.2 Process Simulation Tools

Simulation modeling has become a potential technology that is being used for a variety of operations management applications. Many technology driven companies rely on use of simulation to test new ideas and options before actual implementation of their ideas. It is possible to model and analyze the process and quantify and observe the behavior. Whether the system is a production line, a distribution network or a communications system, simulation can be used to study and compare alternative designs or troubleshoot existing operations. With simulation models, it is possible to explicitly visualize how an existing operation might perform under varied inputs, and how a new or proposed operation might behave under same or different inputs. The ability to easily construct and execute models and to generate statistics and animations about results has been the main attractions of simulation. The modern simulation software is windows-based, requires no programming, and hence, much easier to be learned by operations and production managers, who could then use it for a variety of daily operational issues including feasibility studies, detecting bottlenecks and process improvement. Application areas for simulation are practically unlimited. Simulation models are used for creation of workflows, layout, design, allocation, resource management, process change.

For example, in the area of customer service, simulation can be very helpful. Customer service is the ability of an organization to constantly and consistently give the customer what they want and in a timely fashion. Customer service processes can be telephonic services (call centers), service factories (restaurants), hospitals or retail stores. Simulation of customer service processes demonstrates a unique challenge because both the flow objects and resources are humans. Humans have much more complex and unpredictable behavior than products. Simulation modeling helps companies not only to find the best ways to improve customer satisfaction level without disrupting the current customer service processes but also it helps to see different aspects of customer service such as process flow, communication with customers, handling problems, and resolution of the problems and feedback.

Productivity

Productivity growth depends on finding better ways to produce goods and services. Simulation models are designed to mimic the process (or system) under study. Thus, the analyst has access to all variables and their values at any instant of time during the simulation. Some common approaches to productivity improvement are identification and removal of bottleneck in a process or operation, reducing inventory and work-in-process, and reducing cycle time

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3.5 WORK STUDY: DEFINITION AND SIGNIFICANCE

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'*.

Work Measurement: 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.

3.5.1 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:

(i) Eliminates drudgery, frustration and unhealthy working environment

(ii) Provides opportunity to e workers to increase their earnings (by achieving increased rate of output)

(iii) 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.

3.6 METHODS AND EVOLUTION OF STANDARD/ NORMAL TIME

3.6.1 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.

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

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 shown in Figure 3.5.

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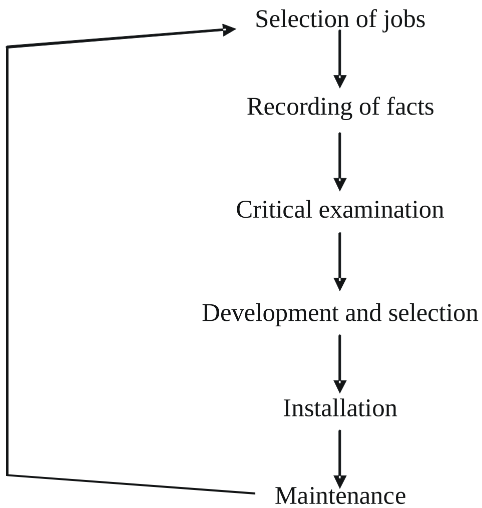

Fig. 3.5 *Flowchart of the Method Study Procedure*

1. 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

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(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

2. 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:

(i) ○ **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.

(ii) ⇨ **Transportation** This symbol indicates that the product, service or worker is moving from one location to another.

(iii) □ **Inspection** This symbol stands for checking/observing for quality/correctness/adherence to specifications, etc.

(iv) D **Delay** This symbol indicates that the subject of study (product, service or worker) has to wait before starting the next process.

(v) ▽ **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.

3. Critical Examination

Critical Examination: Analysing the facts related to a method

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:

(i) Purpose: Analyses whether the selected activity is necessary for completing a method or not.

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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?

(ii) 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?

(iii) 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?

(iv) 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?

(v) 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?

4. 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 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

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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.

5. 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.

6. 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.

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.

3.6.2 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.

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Work Measurement: A technique to find out the time required to do any activity, at a predetermined level of performance, by a qualified worker

Objectives of work measurement

The primary objectives of Work measurement are –

1. To establish the standard time for completing a job.
2. To fix the salary of employees and to determine and calculate incentives based on their performance.
3. To estimate the machine and labour requirements for planning and scheduling of production, the time required for jobs and when deliveries are possible, etc.
4. To distribute workload among the workers.
5. To calculate the number of employees needed for various tasks of the organization.
6. To determine the number and nature of machines that a worker can run.
7. To help managements accurately determine the costs incurred in Production.
8. To compare the efficiency of various alternative methods and determining the best alternative among them.
9. To establish standards for the performance of employees and utilization of machinery. This way, substandard workers can be identified.
10. To control costs by uncovering wastages of both machine and labour and thus help to increase the operating efficiency.
11. To track the performance of workers, their training needs, etc.

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.

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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 -

$$NT = \frac{\text{Time worked}}{\text{No. of units produced}} \times \text{Performance rating} \qquad \text{... 3.1}$$

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) ... 3.2

Note: Allowances may be given in minutes or as a percentage of the normal time

ST = NT (1+ Allowances) ... 3.3

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.

NOTES

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.
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:

- Work study is not economical in case of a short cycle time. In such cases time study is more appropriate.
- 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.
- 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 $50\ \{2 + .05\ (18 - 10)\} = 50 \times 2.4 = 120$ 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.

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.

3.7 JOB DESIGN AND RATING

Job design is defined as the integration of various individual activities or tasks into a job, which can be assigned to either an individual worker or a group of workers. In job design it is determined how a particular work is distributed within the organization. The job design specifies what tasks to be done, who will do them and what results are expected. Just as an architect can build a house in many different ways with many different materials, so can a manager design a job with many different approaches such as job specialization and job enlargement.

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Job Design: The integration of various individual activities or tasks into a job, which can be assigned to either an individual worker or a group of workers

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3.7.1 The Objectives of Job Design

A manager tries to realize the objectives of specifying jobs. The three main objectives are:

- Technical feasibility
- Economic feasibility
- Behavioural feasibility

Technical feasibility

A person is assigned various tasks or duties that he needs to perform. The person to whom a task is assigned must be capable of performing the task. A job must not be above the limits of a person's skills and physical and mental levels. Providing proper knowledge and training to the employees helps in ensuring technical feasibility.

Economic feasibility

The cost of performing the job must not be too high. It means that the worker's compensation and the appropriate work environment must be reasonable. Businesses are carried on in a competitive environment, so they are bound to face pressure to keep the prices of the resources at reasonable levels.

Behavioural feasibility

When a person is assigned many jobs and responsibilities, then he must be motivated so that he can perform the tasks efficiently. The job should develop a positive attitude among the workers by providing them intrinsic rewards.

3.7.2 The Approaches of Job Design

There are various approaches to job design that a manager uses to design the jobs, which are:

- Job specialization
- Job enlargement
- Job enrichment

Job specialization

An important consideration that must be kept in mind while deciding the tasks and responsibilities of an employee is to maintain a balance between the job specialization and the task assigned. In job specialization, the work is divided into small component parts and these components are assigned to specialists. When different works or tasks are assigned to the specialists, then they become more skilled and efficient in their field. Also a worker is easily trained to get him specialized to perform his assigned task with greater satisfaction.

The advantages of job specialization

The various advantages of job specialization are:

- Workers can develop greater skill and establish a better work rhythm, which results in high productivity.

- It is easier to train and supervise workers.
- It helps in reducing costs because a lower level of basic skills are required.

The disadvantages of job specialization

The various levels of job specialization are:

- There is no worker control and autonomy over what is done and how.
- It results in absenteeism among the workers.
- The work performed by the workers is of poor quality.

Job enlargement

Job enlargement can be defined as the expansion of job content that includes a wide variety of tasks and increases the worker's freedom and responsibility. At one point of time the workers may feel bored and dissatisfied by performing the same kind of work repeatedly. It may force them to withdraw from the organization. As a result, the organization suffers from high levels of absenteeism and attrition. If managers could enlarge the jobs by adding tasks and additional incentives then it could reduce the ill-effects of specialized jobs.

A job may be enlarged in two basic ways. A job design is said to be enlarged horizontally if the worker performs a greater variety of tasks without increased responsibility. For example, if the job of a worker consists in tightening one nut on one bolt, then it could be redesigned to tightening four different nuts on four different bolts. The job would then be enlarged horizontally. Secondly, more tasks of a different nature but similar skill level can be added. For example, instead of tightening one nut on one bolt, the worker could assemble two pieces of metal and a piece of plastic, tighten a nut and bolt to hold the assembly together. The job would thus be enlarged vertically.

Job enlargement offers the employees four opportunities, which are:

- **Variety**: The opportunity to use a variety of skill
- **Autonomy**: The opportunity to exercise control over how and when work is completed
- **Task identity**: The opportunity to be responsible for an entire program of work
- **Feedback**: The opportunity to receive current job performance information

Job enrichment

Vertical job enlargement is sometimes known as job enrichment. It involves redesigning jobs to give more enjoyment to the job by involving employees in the managerial functions of planning, organizing and controlling. This is a vertical change similar to the vertical job enlargement but the only difference is that managerial functions are added to it rather than adding similar tasks. For example, an organization that is engaged in the production of cornflakes is trying to sell its variety as the brand label for a larger grocery chain. Buyers from the grocery chain visited the organization to check the quality of the cornflakes. Two production workers were selected and brought directly into the organization's conference room where the boxes of the competitors and the company's cornflakes were displayed. The workers were asked to choose which of

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Job Enlargement: The expansion of job content that includes a wide variety of tasks and increases the worker's freedom and responsibility

Check Your Progress

4. Fill in the blanks with appropriate words.
   (a) Work study means study of _____ work.
   (b) A method study generally uses the _________ method to record facts such as completion time and labour required in a method.
   (c) Element times are measured in ____.
   (d) Vertical job __________ is sometimes known as job enrichment.
5. State whether the following statements are true or false.
   (a) External suppliers are businesses or individuals within the firm.
   (b) Process selection depends on a variety of economic, quantitative and qualitative factors.
   (c) There is just one method for selecting a production process.
   (d) Work study is economical in case of a short cycle time.

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the cornflakes were better. They answered by eating the various brands on the table and explaining in detail their jobs and quality control.

Two benefits resulted from this. Firstly, the buyers were impressed with the workers' knowledge, and secondly, the workers returned to the workplace enthused about their contribution. As a result their attitude towards their jobs also improved. Two conditions that are required for effective job enrichment are:

- Management must share information with the workers on goals and performance.
- The behaviour of the workers must not be excessively controlled by the organization.

3.8 SUMMARY

- The activity of establishing the workflow, equipment requirements, and execution requirements for a specific process is referred to as process design. It characteristically uses many tools including flowcharts, process simulation software, and scale models.
- This unit discusses the need for process design and process selection. The latter involves the use of an organization's resources to provide something of value to the customer.
- We have also studied various ways in which processes can be categorized. Process selection depends on a variety of economic, qualitative and quantitative factors.
- Every process must assess the critical dimensions that help to satisfy its internal and external customers, now and in the future.
- This unit gave an overview about process design and selection process, as well as manufacturing systems.
- The product-process matrix. The latter determines how an appropriate technology or manufacturing process must be selected.
- 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.
- Job design comprises methodical endeavors to organize responsibilities, functions and accountabilities into an element of work to accomplish definite objectives. The procedure is used by managers for determining individual responsibilities and authorities.

3.9 ANSWERS TO 'CHECK YOUR PROGRESS'

NOTES

1. A single 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.
2. The four major competitive priorities of any firm are:
   - Cost
   - Time
   - Quality
   - Flexibility
3. A product-process matrix has three parameters. These are: volume, product design and process.
4. (a) human

   (b) graphical

   (c) TMUs

   (d) enlargement
5. (a) False

   (b) True

   (c) False

   (d) False

3.10 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
4. What are the objectives of work study?
5. What is the relevance of method study?
6. How does work measurement help an industrial engineer?
7. Write short notes on PMTS, use of symbols in method studies, work sampling and time studies.
8. What are the objectives of job design?

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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?
5. Explain the steps involved in method study, giving suitable examples.
6. Write a detailed note on the objectives and techniques of work measurement.
7. Is work sampling a better technique than time study for measuring work? Give reasons and examples to justify your answer.
8. Write a note on the different approaches of job design.

UNIT 4 PLANT LAYOUT

NOTES

Structure

4.0 Introduction
4.1 Unit Objectives
4.2 Plant Layout: Importance and Function
4.2.1 Objectives of a Plant Layout
4.2.2 Advantages of a Good Plant Layout
4.2.3 Types of Layout
4.2.4 Layout Planning for Storage and Warehousing
4.2.5 Methodology of Layout Planning
4.3 Products Planning
4.3.1 Elements of Production Planning
4.3.2 Planning and Control in Mass Production
4.4 Aggregate Planning
4.4.1 Capacity Planning
4.4.2 Main Functions of Production Planning and Control
4.4.3 Production Control
4.4.4 'REL' Chart
4.4.5 Assembly Line Balancing
4.4.6 Line of Balance/Line Balancing
4.5 Production Scheduling
4.5.1 Objectives of Scheduling
4.5.2 Job Sequencing (or Scheduling)
4.5.3 Scheduling with Several Jobs and One Machine
4.5.4 Sequencing with Several Jobs and Several Machines
4.5.5 Gantt or Bar Charts
4.5.6 Shop Floor and Batch Production
4.6 Forecasting Methods
4.6.1 Objectives of Sales Forecasting
4.6.2 Forecasting Techniques
4.7 Summary
4.8 Answers to 'Check Your Progress'
4.9 Questions and Exercises

4.0 INTRODUCTION

Studying a plant layout comprises an engineering study carried out for the analysis of different physical arrangements for an industrial plant. A well-established plant trims down production costs with the help of reduced materials handling, reduced personnel and equipment requirements and reduced process inventory.

Unsuccessful sales forecasting and production planning activities may prove to be unfavorable for a well-organized plant layout. The beginning of the plant layout process is at an aggregate stage, considering the various divisions. Once these are elaborated upon, different issues emerge and the original arrangement may undergo modifications through a feedback process. A decent plant layout means a good spacious system. This should make manufacture scheduling and management simpler and should as a result bring down the delays in manufacturing and increase consumption of the existing plant capacity.

It is imperative to anticipate future transformations to avert the possibility of an unproductive plant layout in a short-term.

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4.1 UNIT OBJECTIVES

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

- State the importance and function of plant layout
- Define and explain production planning
- Classify aggregate planning
- Recommend production scheduling
- Summarize different forecasting methods

4.2 PLANT LAYOUT: IMPORTANCE AND FUNCTION

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.

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.

4.2.1 Objectives of a Plant Layout

Plant Layout:
The method to plan and arrange materials and facilities so that a steady flow of production is ensured at minimum cost

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

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4.2.2 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. **Production flow**: The prime concern of plant layout is smooth flow of the production function. Unhindered, steady, prompt and even work flow is a boom from good plant layout.
2. **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.
3. **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.
4. **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.
5. **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.
6. **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.

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4.2.3 Types of Layout

There are four basic types of layout.

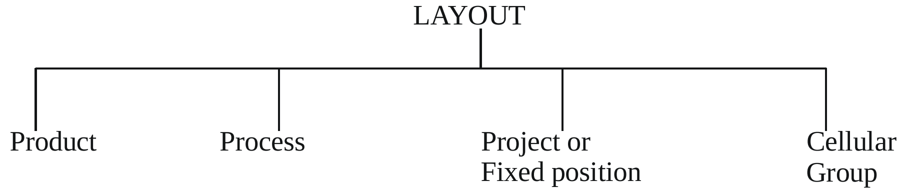

Fig. 4.1 *Types of Layout*

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 4.2.

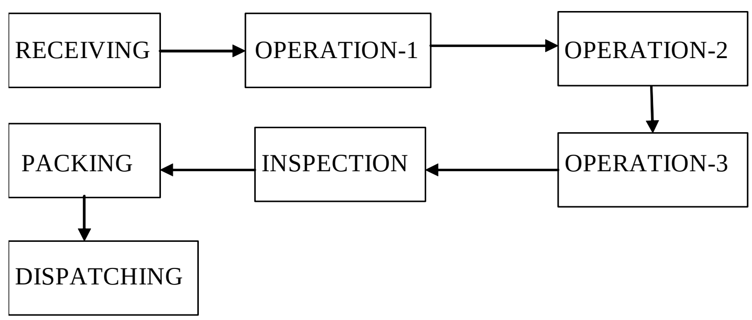

Fig. 4.2 *Flow Diagram of a Product/Line Layout*

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.

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.

STORES	GRINDING	FOUNDRY
RECEIVING	PLANNING PRODUCTION CONTROL	DESPATCH
MILLING	CASTING	WELDING

Fig. 4.3 *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.

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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.

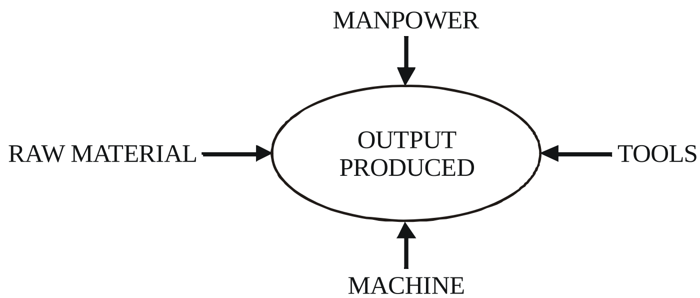

Fig. 4.4 *A Project Layout*

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.

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.

4.2.4 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.

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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.

4.2.5 Methodology of Layout Planning

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.

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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 $\Sigma D_{IJ} \, x \, L_{IJ} Ij$ ... 4.1

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.

Closeness Ratings: The relative degree of desirability of having one department situated near another

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 in Table 4.1.

Table 4.1 *Closeness Rating Significance*

Closeness rating	*Importance*
Absolutely necessary	1
Highly important	2
Important	3
Slightly important	4
Unimportant	5
Undesirable	6

Example 4.1

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 D_1 and D_2 is 2, departments D_1 and D_3 is 4, D_6 and D_1 as 5, and so on.

NOTES

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:

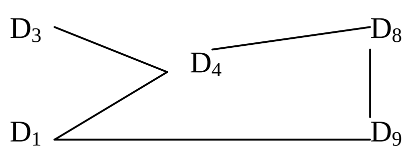
Step 1: Make a list of department pairs with ratings 1. This is necessary.

$D_1 – D_4$
$D_3 – D_4$
$D_1 – D_9$
$D_4 – D_8$
$D_8 – D_9$

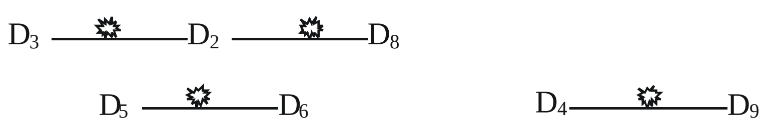
Make a list of department pairs with ratings 6. This is undesirable.

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

NOTES

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.

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.

Example 4.2

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

NOTES

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.

4.3 PRODUCTS PLANNING

In the previous units you have learned about the 6 Ms of a business that form the input—man, machine, materials, money, methods and management. 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 time frame 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.

4.3.1 Elements of Production Planning

Production planning is a complex activity encompassing diverse elements. Figure 4.5 show the elements of production planning.

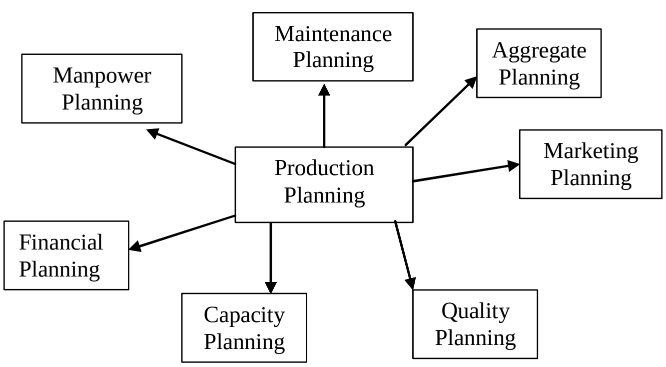


Fig. 4.5 *Elements of Production Planning*

4.3.2 Planning and Control in Mass Production

The scope of planning for mass production extends beyond the production system itself. The considerable and uninterrupted flow of goods from the factory shop floor requires a well-planned distribution and marketing setup to ensure the product reaches the consumer. Market research, advertising, transportation, licensing and tariffs must all be considered to set up mass production. Thus, planning for mass production includes a comprehensive system plan that transforms a raw material (from source) to a finished product (to user).

NOTES

Mass production planning not only lowers costs but also leads to significant improvements in uniformity and quality of products. Large volume, standardized design, materials and processes enable control and inspection techniques to ensure production and control quality.

The basic principles of mass production are listed as follows:

- **Division of work into specialized tasks:** Division of the generalized production functions into specialized tasks that consist of relatively easy and highly repetitive motion patterns. This facilitates the establishment and analysis of human motion patterns that can be easily learned and rapidly performed with the least of unnecessary motion or mental readjustment.
- **Simplification and standardization:** Simplification and standardization of constituent parts to allow production of components that are easily suited to other components without adjustment.
- **Development and use of specialized tools:** Development and use of machines, materials and processes lessens the human effort involved, maximizes per unit output of capital investment, cuts down the production of off-standard units and reduces cost of raw material.
- **Systematic engineering and planning:** Systematic planning and engineering of the production process permit the balancing of the following: human effort and involvement of machinery, effective division of labour and specialization of skills and integration of the production system to enhance productivity and minimize costs.

Mass production planning is a important feature of the design process and shows how a product design can be made on a mass production line by employing both skilled and non-skilled labour. At the outset of the century, the first mass production line was set up in the United States. The Ford Motor Company established a 'line' of workers who put together every car that passed out of its production line. The line comprised of several people, each of whom did only one job. While planning for the production line, it is imperative that each stage of manufacture is kept uncomplicated. This is called planning for 'mass production'.

It is also very important to keep in mind quality control when a product is manufactured either in a school workshop or on the production line of a factory. At every stage of production, the quality of the work should be checked and defects rectified. For example, for a brand of coffee, taste and smell are two quality indicators. Each point of quality control is called a 'critical control point'. The quality of a product is ensured by comparing it against these quality control indicators. How well a process is executed depends mostly on how efficient the control and monitoring systems are in a mass production environment. An increase in the efficiency of control and monitoring systems is related to the level of automation of procedures.

4.4 AGGREGATE PLANNING

NOTES

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, it is difficult to do it efficiently in the short run.

A master production schedule (MPS) 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 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 4.2 illustrates the difference between aggregate plan and master production Schedule for a toy manufacturing company.

Table 4.2 *Differences between Aggregate Plan and Master Production Schedule*

Aggregate Plan *Figures in '000*

Apr.	May	June	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
B 100	80	125	125	110	100
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.

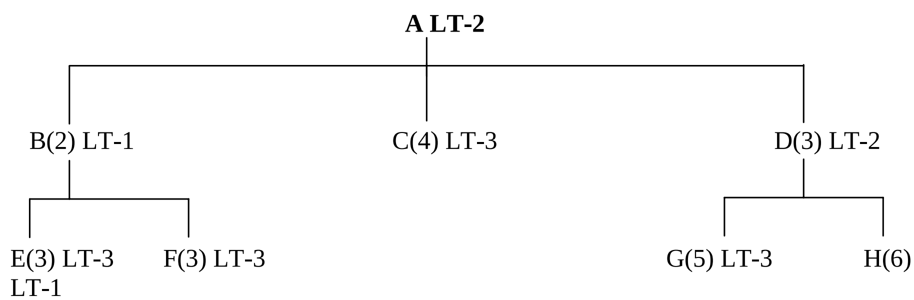
NOTES

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 4.3

Study the product structure tree given as follows. 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 (2×3) 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 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

NOTES

4.4.1 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.

Capacity Planning: 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.

Factors affecting capacity planning

The factors that affect capacity planning are as follows:

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, and 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.

Methods to modify capacity

NOTES

Strategies to modify the capacity can be broadly classified into short term and long term.

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. **Multiple skills:** 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 workstation can also take care of fluctuating demand.
5. **Subcontracting:** Many companies subcontract 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.

Long-term methods

These methods take a long time to modify capacity. They can be of two types:

1. Capacity expansion
2. Capacity contraction

1. **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.
2. **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.

NOTES

Example 4.4

A production house consists of four machines, each of which is used during an 8-hour, one-shift operation. The efficiency of each machine is 90 per cent (that is, the machines are expected to be down 15 per cent of the time). Find the capacity of the production house.

Solution:

The capacity of one machine in the production house in one shift

$8 \times 0.9 = 7.2$ hours

For 4 machines it is $= 7.2 \times 4 = 28.8$ hours.

Example 4.5

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:

$$\text{Rated Capacity} = \frac{168 \times 60 \times 0.9}{4} = 2268 \text{ tons/week}$$

The linear programming method is however the most commonly used method to find capacity.

4.4.2 Main Functions of Production Planning and Control

The main activities encompassing production planning and control (PPC) are as follows:

1. **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.
2. **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.
3. **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. 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: Determination of the sequence of operations for manufacturing a product or service

NOTES

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:

(i) The product is analysed with regard to its constituent parts. A decision is then taken as to what parts are to be manufactured and which are to be purchased.

(ii) The specifications, grade, quality and quantity of materials to be used in production are determined.

(iii) The number of manufacturing operations and their sequence is determined and listed on the route sheet.

(iv) The process time for each operation and the type and number of machines necessary to produce are determined.

(v) The lot size for production is determined keeping in mind the customers' orders and rejections and spoilage anticipated during the course of manufacturing.

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

6. **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
7. **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'.
8. **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.
9. **Expediting and follow-up:** Follow-up means to see whether the work is being carried out according to the plan 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.
10. **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.
11. **Cost control:** Production planning and control is responsible for cost control and cost reduction by reducing or eliminating wastes, value analysis, etc.
12. **Miscellaneous functions**: In addition to the above stated functions of production planning and control, 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.

NOTES

Dispatching: 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

NOTES

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.

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

4.4.3 Production Control

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.

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.

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.

NOTES

4.4.4 "REL" Chart

This denotes Relations Chart. The chart depicts the relationships between various departments and their relative importance. The relationship is graded as:

A - Absolutely Essential

E - Essential

I - Important

O - Ordinary

U - Unimportant

X - Undesirable

Assembly	
Fabrication	
Job planning	
Pattern shop	
Shipping	
Testing	
Wiring	

Fig. 4.6 *'REL' Chart*

The departments which falls in the "A" relationship should be placed together, whereas those falling under "x" relationship can be mutually exclusive. This gives scope for the layout designer to position various departments of the organization for optimum utility.

4.4.5 Assembly Line Balancing

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:

- Establishing production rates of the final product from the line
- Obtaining 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.

NOTES

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. 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.

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 (as shown in Figure 4.7 — it helps us to visualize the predecessor relationships better.

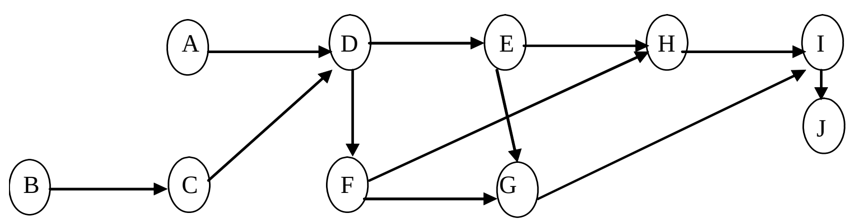


Fig. 4.7 *Precedence Diagram*

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 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 $80 \times 5 - 330 = 70$ 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 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.

4.4.6 Line of Balance/Line Balancing

Standardization of products, processes, materials, machines and uninterrupted flow of materials are the main characteristics of this system. For such a system of continuous production, a line layout is preferred. This is also called an assembly line. We have learnt that assembly line balancing has to be done in continuous mass production systems.

On an assembly line, several operations are tightly coupled. As one operation finishes the task, the job is transferred to the next operation on the assembly line. Each operation or set of operations is allotted the same amount of time to complete the task. An unbalanced line leads to inequities in the time required of each operation.

NOTES

Cycle Time: The time required to produce one unit of the finished product or the time available at each work centre

Idle Time: The total unproductive time for all stations in the assembly of each unit of the product

Balance delay: The amount by which efficiency falls short of 100 per cent

NOTES

A balanced line provides two significant advantages:

1. The work is distributed more evenly, reducing the inequity in worker effort;
2. The gating station finishes the task faster.

The result is a faster-moving line with an increased rate of output and a lower cost per unit.

Balancing the line is an iterative process that requires allocating work and assigning the work force to each station. The following steps give the planner a starting point for balancing the line:

1. Determine the output required for a specific period of time, such as hour, shift or week.
2. Determine the number of standard hours each unit of output requires.
3. Determine the total load for the period by multiplying the desired output and the number of standard hours per unit.
4. Divide the total load by the number of standard hours of work each worker can provide during the period. This number rounded upward is the minimum number of crew members necessary to produce the required output.
5. Divide the total work per unit by the minimum crew size to obtain the theoretical or ideal work cycle. This number is the time each crew member is expected to work to balance the line perfectly.

The following example demonstrates how to do line balancing:

Example 4.6

An assembly line is designed for making electronic wrist watches. If 2,000 watches need to be produced in an 8-hour shift, each watch requires 54 seconds of work. If each worker is available 85 per cent of the time and has an average efficiency of 90 per cent, calculate the number of workers required per shift.

Solution

The load time required to produce 2000 watches = $2000 \times 54 = 1800$ mins.

Effective availability of each worker = $8 \times 0.85 \times 0.9 = 367.2$ minutes

Therefore, number of workers required = $1800/367.2 = 5$

4.5 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.

NOTES

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.

4.5.1 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 setup 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.

4.5.2 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 for 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.

Check Your Progress

1. Name the four basic types of plant layouts.
2. List the main elements of production planning.
3. What do you understand by REL Charts?

NOTES

4.5.3 Scheduling with 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 the job with the 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. Job with the 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 the 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 4.7

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 (no. of days)	*Process Time (days from today)*	*Due Date*
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.

NOTES

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

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 = 19.5

Average. 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).

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

NOTES

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*	*Average time lateness*	*Avrage Job*
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.

4.5.4 Sequencing with 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 4.8

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; M_1 first and followed by M_2. The time taken by each job on each machine is given below. Determine the sequence of the jobs.

JOB	*M_1*	*M_2*
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 M_1 is job F. So F is first.

(b) Next ‘2’ is taken by job A on M_2. 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.

1. 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 4.9

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.

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.

NOTES

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.

2. 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.

4.5.5 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.
4. These types of chart boards are available in standard sizes in the market, which substantially saves the cost of developing customized Gantt chart boards.

NOTES

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.

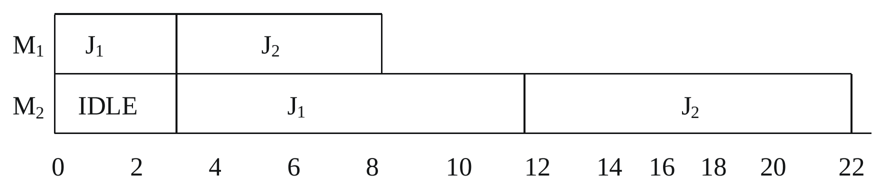
Example 4.10

Two jobs, J_1 and J_2, need to be performed on two machines in that sequence, that is M_1 first and then M_2. 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:

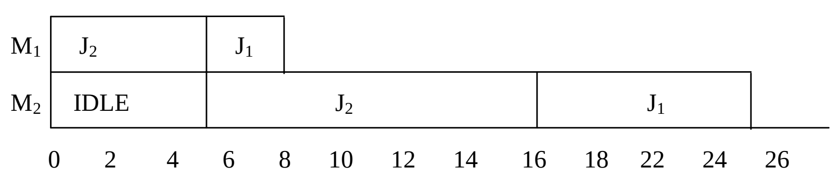
Suppose we follow sequence J_1, J_2.



When J_1 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 J_2, J_1.



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.

4.5.6 Shop Floor and Batch Production

Shop floor control system

A shop floor control (SFC) system is a setup of controllers and computers that schedule, despatch and monitor the progress of work orders through manufacturing on the basis of specific routings.

NOTES

Batch Production: The manufacturing and production of a number of identical articles with the purpose of meeting a specific order or a continuous demand.

An SFC is the interface between the two following stages: pre-production planning and shop floor execution. The SFC must be able to meet the demands of a multi-facility corporation, in which control must be sustained between co-located facilities down to individual workstations within a facility, as well as the demands of a small corporation, where there may be only one facility. A hierarchical architecture is required to meet such varied needs. The hierarchical architecture contains the following levels: enterprise, factory, cell, station and equipments. Each level of the hierarchy is divided into three basic functions: scheduler, dispatcher and monitor.

Establishing shop floor control is known to be difficult to achieve because one must supervise the execution of manufacturing processes according to plans, keep in mind possible delays and learn to deal with real-time system interruptions. Modern shop floor control systems must be reactive, that is they should possess the ability to react quickly and in a timely manner to disturbances, whether these are external or internal to the system to be controlled.

Batch production

Batch production can be defined as the manufacturing and production of a number of identical articles with the purpose of meeting a specific order or a continuous demand. Batch production can be undertaken:

- only once or
- or repeatedly at irregular time periods as and when demand arises (specific) or
- or repeatedly at regular time periods to satisfy a continuous demand.

The important features of batch-type production system are listed as follows:

- Economy of scale can be attained to some extent because the final product can be made standard and manufactured in batches.
- Machines are categorized based on function, similar to the job shop manufacturing.
- Semi-automatic, special-purpose automatic machines and semiautomatic material-handling systems are usually utilized to avail of the sameness among products.
- Skilled labor should be employed to work upon different batches of products.
- The layout type and material handling policies lead to high levels of inventory.
- The disadvantage is that production control and planning are difficult because of the odd size and non-repetitive nature of ordered products.

4.6 FORECASTING METHODS

All business and industrial activities revolve around sales and its future planning. To know how a business will do we must know its future sales. So sales forecasting is the most important activity in a concern because all other activities depend upon the sales of the concern. In order to understand the meaning of sales forecasting, we must first understand the meaning of forecasting. According to Allen, ‘Forecasting is a systematic attempt to probe the future by inference from known facts.’

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C.E. Saltan says, 'Business forecasting is the calculation of probable events to provide against the future. It, therefore, involves a look ahead in business and idea of predetermination of events and then financial implications as in the case of budgeting.' Thus, forecasting means predicting the future with the help of existing facts.

Sales forecasting means estimating the future sales either in terms of value or in terms of units of a product or several products. Sales forecasting is related to a fixed period of time. Mostly it is made for a year. According to American Marketing Association, sales forecasting is 'an estimate of sales in dollars or physical units for a specified future period under a proposed marketing plan or programme and under an assumed set of economic and other forces outside the unit for which the forecast is made. The forecast may be for a specified item of merchandise or for entire line.'

The above definitions clearly explain that sales forecasting is nothing but a guesswork which is based on past data, present circumstances and future prospects. In short, sales forecasting implies the development of an effective system to estimate sales for a specified period and includes the following activities:

- Market research
- Analysis of the data of sales vis-à-vis estimation of sales prospects by salesmen in their respective territories.
- Combining these two steps to estimate the volume of sales and present the data before the top management for approval and revision, if necessary.

Sales forecast helps to predict the future taking note of the past and being aware of the present.

Sales forecast helps you to evaluate the past and current sales level to increase the annual growth the company, which further helps you to assess the company according to industry norms. It also helps you to establish policies so that you can easily monitor the prices and operational cost and hence increase the profits. Sales forecast makes you aware of the minor problems before they become your major problems.

Sales forecasting is an important activity in the production field and the whole production system revolves around this concept. Production activities are planned according to the sales estimates. Buying, selling, advertising, sales promotions, storage, packaging, that is, all the marketing activities are also planned accordingly. Thus, sales forecasting may be said to be the very basis of planning, whether concerned with marketing, production, finance or personnel, and, therefore, for the successful achievement of overall objectives of the organization, accurate sales forecasting is necessary. It is advisable that the figures of sales forecasting once estimated should be reviewed periodically so that the organization's plans can be adjusted accordingly. Sales forecasting is the basis of budgeting too, which is an important tool for controlling the business affairs.

Factors affecting sales

Following are the factors that affect the sales of a company:

- Seasonality of the business
- Relative state of the economy
- Direct and indirect competition

NOTES

- Political events
- Styles or fashions
- Consumer earnings
- Population changes
- Weather
- Productivity changes

4.6.1 Objectives of Sales Forecasting

The objectives of sales forecasting can be of two types:

- Short-run objectives
- Long-run objectives

Short-run objectives

The sales forecasting for one year or lesser period is known as short-run forecasting. The short-run objectives of sales forecasting are as follows:

- **Formulation of suitable production policy**: The first objective of short-run sales forecasting is to formulate a suitable production policy. It is necessary so that problems of under-production or over-production do not arise and future production of goods is available according to the demand forecast.
- **Regular supply of raw materials**: The second objective of forecasting is to make provisions for the regular supply of raw materials for production on the basis of estimated sales during a short period. It helps in maintaining the flow of production and minimizing the cost of holding inventory.
- **Best utilization of machines**: One of the important objectives of sales forecasting is to utilize the available machines to their maximum capacity in such a way that in case of increase in demand there should not be any hindrance in increasing production and in case of decrease in demand, the machine should not remain idle.
- **Determination of appropriate price policy**: Sales forecast has an important bearing on the organization's price policies so that in a period of depression, the price may not increase and in a period of inflation, the price may not decrease.
- **Regular availability of labour**: The next objective of sales forecasting is to arrange trained personnel and non-technical workers so that the organization does not experience any shortage of personnel during the peak period and at the same time they should not remain idle due to lack of production work. So, production planning ensures the availability of labour.
- **Forecasting of short-term financial requirements**: The financial requirements of the organization depend on the level of sales and volume of production. Sales forecasts enable the arrangement of funds according to the needs of the enterprise on reasonable terms well in advance. It will minimize the cost of finance.
- **Setting the sales target and establishing controls and incentives**: Sales forecasts help in setting the sales target for different market segments. The personnel engaged in the work are controlled with the implementation of necessary incentives.

Long-term objectives

Forecasting of sales of more than a year is called long-term forecasting. The objectives of long-term forecasting are:

- **Estimating long-term financial requirements**: Long-term financial requirements can be predicted on the basis of long-term sales forecasting. Cash inflow can be very well estimated by determining cash and credit sales ratio. It helps planning for credit policy of the organization. It also determines long-term needs as well as capital expenditure.
- **Planning of plant capacity**: The long-run objective of sales forecasting is to plan plant capacity in accordance with the demand or sales forecasts. If the sales forecasts reveal that the plant capacity will fall short of the future demand, a decision to install a new plant or to increase the capacity of the existing plant can be taken.
- **Manpower planning**: Another long-run objective of sales forecasting is planning for the permanent workforce on the basis of sales prediction so that the best labour force may be available to run the production smoothly. Management can decide the mode of training, recruitment, etc for this purpose.
- **Budgetary control over expenditures**: In forecasting the sales, all the activities are to be forecasted and for this purpose, various budgets are to be prepared for the income and expenditure of the organization. The budgetary figures are then compared with the actual performance and any variation is removed.
- **Long-run production planning**: With the help of long-run sales forecasting, long-run production policy can be planned. In the long run, the product should meet the demands and other conditions. It will also help the company in arranging long-term finance.
- **Dividend and reserve policies**: Long-run sales forecasting can also forecast the profits of the firm on the basis of gross profit ratio on sale. A number of managerial decisions are influenced by the quantum of profits reserve policy, and thus the dividend policy can be determined in advance.

  Management should take more care in forecasting and analysing long-term sales forecasting figures and ensure accuracy because long-term policies of companies are sometimes not correct.

4.6.2 Forecasting Techniques

Walmarts formula for success has been to get the right product on the appropriate shelf at the right time at the lowest price. This is possible only when there is in place a perfect forecasting system, backed by the most accurate data possible. The company has invested several million dollars in data warehousing. They have more details than any of their competitors on what is going on by product, by store, by day. Their forcasting system has data on point of sale, inventory, products in transit, market statistics, customer demographics, finance, product returns and supplier performance. The data is used for analysing trends, managing inventory, understanding customers and determining product mix and presentation at each store.

contd...

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> Walmart has developed a demand-forecasting application that looks at individual items for individual stores to decide the seasonal sales profile of each item. The system keeps a year's worth of data on the sales of 100,000 products and predicts which items will be needed in each store.
>
> The dictionary meaning of forecasting is to estimate or predict a future event or trend. It involves estimating the future - it is not exactly planning but is an important input which sets the planning aspect in motion.

You will not learn about the statistical aspects of forecasting here. The discussion is limited to learning what are the different types of forecasting and when and why they are carried out.

Whenever one has to make decisions about managing or controlling inventories for production, two basic questions have to be asked:

- How much of each item must be stocked?
- When should an order be released and for what quantity?

In a situation of certainity, where the demand and supply are both known and predictable, it is possible for the decision maker to express in terms of probability situations. But this is not possible in situations of uncertainity and here, subjective probability comes into the picture. In this case also, it is seen that uncertain conditions tend to repeat themselves, so the knowledge towards them increases and they tend towards certainity. Forecasting is very helpful in dealing with uncertainties.

From forecasts of demand, the operations plan is drawn out. Since frequent modifications to the plans are difficult, accuracy of the plans becomes important and forecasts becomes vital. You plan because you cannot forecast accurately. Therefore, forecasting should be viewed in close relationship with planning and techniques should be so chosen as to meet the accuracy needs required by planning.

When an operations manager draws out the plan for materials requirement, he sends it to the materials management department for initiating procurement action. The materials manager takes action for procurement, based on his estimate of how long it will take for the material to arrive, which depends on the lead time for ordering and delivery. So, the operations manager, forecasts requirements, while materials manager forecast lead times. Every aspect of logistics is affected by the forecasting process. So, forecasting affects every aspect of production planning and control and inventory control.

Forecasting helps in:

- Increasing customer satisfaction
- Lowering safety stocks
- Reducing stock outs
- Reducing obsolescence
- Better negotiations
- Better prices
- More efficient production schedules

There are however, certain limitations in forecasting. Before embarking on forecasting it should be remembered that:

- Forecasting is more accurate for shorter periods.
- Forecasting is more accurate for larger groups.
- Forecasting should include a provision for error.
- A sound database is a prerequisite for forecasting.
- Forecasting techniques should be tested and proven.

Steps in forecasting

For forecasting, the following basic steps are to be followed:

Step 1: Identify the objectives. It can vary from trying to reduce idle time by appropriate job scheduling or design changes to keep pace with the changing demand

Step 2: Determine the time period of forecast. For capacity planning, long-run estimates are a better option, while for optimal utilization of existing facilities, short-run estimates are a better option.

Step 3: Select the right forecasting method, in line with the objectives and time frame. Sometimes, more than one model may be adopted simultaneously. For example, forecast for the next period may be useful for shop floor planning and a quarterly forecast may be done for capacity planning and inventory planning.

Step 4: Collect required data/ information. For time series analysis, past data is collected, whereas for market reseearch, primary data is collected by conducting surveys.

Step 5: Implement results for managerial decisions of planning and control.

Step 6: Periodically evaluate forecasts by assessing degree of error and reliability and revise.

Types of forecasting

Forecasting can be classified based on several parameters. You will learn here some of the most commonly used methods of forecasting.

1. Classification on the basis of the length of term

- **Long-term forecast:** It is used for long term or long-range planning. The duration is usually three years or more and covers such aspects as sales by product line, demand or supply in a five-year plan etc.
- **Short-term forecast:** It is used for planning for the immediate future, say several months, or weeks. It covers such aspects as requirements for the next season, next month, etc.
- **Mid-term forecast:** It ranges from one to three years, e.g., address budgeting issues, sales plan, future demand, etc.

2. Classification on the basis of situations

Forecasting can be classified on the basis of situations. On the basis, forecasting may be classified into the following types:

- **Forecasting in situation of certainity:** This involve prediction of demand based on a certain criteria which is usually the end product e.g. For example, in

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construction of a building the requirement of girders, cement, bricks, etc. can be predicted during each week of construction.

- **Forecasting in situation of uncertainity:** This forecasting is resorted to when the knowledge about the end product or future demand is minimal or does not exist. An example of this would be the material planning for maintenance for a newly installed machinery. In such cases, forecasting is based on an intelligent assessment of assumptions, often by a committee of experts. Delphi techniques, gross impact matrix, etc. help in this regard.
- **Forecasting in situation of risk:** Imagine the stock of groceries in a grocery store. A certain amount of groceries is stocked based on past patterns and the assumption that this pattern will repeat itself. This is a situation of risk. Statistical operational research techniques help in such situations.

3. Classification on the basis of topics of forecast

Forecasting can also be classified based on the topics of forecast. On the basis, forecasting is of the following types:

- **Demand forecast:** This takes into account the current and projected demand, inventory status and lead times for an organization. This forecasting is the most relevant in inventory management.
- **Supply forecast:** This takes into account the issues that affect supply such as data on current producers and suppliers, technology and political trends, product lead times, changeover times, etc.
- **Price forecast:** This involves forecasting of long-term and short-term prices based on information gathered and analysed about demand and supply.

Types of demand

Before a materials manager begins to decide how much of an item is to be purchased, an operations manager needs to work out how much of the item is required for producing the end product. For this, he needs an additional bit of fundamental information about each of the items in the inventory. An item can exhibit any of the following three types of demands:

(i) Dependent demand: An item is said to exhibit dependent demand characteristics when its use is directly dependent on the scheduled production of the larger component or parent product of which the item is a part. Once the total quantity of end product to be manufactured during a period is known, the precise requirement of inputs can be worked out from the bill of materials (BOM). Dependent demand should not be forecasted but precisely calculated, even though the demand for the end product might have been forecasted. For example, for every motorcycle to be made, two wheels are needed. The number of motorcycles produced can be forecasted, but the number of wheels required have necessarily to be calculated, depending on the number of motorcycles made. This is a dependent demand.

(ii) Independent demand: The items for which the demand cannot be calculated accurately from the production schedule and bills of materials are said to have an 'independent demand'. Such demand can only be forecasted and not calculated precisely. The demand for a consumer durable in the market is not dependent on any predictable factor since the tastes and needs of consumers vary. The consumer can choose what, where and when they will buy. Similarly, spares required for day-to-day operation and maintenance of a machinery may be entirely probabilistic and independent of any specific factor.

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For example, in an iron-making facility, iron ore, coal, limestone and manganese ore have a dependent, demand whereas furnace oil, refractory bricks, gallery lights and conveyor belts have an independent demand.

The distinction between dependent and independent demands is relatively simple but very essential to the inventory manager. It helps him to decide what should be the inventory control policy applicable for the item.

(iii) Semi-dependent demand: This third category is especially applicable in case of logistics and transportation providers. While overhauling vehicles, components are replaced based on their condition of wear and tear, the criteria being whether they could safely operate for another overhaul life or not. The decision is usually judgemental, taken based on a list of spares replaced on an average during each overhauling activity. The demand for these spares is semi- dependent; the wearing pattern changes with the life of the equipment.

Forecasting techniques

Numerous techniques are available for forecasting, which can be broadly classified into two categories: qualitative techniques and quantitative techniques.

Qualitative techniques

Qualitative techniques involve collection of opinions and preferences, which are further quantified using different statistical tools. The most commonly used qualitative techniques are:

Qualitative Techniques: Collection of opinions and preferences, which are further quantified using different statistical tools

(i) Grass roots
(ii) Consensus forecasting
(iii) Delphi method
(iv) Historical analogy
(v) Market Research

(i) *Grass roots method:* It is the simplest method of forecasting. It starts with estimates and opinions and the final forecast is arrived at from these estimates by review and discussion. Its advantage lies in its simplicity and the association of all the people who matter. For example, the overall sales forecast may be derived by combining the inputs from each sales person, who is responsible for sales in his or her territory. However the grossroots method suffers from the disadvantage of being highly subjective. It may also be time-consuming and is very much influenced by immediate events.

(ii) *Consensus method:* It believes that open discussion by a group would produce better forecasts than any single individual's endeavour.

(iii) *Delphi method***:** It was developed by the Rand Corporation in the 1950s. In this method, a panel of experts is selected whose comments are crystallized from their responses to a series of questionnaires. It is of special relevance in situations of uncertainty. There is a learning process for the group members also and at the same time there is no influence of group pressure or dominating individuals as the identity of the individual is often concealed.

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(iv) *Historical analogy method:* It ties up the forecast to a previous forecast. This method is specially relevant when new products are being launched, where a forecast may be derived by using the history of a similar product. You just need to click on any site selling books and you will be flooded with mails offering all kinds of books! The products are in the same general category of books and may be bought by the consumers. Similarly a firm which already produces kettles and now wants to produce electric kettles could use the kettle history as a likely growth model.

(v) *Market research method:* It is based on surveys conducted and is usually employed by organizations to forecast new product sales or sales of established products in new markets. Data is collected in a variety of ways, such as surveys, interviews, questionnaires, etc. to test hypothesis about the market. You would certainly not have escaped telephone calls, asking you about newspaper preferences, your income, habits, and so on.

Quantitative techniques

These techniques are of the following three types:

(i) Time series analysis

(ii) Causal relationships using cause – effect models

(iii) Simulation

(i) ***Time series analysis method:*** Time series method uses historical data to predict the future. In this method, the element of time comes into the picture. Time can be short term, medium term or long term. While these terms are relative to the context in which they are used, a short term often refers to a time period of under three months, medium terms refers to three months to two years and long term is more than two years.

Several time series analysis forecasting techniques are available; which method to choose would depend on the following factors:

- Time period of forecast
- Data availability
- Accuracy desired
- Size of budget available
- Availability of qualified personnel

The most commonly used methods of time series analysis are:

(a) Last period demand method

(b) Simple average method

(c) Moving average method

(d) Exponential smoothing

(e) Trend projections

(f) Regression analysis

(g) Shiskin time series

(h) Box jenkins technique

(a) Last period demand method: It is the simplest method based on past demand. It does not take into account seasonal fluctuations and so may not always be foolproof.

(b) The simple average method: It smoothens random fluctuations. When the demand for a product is neither growing nor declining rapidly, and does not show seasonal characteristics, this method of forecasting can be useful. However, this method also does not take into account seasonal fluctuations. The formula for calculation is:

$$Ft = A(t\text{–}1) + A(t\text{–}2) + A(t\text{–}3) + \text{----------} + A(t\text{–}n)n$$

where Ft = Forecast for the coming period

$A(t\text{–}1)$, $A(t\text{–}2)$ ---------- + $A(t\text{–}n)$ = Actual occurrence in the past period

N = No. of periods to be averaged

(c) Weighted moving average method: It is useful to guard against random fluctuations due to seasonal demand characterestics. Weights are assigned to each component of the moving average database, provided that the sum of all weights is exactly equal to 1.

(d) Exponential smoothing method: The drawback of the methods discussed so far is that as each new piece of data is added to these methods, the oldest observation is dropped and the new forecast is calculated. Also, in most cases, the more recent occurrences are a better indicator of the future than the past ones.

You can be better understand these methods with the help of an example.

Example 4.11

Sturdex Mopeds limited has the following demand data for their mopeds for the six months:

Month	Demand of Mopeds
April	1500
May	2000
June	2300
July	1700
August	1000
September	1200

You need to forecast the demand for october. You will do it by the various methods you have learned so far.

Last period method

Since demand for September was 1200 units, the forecast for October would be 1200 units.

Simple average method

(1500 + 2000 + 2300 + 1700 + 1000 + 1200)/6 = 1616 units

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Moving average method

In using four period moving average method to forecast sales for October, you will consider the sales for the last four months and get the forecast as follows -

$$(2300 + 1700 + 1000 + 1200)/4 = 1550 \text{ units}$$

Weighted average moving method

Assume that the analyst assigns weights of 3,2,1,2,4 and 3 for the sales from April to September. The revised forecasted demand would then be:

$$3(1500) + 2(2000) + 1(2300) + 2(1700) + 4(1000) + 3(1200) \div 15$$
$$= 1453 \text{ units}$$

Exponential smoothing method

In the exponential smoothing method, only three pieces of data are needed to forecast the future: the most recent forecast, the actual demand that occurred during that period and the smoothing constant alpha (α). Alpha is given a value between 0 and 1. If the real demand is stable, say the demand for food, you would like a small value of alpha to lessen the effect of short-term or random changes.

In the given example, suppose the actual demand for October was 1200 units against the forecast of 1453 units. Considering α as 0.5 (which the company feels produces best results), the demand for November would be:

$$1453 + 0.5(1200 - 1453)$$
$$1453 - 126 = 1327 \text{ units}$$

Regression: A functional relationship between two or more correlated variables

(e) Trend projections: This method fits a trend line to the data points to get trend projections and projects it into the future.

(f) Regression analysis: Regression is defined as a functional relationship between two or more correlated variables. The relationship is developed from observed data. The data is plotted first to see if they appear linear or atleast parts of the data are linear. This method is useful for the long-term forecasting of major occurrences and aggregate planning.

(g) Shiskin time series: This method was developed by Julius Shiskin. This method is used to decompose a time series into trends, seasonal and irregular. It needs at least three years of historical data. It is very good in identifying turning points, in company sales.

(h) Box Jenkins technique: This method is very complicated but is one of the most accurate statistical techniques available. It relates a class of statistical models to data and fits the model to the time series by using the Bayesian posterior distribution.

(*ii*) ***Causal relationships using cause–effect models***

This method focuses on the system underlying and influencing the item under forecast. For example, sales may be affected by advertising, presence of competitors or quality. Forecasting using cause-effect models is done by using the following methods –

(a) Corelation-Regression method

(b) Econometric method

(c) Input–output analysis
(d) End use analysis

(a) Corelation regression method: It is similar to the time series method. The only difference is that it contains multiple variables. The basis is that forecast is caused by the occurrence of other events.

(b) Econometric method: It is considered very useful in case of long-term forecasts and is considered very accurate. It is based on econometric models describing some area of economic activity. All the parameters of the regression equations are usually estimated simultaneously. This model is very expensive to develop but is very accurate. It is often used for aggregate demand analysis. It is based on mathematical statistics, a theory which tells how to make inferences about a population (gross number) on the basis of a sample. Usually, firms in an industry are not too numerous and it is not useful to select a representative sample from a cross-section study of firms in an industry. Another difficulty is that firms cannot neglect the random variables in the relationship to be considered, which is not exact but probabilistic.

(c) Input–output models: They focus on sales of each industry to other firms/ government. They indicate the change in sales that a product industry might expect because of purchasing changes by other industry.

(d) End use analysis: It takes into account statistics that move in the same direction as the series being forecast. For example, an increase in the price of petrol would indicate a future drop in the sales of cars.

(*iii*) ***Simulation models***

Simulation models are dynamic models, usually computer based, that allow the forecaster to make assumptions about the internal variables and external environment in the model. Depending on the variables in the model, the forecaster may ask questions such as - what would happen to my forecast if price would increase by ten per cent ? What effect would a three per cent drop in GDP have on my forecast?

Such studies are however considered to fall in the realm of specialists and not operations. These methods combine economic theories with statistical procedures.

4.7 SUMMARY

- The importance of plant layout can be summarized in the following points:
  - o Economic handling
  - o Effective use of available area
  - o Reduction in production delays
  - o Better quality control
  - o Minimum equipment investment
  - o Avoidance of bottlenecks
  - o Improved production control
  - o Improved supervisory control

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Check Your Progress

4. Fill in the blanks with appropriate words.
   (a) Industrial robots were first introduced in ______.
   (b) Scheduling systems can use either finite or infinite _______.
   (c) The ________ model is a combinatorial optimization algorithm that helps in solving the assignment problem.
   (d) Production activities are planned according to the _____ estimates.
5. State whether the following statements are true or false.
   (a) Capacity is usually specified in terms of available hours, either for machines or labour.
   (b) Backward scheduling starts from some date in the past and schedules the required operations in sequence.
   (c) Sales forecast helps to predict the future by taking note of the past and being aware of the present.
   (d) Econometric method is considered very useful in case of short-term forecasts and is considered very accurate.

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- Better utilization of labour
- Increased motivation in employees

- There are four basic types of layouts:
  - Product layout
  - Process layout
  - Project of fixed position layout
  - Cellular or group layout
- Production planning is the cross-functional process of creating an aggregate, family-level plan for a month or quarter based on the goals of the management for manufacturing, sales and inventory levels.
- Aggregate planning is an operational activity that devises a cumulative plan for the production process well in advance, for providing ideas to the management in terms of the quantity of materials and other resources to be obtained.
- Production scheduling can be referred to as the allotment of the accessible production resources over time to ideally fulfill some set of criteria.
- A large number of forecasting methods in business are available for enhancing governing and competence. The types of forecasting method to use are based on the type of the information and the degree of precision the business requires.

4.8 ANSWERS TO 'CHECK YOUR PROGRESS'

1. The four basic types of plant layouts are: product layout, process layout, project or fixed position layout and cellular or group layout.
2. The main elements of production planning are:
   (i) Manpower planning
   (ii) Maintenance planning
   (iii) Aggregate planning
   (iv) Marketing planning
   (v) Quality planning
   (vi) Capacity planning
   (vii) Financial planning
3. REL charts depict the relationship between various departments and their relative importance.
4. (a) 1954
   (b) loading
   (c) Hungarian
   (d) sales

5. (a) True
   (b) False
   (c) True
   (d) False

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4.9 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What are the objectives or a plant layout?
2. What are the advantages of project layout?
3. List the basic principles of mass production.
4. What are the benefits of production planning and control?
5. What are the objectives of scheduling?
6. What are the disadvantages of Gantt charts?
7. List the limitations of forecasting.
8. What are the different quantitative techniques used in forecasting?
9. Define the correlation regression method.

Long-Answer Questions

1. Explain the advantages of a good plant layout.
2. Give a detailed account of the different types of layouts with the help of diagrams.
3. Discuss the concepts of closeness rating and load distance analysis with the help of examples.
4. Elaborate on the nature of planning and control in a mass production scenario.
5. Describe the short-term and long-term methods of capacity planning.
6. Write a note on the different elements of automation used in production control.
7. Explain assembly line balancing in detail with the help of a diagram.
8. What is job sequencing? Explain the concept with the help of examples.
9. Discuss the different types of forecasting methods used in businesses.

UNIT 5 MATERIAL REQUIREMENT PLANNING (MRP) AND CONTROL

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Structure

5.0 Introduction
5.1 Unit Objectives
5.2 Materials Management: An Overview
    5.2.1 Materials Requirement Planning
5.3 Just-In-Time (JIT)
    5.3.1 JIT process
    5.3.2 Advantages of JIT
    5.3.3 The 'Kanban' System
    5.3.4 Difference between JIT and MRP Systems
5.4 Network Techniques
5.5 Summary
5.6 Answers to 'Check Your Progress'
5.7 Questions and Exercises

5.0 INTRODUCTION

Material requirements planning (MRP) and control is a computerized inventory management system created to support production managers in setting up and placing requests for items of dependent exigency. Dependent demand goods are constituents of finished products—like raw materials, constituent parts and sub accumulations. The inventory required for these is dependent on the degree of production of the finished product. For instance, in a factory that manufactures bicycles, dependent demand inventory articles may consist of aluminum, tyres, seats and bike chains.

The foremost MRP and control systems of inventory management came up in the 1940s and 1950s. They made use of mainframe computers to transmit information from a bill of materials for a certain finished product into a manufacturing and purchase plan for constituents. Sooner than expected, MRP and control grew to takeover information answer-back loops so that production staff can modify and update the inputs into the system as required. The next generation of MRP, known as manufacturing resources planning or MRP II, additionally included promotion, finance, accounting, engineering, and human resources features into the planning process. An associated perception that develops on MRP is Enterprise Resources Planning (ERP). This makes use of computers to connect various operative domains across a whole business enterprise.

MRP works in the reverse direction from a production plan for finished products to develop requirements for constituents and raw materials. MRP starts with an agenda for completed products that is transformed into an agenda of requirements for subassemblies, the constituent parts and the raw materials required for making final products in the given time period. MRP is equipped to respond to three questions: '*what* is needed?', '*how much* is needed?' and '*when* is it needed?'

MRP changes inventory requirements to planning periods for the manufacturing to finish on time, while inventory levels and associated carrying costs are reduced. However, MRP systems can take a lot of time and prove expensive in implementation. This can render them unaffordable for small businesses. Additionally, information that results from an MRP system is of the same quality as that which goes into it. Companies should have an organized record of current and accurate bills of materials, part numbers, and inventory records for determining the probable benefits of MRP.

5.1 UNIT OBJECTIVES

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

- Discuss the concept of materials management
- Define materials requirement planning
- Explain the concept of JIT and its significance
- List the advantages of JIT

5.2 MATERIALS MANAGEMENT: AN OVERVIEW

Materials Management: The control and management of materials/ stock in a way that guarantees the maximum return for a business

Definition of materials management

Materials management can be defined as the control and management of materials/ stock in a way that guarantees the maximum return for a business. Materials management involves determining the purchase, location, storage, account-keeping and transportation of stock. By transportation of stock, we mean the planning of movement of stock through various processes of manufacturing, warehouses and channels of distribution.

Materials management is concerned with the planning, organizing and controlling of all those actions that are chiefly concerned with the inflow and outflow of materials into a business. The reach of materials management differs between organizations, and may include production planning, materials planning and control, inventory control and stores management, purchasing, movement of materials in the and waste management.

Functions of materials management

Materials management generally includes the following activities:

- Purchasing
- Procurement
- Distribution
- Warehousing

In materials management, the business operates by toeing the line between its financial parameters and the needs of its internal customers, i.e., workforce. Effective materials management relies upon the personal involvement of supply and purchase managers and supervisors in executing various supply functions. Some functions of materials management carried out in various supply areas directly affect stock and they are as follows:

- Maintenance of allowance list
- Processing of issue orders

- Processing of receipts
- Count and reconciliation of physical inventory
- Maintenance of stock record

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Importance of materials management

Materials management involves the purchasing mix. It is to do with material acquisition and the ability to forecast the goods available in the store and the goods to be supplied on request. The functions are chiefly executed by the store manager and it is his duty to make sure that goods supplied meet the expectations of the customers.

The most important role of materials management is to ensure that the stores and supply manager streamlines the business's demand, sales and issues as to enable the manager to be alert to when the organization is running short of stock and will avoid making use of its buffer stock.

5.2.1 Materials Requirement Planning

Materials requirement planning

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 the materials requirement planning. McGraw Hill has defined (MRP) 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. **Dependent demand:** Dependent demand means that the demand for an item is related directly to the demand for some other product. The item may be a component, raw material or sub-assembly. 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.

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Lead Time: The time that must be allowed to complete the job from start to finish

2. **Lead time :** The lead time for a job is the time that must be allowed 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 dates are obtained from the dates 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.

Three pre-requisite inputs for MRP

Three pre-requisite 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 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 re-adjusting 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 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 the 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 changing sales demand and also internal problems which require scheduling.

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 requirements 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.

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Bill of Materials: List of all the materials and their quantities required to manufacture an item

Inventory Records File: The item wise inventory records indicating the item as well as the quantities in stock

The 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 as shown in Figure 5.1.

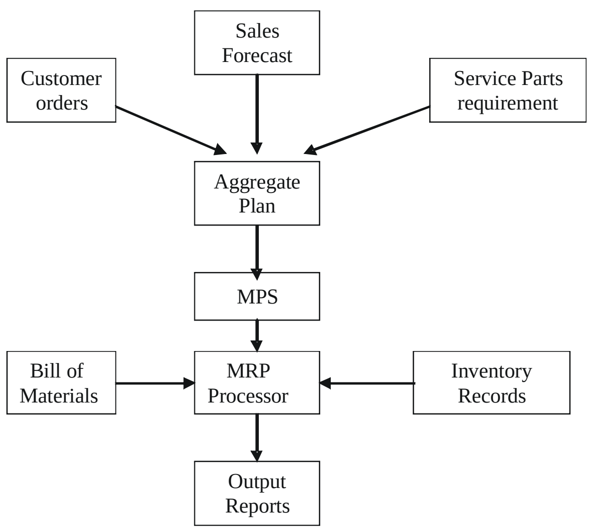

Fig. 5.1 *The MRP Process*

The flow chart above 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 dependent demand. The independent demand items are forecast and specified on MRP. The dependent demand items are calculated based on the bill of materials and 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 1,000 units of Product A have to be manufactured, 1,000 units of B and 2,000 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.

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Next issue is the lead time. The time taken to procure the raw materials, component parts, sub-assemblies 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 sub assemblies

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 then 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 5.1

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 stock out.

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.

Example 5.2

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. The question is to 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 dependent 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 is that the on hand 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 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):

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.

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With this information, the table is as follows:

	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 sock 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 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 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 systems and integrate it with other manufacturing and business functions. This renaissance is commonly known as 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.

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 sales and operations (production planning, master production scheduling and capacity requirements planning). Once the plans have been accepted, its execution begins. These include input–output (capacity) measurement, detailed scheduling and dispatching, anticipated delay reports from both the plant and the suppliers, supplier scheduling, etc. The term 'closed loop' implies that not only are each of these elements included in the overall system, but also that feedback is provided by the execution functions so that the planning can be valid at all times. This took care of the capacity variable. But still, the financial aspect of running a business had not yet been integrated.

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 more and more of the firm was becoming involved in the programme.

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?

Definition of MRP-II

MRP-II or manufacturing resources planning can be defined as an information system that integrates all manufacturing and related applications, including decision support, MRP, accounting and distribution. It is a system, which allows manufacturers to optimize materials, procurement, manufacturing processes, etc., and provide financial and planning reports.

According to the American Production and Inventory Control Society, Inc. (APICS), MRP-II is a method for the effective planning of all resources of a manufacturing company. Ideally, it addresses operational planning in units, financial planning in dollars, and has a simulation capability to answer 'what if' questions. It includes business planning, sales and operations planning, production scheduling, material requirements planning (MRP), capacity requirements planning, and the execution of support systems for capacity and materials. Output from these systems is integrated with financial reports such as the business plan, purchase commitment report, shipping budget, and inventory projections in dollars. MRP-II is a direct outgrowth and extension of closed-loop MRP. Companies like Nissan have integrated MRP-II into their production planning processes, and have combined it with radical changes in management philosophy needed to bring about total quality and continuous improvement.

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MRP-II process

MRP-II is a company-wide system concerning all facets of business including sales, production, engineering, inventory and cash flows (refer Figure 5.2).

The primary control focus of an MRP system is order entry. Once an order is entered, all the manufacturing functions are put into motion. These include:

1. **Cost estimates:** Cost builds can be ordered from information in the other modules.
2. **Inventory control:** Existing stock of the product ordered.
3. **Bill of materials:** What parts are needed to produce the product and in what quantity?
4. **Inventory control:** What parts called for by the BOM are in stock and how much? This much is not to be bought.
5. **Purchasing:** What parts listed in the BOM have to be bought, how much to buy and when do they have to be here?
6. **Production control and scheduling:** Controlling and allocation of personnel and resources.
7. **Invoicing:** An invoice and shipping documents are made against the order. Partial shipments and periodic shipments are allowed for, and will draw down the order quantity.

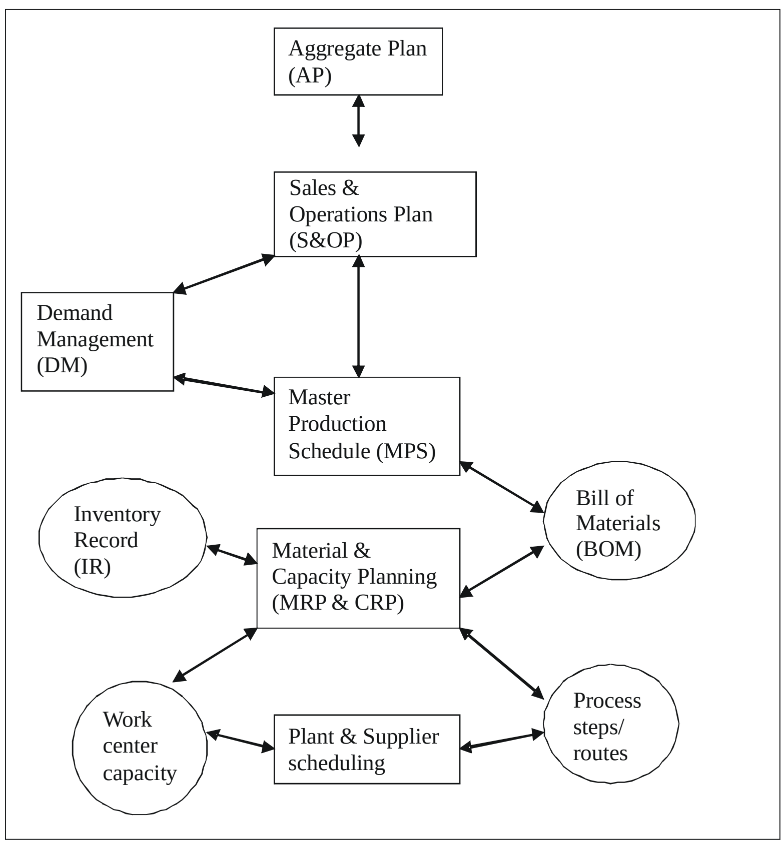

Fig. 5.2 *The MRP-II Process*

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This system works through several modules. The common among them are explained below.

1. **Master planning module:** This module derives the requirement from the annual business plan/aggregate plan/demand/customer orders/ forecasts made. It enables strategic planning and master scheduling of activities. It reports status of availability of products and raw materials on a time period.
2. **Materials planning module/ inventory module:** This module makes possible online transactions of receipts and issues at stores and records the material available on stock. It also maintains a record of the detailed specifications including the part/subpart number, drawings, make/buy details, rate of usage, where used, etc. It also enables the study of inventory such as amount of surplus and obsolete inventory, ABC/XYZ/FSN analysis, reconciliation with respect to physical inventory, allocation of materials for in-house orders, etc., printing of purchase requisitions, stores receipt vouchers, goods reciept note and, sometimes, purchase orders is also possible in this module.
3. **Materials and capacity planning module:** This module uses the master production schedule and the bill of materials to determine the requirements of various raw materials/ components/ sub-assembles/ assemblies, etc. It is also used to compare the production schedule with the availability of critical resources and provides MRP reports. This module also takes into account aspects such as machining capacities, fabricating capacity, assembling capacity, finishing capacity, testing capacity, packaging capacity, etc.
4. **Purchasing module:** Purchase orders are printed either in this module or the materials planning module. Besides, this module maintains data on suppliers and analyses vendor performance, rates vendors and correlates it for negotiations and placement of orders.
5. **Shop floor control module/ engineering data module:** This module is responsible for tracking information on manufacturing. It sequences the tasks that are to be performed for manufacturing a particular product and tracks the work order from the time it is initiated till its completion. All the parameters such as cost of material, labour and overheads are recorded and monitored. It includes feedback from the shop floor on how the work has progressed, to all levels of the schedule so that the next run can be updated on a regular basis. It also maintains record of maintenance: periodicity, parts required, status of machines indicating their life, repair records, etc.
6. **Cost accounting module:** This module calculates the absorbed overhead of materials and labour and does the costing. Financial reports are also generated such as overheads for each work center, work in process cost, purchase price reports, etc.

The modules stated above are not complete by themselves. Combinations of derivations of these modules are used in the industry. For instance, large companies

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would have a separate shop floor control module and a separate engineering data module, separate material control module and a separate inventory module, etc. The expertise is in identifying the requirements of the company and designing the modules accordingly.

An ABC analysis of the requirements of an MRP system shows that it relies on the

- Skill of people 75% (A class)
- Data accuracy 15% (B Class)
- Computer system 10% (C Class)

When implemented, the system streamlines the processes in a company by giving information to plan, responds to changes, meets delivery schedules and keep all the costs under control. MRP can be applied even by very small manufacturing companies to ensure a smooth flow of production.

5.3 JUST-IN-TIME (JIT)

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 1980s, started establishing their leadership in other industries such as automobiles and electronics. The full impact of the Japanese challenge hit the Americans. Companies like Xerox realized that the retail prices listed by the Japanese for small copiers were at or below even its own costs. Ford found that a Japanese Escort-sized car cost $1800 lesser than the Ford Escort in USA. When these companies investigated causes, they found that the manufacturing efficiency of the Japanese enabled the latter to manufacture their products at far lower costs.

Just-in-time (JIT):
A management philosophy that strives to eliminate sources of manufacturing waste by producing the right part in the right place at the right time

Study teams flew to Japan to see and learn what they were doing. They found that the Japanese had a different philosophy for manufacturing called 'just- in-time' or more commonly, JIT. **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. JIT can also be defined as an operations management philosophy. Its dual objectives are:

- To reduce waste
- To increase productivity

JIT (also known as lean production or stockless production) improves profits and return on investment by reducing inventory levels (increasing the inventory turnover rate), reducing variability, improving product quality, reducing production and delivery lead times and reducing other costs (such as those associated with machine setup and equipment breakdown). In a JIT system, underutilized (excess) capacity is used instead of buffer inventories to hedge against problems that may arise.

JIT applies primarily to repetitive manufacturing processes in which the same products and components are produced over and over again. Flow processes are established (even when the facility uses a jobbing or batch process layout) by linking work centers so that there is an even, balanced flow of materials throughout the entire production process, similar to that found in an assembly line.

Check Your Progress

1. What are the activities included in materials management?
2. What is Bill of Materials?
3. What do you understand by MRP-II process?

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The Textron Automotive Trim Division Plant at Michigan manufactures lower and upper interior door panels and other inside trim products such as arm rests for Daimler Chrysler cars, as well as the mini vans. The plant's high volume, high mix manufacturing process requires 134 door panels and thirty-seven additional interior components, with nine different colour combinations and twelve different fabric materials. The company had won many quality and safety awards and knew they were good. Nonetheless, their problem was that they had too much work in process and finished goods inventory. The surplus created production bottlenecks and hogged floor space. The excess inventory forced the company to lease space in another facility to make back side panels for the Chrysler minivans.

The company then adopted the JIT principle. This created a quantum leap in production, WIP plummeted by more than 60 per cent, and average finished goods inventory dropped from eight–ten hours to two hours. This inventory reduction freed more than 10,000 square feet of space and the company terminated the lease for production of backside panels for the Chrysler minivan and took it into its production line.

Over the years, lot sizes have been cut by 80 per cent and mold change time has been reduced by 50 per cent. The current mold change time is twenty-one minutes and the company has set itself a target of fifteen minutes in two years.

The plants' lean manufacturing success has enabled it to go after new businesses. They have now signed a contract with General Motors to supply them interior trim products. All this within the same factory premises!

The basic elements of JIT were developed by Toyota in the 1950s, and became known as the Toyota Production System (TPS). JIT was firmly in place in numerous Japanese plants by the early 1970s.

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 needed and no more.

JIT is fundamentally based on two tenets:

- Elimination of waste
- Respect for humans.

1. **Elimination of waste**

   Waste is defined as any activity that does not add value. Anything over the minimum amount necessary is waste. Waste results from any activity, that adds to its cost without adding value to it, such as moving and storing.

   Shigeo Shingo, a prominent management guru who promoted the use of JIT in manufacturing listed the 'famous seven wastes' as follows:

   - Waste of over production
   - Waste of waiting
   - Waste of transportation
   - Waste of stocks
   - Waste of motion
   - Waste of making defects
   - Waste 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 rejects, excessive materials handling, movement and time spent waiting for resources to become available, and overhead related to setup times and inspections.

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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 toward a common goal. In a JIT environment, considerable effort is dedicated to building teams. Work is handled by teams on the shop floor, rather than by individuals. Rather than have each worker on the assembly line responsible for a narrowly defined task, teams are charged with the responsibility to assemble the entire part. Workers are given more responsibility. In JIT companies, the following is seen:

Expanded job scope

In addition to performing their tasks, workers should suggest ways to improve their performance, perform 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 inventory and reduces the manpower required. Workers, however, will have to run several machines and processes hence their skill level increases. This increases their job security and commitment to the company.

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 twelve plants located in and around Toyota city. They find large operations and their bureaucrats difficult to manage. The bulk of Japanese plants (around 6,000 and counting) have between 30 and 1,000 workers.

Automation and process redesign

Monotonous and repetitive jobs are automated or designed out of the process. This makes the work environment better for the worker.

Employee empowerment

Workers are given the authority to stop the line. Thus they 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 layouts, can be implemented within finite time frames. The change to the work culture takes longer and is an ongoing process.

5.3.1 JIT process

Figure 5.3 below shows a normal operation in a factory.

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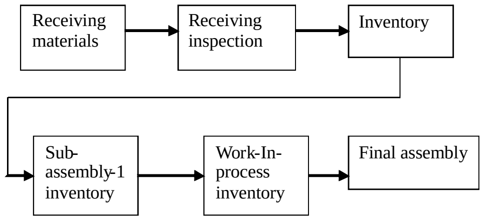

Fig. 5.3 *Normal Operation in a Factory*

In this figure, after incoming material is received and counted, it is inspected for quality and adherence to specification. If found all right it is accounted for and taken into the inventory. This is then sent to sub-assembly operation-1 shop floor, where it becomes the shop floor inventory. Work-in-process inventory follows sub-assembly operation-1. This 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 processes 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 helps to eliminate pile up of work in process inventory and also helps in continuous production, as shown in Figure 5.4.

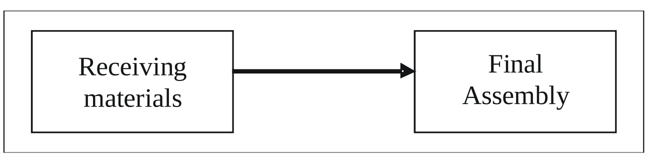

Fig. 5.4 *JIT Inventory Process*

In JIT, the management focuses on one goal: reducing work-in-process inventory. The question that is asked over and over again is, ‘why is inventory required?’ 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.

Companies that have implemented JIT have recorded phenomenal success. Harley Davidson returned from the brink of bankruptcy to regain its market share. Hewlett-Packard reported a $16 million reduction in inventory and a 65 per cent reduction in assembly floor space at its Waltham Plant. Corning reduced customer lead time from five weeks to a few days while achieving a 98 per cent on-time delivery to customers.

5.3.2 Advantages of JIT

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1. **Reduction in setup times**

When the setup time is large, economics dictates that the lot size must also be large. By reducing the setup time, lot sizes can be smaller and more production time is now available. Several products can be made at shorter intervals of time. Inventories can be reduced, capacity can increase and the company can respond more quickly to changes in demand. Setup time reduction can be accomplished by changing the process, introducing flexible automation or changing the setup procedure. One of the advantages of short setup times is that they facilitate 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.

The benefits of improving quality are as follows:

- Less rework
- Less allowance for scrap
- Less handling
- Let setups
- Less substitution of tools and materials

3. **Steps in the production process**

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 center to the stockroom and later from the stock room to another work centre, the double handling adds to cost with no increase in value.

Sometimes, the process steps can be reduced by changing the design of the product. Another example is the receiving inspection activity in most traditional factories. In a JIT factory, materials are directly delivered to the line at the point of use.

4. **Emphasis on maintenance**

For equipments to produce quality parts consistently, they must be in good condition. Japanese factories do not have modern equipment, they which, only have equipment that has been well maintained as a result, runs better.

A JIT factory has the discipline to allocate maintenance time on a regular basis. Workers are involved in performing maintenance activities. 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 brought about due to JIT gives a substantial reduction in throughput time as well as labour productivity for the organization. All these will directly translate into reduction in the manufacturing costs and resulting in an increase in profits for the company.

6. **Consolidating the supplier base**

In JIT, the supplier base is reduced to a manageable few, and communications with them are 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, deliveries can be scheduled more easily. For the supplier, it may yield economies in the suppliers that can be passed on to the buyer in terms of lower costs. The Japanese have been very successful in using this approach. They put together a tightly knit family of suppliers called *keiretsu* and have succeeded in obtaining a better quality at lower costs than their American competitors.

Even though JIT does an excellent job in reducing lead times and work-in-process, it has several disadvantages. They are:

(a) JIT has been successful basically in assembly line manufacturing.

(b) JIT requires a stable production plan (that is, without frequent changes in production plan).

(c) JIT is more effective when the number of products produced is less.

(d) 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.

(e) Suppliers need to be located nearby because the system depends on smaller, more frequent deliveries.

This is further discussed in unit 6.

5.3.3 The 'Kanban' System

'**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 the Kanban system, imagine two work centers A and B. Work center A produces a part which is kept in a bin. Work center B uses the parts from that bin. When the bin gets empty, it is a signal for work centre A to refill it. This empty bin is the Kanban signal.

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Kanban:
The name given to small cards attached to containers which hold a standard quantity of a single part number

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The following example shows how the Kanban system works in an industrial setup.

Company A buys parts at the rate of 1,000 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 9.00 AM, delivers them at noon and returns to the supplier by evening.

This means the supplier should be getting ready 1,000 parts for supply the next day. There should also be 20 empty containers available at the supplier's factory, by the evening of the previous day.

On Day 1, the truck leaves the supplier's 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 available with them. 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 has returned, the supplier has completed the 20 containers of work. On Day 2, the same schedule repeats.

This system has 60 Kanban containers. The inventory in the system is 30 full containers.

Hour of Day	***Supplier***	***Truck***	***Company A***
9.00 AM	20 E	20 F	10 F, 10E
12.00 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 center to the next
- A Production card to authorize the production of parts by the work center.

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 entire production inventory is located on the plant floor. At each work center, they have established points where incoming inventory would be delivered. The objective is to have inventory easily accessible. When the work center 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 centers, the containers are a standard size, which are fixed lot sizes. The standard container size also affects the inventory level. This concept is further discussed in unit 6.

The following example will demonstrate how to calculate the number of kanbans required.

Example 5.3

The demand at a work centre A is 100 units per hour. The container size is 25 units. Assume that the materials handler comes every hour to check the box and that if there is a move card, it will take another hour to fill the request. Using a safety factor of 5 per cent, how many production and move kanbans are required? What is the average inventory level? What happens when the container size is increased from 25 units to 50 units? If the materials handler picks up the kanbans every half hour, calculate the number of kanbans required and the average inventory level.

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Solution

No. of containers required per hour = 100/25 = 4

Lead time — 2 hours (i.e., materials handler comes every hour to check and then it takes one more hour to fill)

Therefore, no. of kanbans required — 4×2×(1+0.05) = 8.4 or 9 kanbans

Average inventory level — 9×25/2 = 112.5 units

If container size is 50, no. of kanbans required is 9/2=4.5, or 5

Average inventory level — 5×50/2= 125 units

If materials handler checks every half hour, lead time — 1+1/2=1.5 hours

No. of kanbans required — 6.3 or 7 (by the same method)

Average inventory level — 7×25/2=87.5 units

5.3.4 Difference between JIT and MRP Systems

The MRP system is a push system, meaning that the production at one work centre depends on it's detailed production schedule — it is produced and 'pushed' to the next production stage, without considering whether the second stage needs it or not. But JIT is a pull system, i.e., parts are pulled from the previous work station only when required. A push system such as MRP starts with a forecast of customer demand and production lead times are then estimated. Incorrect forecasts and estimates result in excess inventory and longer lead times. The weakness of JIT is that the system allows no room for even a slight error in judgement. Smaller lot sizes and near zero inventory gives no room for force majeure conditions, which are beyond control.

In MRP, the administrative costs are high. It relies on technology and its effective use for success. However, JIT is a very simple system that requires almost no administrative cost to maintain it. Commitment of humans is the only investment. Inventory turns are very high due to almost zero inventory. Where there is human commitment, JIT system is bound to succeed.

5.4 NETWORK TECHNIQUES

Network scheduling is a technique used for planning and scheduling large projects, in the fields of construction, maintenance, fabrication and purchasing of computer systems, etc. It is a method of minimizing the trouble spots such as production, delays and interruptions, by determining critical factors and co-ordinating various parts of the overall job.

There are two basic planning and control techniques that utilize a network to complete a predetermined project or schedule. These are Programme Evaluation Review Technique (PERT) and Critical Path Method (CPM).

A project is defined as a combination of interrelated activities, all of which must be executed in a certain order for its completion.

The work involved in a project can be divided into three phases, corresponding to the management functions of planning, scheduling and controlling.

Planning: This phase involves setting the objectives of the project as well as the assumptions to be made. It also involves the listing of tasks or jobs that must be performed in order to complete a project under consideration. In this phase, in addition to the estimates of costs and duration of the various activities, the manpower, machines and materials required for the project are also determined.

Scheduling: This consists of laying the activities according to their order of precedence and determining the following:

(*i*) The start and finish times for each activity

(*ii*) The critical path on which the activities require special attention.

(*iii*) The slack and float for the non-critical paths.

Controlling: This phase is exercised after the planning and scheduling. It involves the following:

(*i*) Making periodical progress reports

(*ii*) Reviewing the progress

(*iii*) Analyzing the status of the project

(*iv*) Making management decisions regarding updating, crashing and resource allocation, etc.

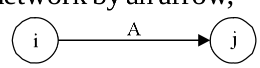
Basic Terms

To understand the network techniques, one should be familiar with a few basic terms of which both CPM and PERT are special applications.

Network: It is the graphic representation of logically and sequentially connected arrows and nodes, representing activities and events in a project. Networks are also called arrow diagrams.

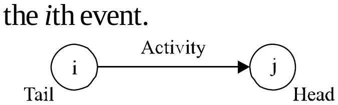
Activity: An activity represents some action and is a time consuming effort necessary to complete a particular part of the overall project. Thus, each and every activity has a point of time where it begins and a point where it ends.

It is represented in the network by an arrow,

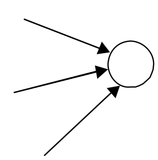


Here *A* is called the activity.

Event: The beginning and end points of an activity are called events or nodes. Event is a point in time and does not consume any resources. It is represented by a numbered circle. The head event called the *j*th event always has a number higher than the tail event, which is also called the *i*th event.



Merge and burst events: It is not necessary for an event to be the ending event of only one activity as it can be the ending event of two or more activities. Such an event is defined as a merge event.



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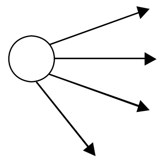
If the event happens to be the beginning event of two or more activities, it is defined as a burst event.



Preceding, succeeding and concurrent activities: Activities that must be accomplished before a given event can occur, are termed as *preceding activities.*

Activities that cannot be accomplished until an event has occurred, are termed as *succeeding activities.*

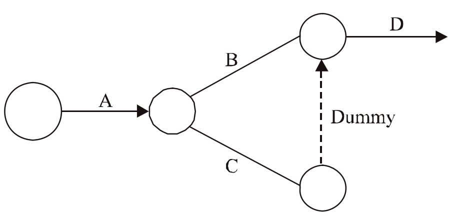
Activities that can be accomplished concurrently, are known as *concurrent activities.*

This classification is relative, which means that one activity can be preceding to a certain event, and the same activity can be succeeding to some other event or it may be a concurrent activity with one or more activities.

Dummy activity: Certain activities, which neither consume time nor resources but are used simply to represent a connection or a link between the events are known as dummies. It is shown in the network by a dotted line. The purpose of introducing dummy activity is:

(*i*) To maintain uniqueness in the numbering system, as every activity may have a distinct set of events by which the activity can be identified.

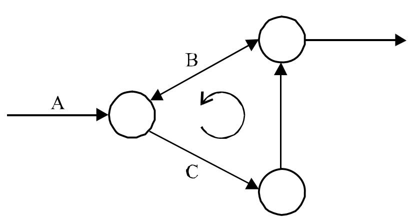
(*ii*) To maintain a proper logic in the network.



Common errors

Following are the three common errors in a network construction:

Looping **(*cycling*):** In a network diagram, a looping error is also known as cycling error. Drawing an endless loop in a network is known as error of looping. A loop can be formed if an activity is represented as going back in time.



Dangling To disconnect an activity before the completion of all the activities in a network diagram, is known as dangling.

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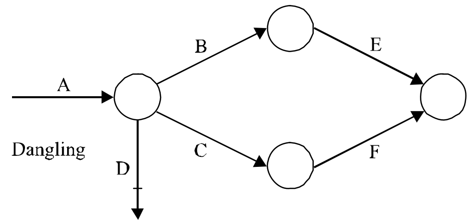
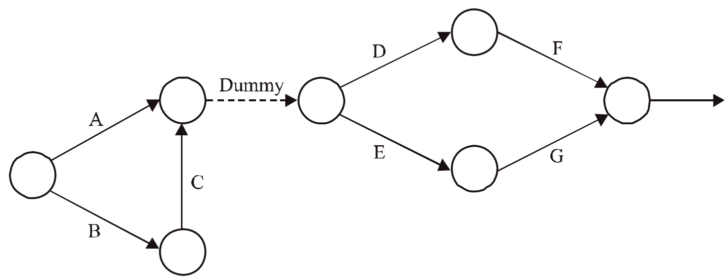


Redundancy: If a dummy activity is the only activity emanating from an event and can be eliminated, it is known as redundancy.



Rules of Network construction

There are a number of rules in connection with the handling of events and activities of a project network that should be followed.

(*i*) Try to avoid arrows that cross each other.

(*ii*) Use straight arrows.

(*iii*) No event can occur until every activity preceding it has been completed.

(*iv*) An event cannot occur twice, i.e., there must be no loops.

(*v*) An activity succeeding an event cannot be started until that event has occurred.

(*vi*) Use arrows from left to right. Avoid mixing two directions, vertical and standing arrows may be used if necessary.

(*vii*) Dummies should be introduced only if it is extremely necessary.

(*viii*) The network has only one entry point called the start event and one point of emergence called the end or terminal event.

Critical activity: An activity is said to be critical if a delay in its start cause a further delay in the completion of the entire project.

We shall use the following notation for basic scheduling computations.

(i, j) = Activity (i, j) with tail event i and head event j

Tij = Estimated completion time of activity (i, j)

$ESij$ = Earliest starting time of activity (i, j)

$EFij$ = Earliest finishing time of activity (i, j)

$LSij$ = Latest starting time of activity (i, j)

$LFij$ = Latest finishing time of activity (i, j).

Critical path: The sequence of critical activities in a network is called the critical path. It is the longest path in the network, from the starting event to the ending event

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and defines the minimum time required to complete the project. In the network it is denoted by a double line and identifies all the critical activities of the project. Hence, for the activities (i, j) to lie on the critical path, following conditions must be satisfied.

(a) $ES_i = LF_i$

(b) $ES_j = LF_j$

(c) $ES_j - ES_i = LF_j - LF_i = t_{ij}$

ES_i and ES_j are the earliest start and finish time of the events i and j.

LF_i and LF_j are the latest start and finish time of the events i and j.

Critical Path Method (CPM)

The iterative procedure of determining the critical path is as follows:

Step 1 List all the jobs and then draw an arrow (network) diagram. Each job is indicated by an arrow with the direction of the arrow showing the sequence of jobs. The length of the arrows has no significance. The arrows are placed based on the predecessor, successor and concurrent relation within the job.

Step 2 Indicate the normal time (t_{ij}) for each activity (i, j) above the arrow, which is deterministic.

Step 3 Calculate the earliest start time and the earliest finish time for each event and write the earliest time E_i for each event i in the $\boxed{}$. Also calculate the latest finish and latest start time. From this we calculate the latest time L_j for each event j and put it in the Δ.

Step 4 Tabulate the various times, namely, normal time, earliest time and latest time on the arrow diagram.

Step 5 Determine the total float for each activity by taking the difference between the earliest start and the latest start time.

Step 6 Identify the critical activities and connect them with the beginning and the ending events in the network diagram by double line arrows. This gives the critical path.

Step 7 Calculate the total project duration.

Note: The earliest start and finish time of an activity, as well as the latest start and finish time of an activity are shown in the table. These are calculated by using the following hints.

To find the earliest time, we consider the tail event of the activity. Let the starting time of the project namely $ES_i = 0$. Add the normal time with the starting time, to get the earliest finish time. The earliest starting time for the tail event of the next activity is given by the maximum of the earliest finish time for the head event of the previous activity.

Similarly, to get the latest time, we consider the head event of the activity.

The latest finish time of the head event of the final activity is given by the target time of the project. The latest start time can be obtained by subtracting the normal time of that activity. The latest finish time for the head event of the next activity is given by the minimum of the latest start time for the tail event of the previous activity.

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Programme Evaluation and Review Technique (PERT)

The network methods discussed so far may be termed as deterministic, since estimated activity times are assumed to be known with certainty. However, in the research project or design of a gear box or a new machine, various activities are based on judgement. It is difficult to obtain a reliable time estimate due to the changing technology since time values are subject to chance variations. For such cases, where the activities are non-deterministic in nature, PERT was developed. Hence, PERT is a probabilistic method, where the activity times are represented by a probability distribution. This distribution of activity times is based on three different time estimates made for each activity, which are as follows:

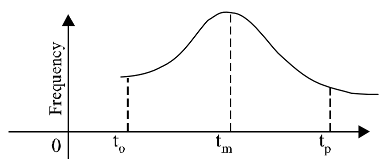
(*i*) Optimistic time estimate (*ii*) Most likely time estimate

(*iii*) Pessimistic time estimate

Optimistic time estimate: It is the smallest time taken to complete the activity, if everything goes well. There is very little chance that an activity can be completed in a time less than the optimistic time. It is denoted by t_o or a.

Most likely time estimate: It refers to the estimate of the normal time the activity would take. This assumes normal delays. It is the mode of the probability distribution. It is denoted by t_m or m.

Pessimistic time estimate: It is the longest time that an activity would take, if everything goes wrong. It is denoted by t_p or b. These three time values are shown in the following figure.



Time distribution curve

From these three time estimates, we have to calculate the expected time of an activity. It is given by the weighted average of the three time estimates,

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$

[β distribution with weights of 1, 4 and 1, for t_o, t_m and t_p estimates respectively.]

Variance of the activity is given by,

$$\sigma^2 = \left[\frac{t_p - t_o}{6}\right]^2$$

The expected length (duration), denoted by to T_c of the entire project is the length of the critical path, i.e., the sum of the t_c's of all the activities along the critical path.

The main objective of the analysis through PERT is to find the completion for a particular event within the specified date T_s, given by $P(Z \le D)$ where,

$$D = \frac{\text{Due date} - \text{Expected date of completion}}{\sqrt{\text{Project variance}}}$$

Here, Z stands for standard normal variable.

Check Your Progress

4. Fill in the blanks with appropriate works.
   (a) Materials management involves the ________ mix.
   (b) _______ demand items are forecast and specified on MRP.
   (c) Design for _____ means that product designers take into account the manufacturing capabilities, as they design the product.
   (d) The ____ system is a push system.
5. State whether the following statements are true or false.
   (a) Waste is defined as any activity that does not add value.
   (b) When the setup time is large, economics dictates that the lot size must be small.
   (c) Kanban means *signboard* in Japanese.
   (d) In MRP, the administrative costs are low.

5.5 SUMMARY

- Materials management is the subdivision of logistics that corresponds to the actual components of a supply chain.
- Materials management includes the following activities: purchasing, procurement, distribution and warehousing.
- Material requirement planning is a combination of computerized inventory control, production planning, management information system and manufacturing control system.
- Just-In-Time Manufacturing: JIT is a viewpoint of incessant upgrading in which non-value-adding activities (or wastes) are recognized and removed with the intention of:
  - o Decreasing cost
  - o Enhancing quality
  - o Performing better
  - o Making delivery better
  - o Augmenting flexibility
  - o Boosting innovativeness
- A Kanban system is a channel to accomplish Just-in-time (JIT) production. It works on the principle that every procedure on a production line pulls only the quantity and category of components the process requires, at just the right time. The procedure used is a Kanban card. This is generally a physical card. However, other devices can also be used.

5.6 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Materials management generally includes the following activities:
   - Purchasing
   - Procurement
   - Distribution
   - Warehousing
2. 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 requirements for a given production schedule during a specific time period.
3. MRP-II is a company-wide system concerning all facets of business including sales, production, engineering, inventory and cash flows.
4. (a) purchasing

   (b) Independent

   (c) manufacturability

   (d) MRP
5. (a) True

   (b) False

   (c) True

   (d) False

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5.7 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is the importance of materials management?
2. What are the drawbacks of the MRP system?
3. How is employee empowerment beneficial?
4. Define the two-card Kanban system.
5. How are JIT and MRP systems different?

Long-Answer Questions

1. Explain the pre-requisite inputs for MRP.
2. Write a note on the MRP process.
3. List and explain the modules of the MRP-II process.
4. Discuss the tenets of JIT.
5. What are the advantages of implementing JIT?

UNIT 6 QUALITY MANAGEMENT

NOTES

Structure

6.0 Introduction
6.1 Unit Objectives
6.2 Quality Concepts
6.3 Quality and Business
6.3.1 Quality Policy
6.3.2 Continuous Improvement
6.3.3 Implementation of Total Quality Control
6.4 Statistical Approach to Quality Control
6.4.1 Quality Planning and Improvement Tools
6.5 Continuous Improvement Tools
6.6 Summary
6.7 Answers to 'Check Your Progress'
6.8 Questions and Exercises

6.0 INTRODUCTION

Quality is regarded as the most dominant feature to arrest, hold on to and expand customer base in the contemporary business state of affairs. The most important factor of any business is to achieve customer satisfaction and quality management is the most efficient endeavor approach. The quality management pertaining to the highest level of development in time is a personification of concepts, methods and applications. In the past few years, the world of commerce has come across a large number of real life success stories.

Scheduling and accomplishing superior quality is a base for the successful working of companies. This makes it necessary to understand and manage a variety of movements in a company for the purpose of setting goals and optimum deployment of resources. The competence and efficacy by which resources are acquired and put to use depends on superior management exercises adopted by organizations. Quality management also renders it necessary for the system to measure, examine and progress various metrics associated with business processes. Affiliation among business processes, their metrics and business accomplishments are influenced by the manner in which an enterprise manages concerns associated with quality. Quite many innovative approaches are required for harmonizing the intent of the associates of the enterprise and the requirements of the clientele, as there are numerous contradictory objectives such as improved quality of customer service, low inventory, low unit cost, etc.

6.1 UNIT OBJECTIVES

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

- Classify quality concepts
- Identify the significance of quality in business
- Discuss the statistical approach to quality control
- Describe the process of quality planning
- Explain continuous improvement tools

6.2 QUALITY CONCEPTS

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Quality, in generic term, relates to the 'features' or 'characters' or some 'attributes' of a product or service or similar offerings. The attributes or features or characters of the product or service should be such that they meet and fulfil the needs of users, i.e. the customers.

To illustrate, let us consider a wrist watch, which

- must give accurate time
- must be durable and weather-proof
- convenient to adjust time, date, etc
- should be easy to read the dial
- should offer value for the money, i.e. cost-effective
- should meet any other specific needs, e.g. style and look, casing and casing material, band, cost, reliability, maintainability, etc., and
- should satisfy any perceived needs – like the brand image, class, etc.

Any deficiency in these features or quality, from the needs of a customer, may lead the customers either not to buy or to complain about the product if it has been already purchased. This means that failure of the quality will cause customer dissatisfaction and entail quality complaint. Therefore, to satisfy the needs of a customer in a business, it is imperative to ensure and maintain the quality of a product or service for winning and retaining the customers.

It is erroneous to assume that quality means something extra in the product or services for customers. In reality, quality is an essential feature of any product or service, which induces a customer to buy that product in order to satisfy his needs. Hence, quality must be built and maintained in any product or services for satisfying the given needs of customers. As mentioned earlier, American Society for Quality (ASQ) has defined the quality as 'the totality of features and characteristics of a product or service that bears on its ability to satisfy the given needs'. Therefore, quality must always be built into the products or services to satisfy the needs of a buyer i.e. the customer.

Quality is assured in products by "conformance to customers' requirements". Dimensions of quality – which should completely define and describe the state of quality – originate from this requirement of conformance to customers' specification. In order to conform to customer specification, the following parameters must be set and maintained in the quality management process, namely:

- Requirements of customers must be clearly captured, stated and defined in the form of quality specification – leaving no scope for misunderstanding
- Setting quality goals to be attained
- Planning and designing appropriate quality features in the product or services
- Measuring and checking for conformance or non-conformance to specification
- Maintaining the quality characteristics by appropriate means and measures, and
- Dealing with non-conformance by corrective and preventive actions.

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These features of quality management system are considered pre-requisites for ensuring (a) the conformance to what customers want, and (b) consistency in manufacturing for quality. Figure 6.1 illustrates this cycle of activity steps in the quality management system.

Therefore, if quality, in generic terms, is understood as the requirements of a customer for fulfilling a given need, which is expressed in the form of specification, the task of quality management should be ensuring the conformance to that specification. This means that quality can be referred to as the conformance to specification, where the specification has been developed from the expressed needs of the customer. Since quality is the means to meet and satisfy the customers' requirements, its importance has rapidly increased with increasing competition in business and industries. Satisfying the needs of customers by consistently maintaining the required quality in products and services has become an essential part of business operations for winning the confidence of customers, and gaining the market share under competitions. Therefore, companies all over the world are paying more and more attention to quality issues to ensure that their products and services meet the customers' needs and enjoy the confidence of customer, which is the basis of building reputations and brands in the market place.

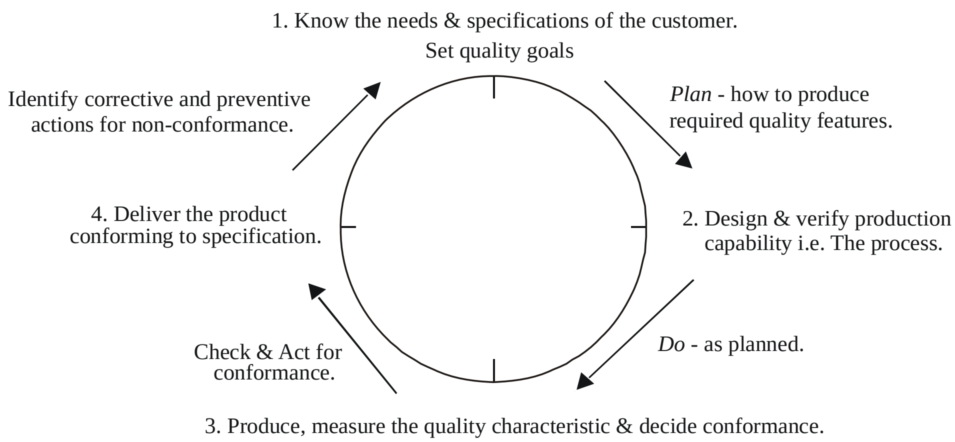

Fig. 6.1 *An Illustrative Cycle of Quality Management Showing the Essential Steps in Quality Management System*

Thus, the challenges of quality refers to planning, producing and meeting total specifications of goods or service that satisfy the customer's needs with respect to features, characteristics (properties), timelines, appropriateness, safety, maintainability, usability and affordability. Affordability implies value for the money spent to acquire the product or service, which in a competitive market scenario would mean producing at least cost without sacrificing any quality. This is, no doubt, the greatest challenge that industries are facing nowadays, but meeting this challenge has become a critical factor for the success of any business or industry. The steps for maintaining this quality are: setting quality goals after understanding the needs and specification of users, planning a cost effective process, producing as planned with least variations of properties, measuring conformance, taking corrective and preventive actions to reduce non-conformance, working for continuous improvement and delivery on time. In view of severe competitions and changing business environment, setting appropriate quality goals and designing the products and processes to meet the customers' needs and expectations have become critical for success.

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Jack Welch – the charismatic CEO of General Electrics, the giant US Corporation, adopted three initiatives to turn around the company – (1) quality, (2) services, (3) globalization. Quality initiative launched by GE was to recreate the processes so that defects and errors did not occur in the first place. Traditional quality initiatives were mostly concerned with detecting and correcting quality faults, which were proving to be too little and too late for efficient and cost-effective running of the business in the face of global competition. Services initiatives changed GE from a traditional provider of highly engineered products to a source of customer-focused high-value high-quality engineering solutions to problems and requirements of customers. Globalization meant to GE looking for a diverse market with competitive products and services to serve the global customers having diverse needs and service requirements. These concepts that turned GE around are not new, but were cast in the right perspective of the company and pursued with the right spirit. These concepts belong to 'Total Quality Management' (TQM) principles, in true spirit and purpose. So great is the force of these 'Total Quality' initiatives that when properly adopted and lead by a visionary leadership (as Jack Welch), it could turn a giant company like GE to its present strength and glory within a span of two to three years. But, this dimension of quality – encompassing customer-focus, value-added products and services, and vision of globalization and world-class quality – developed over the toils of many "Quality Masters", industry leaders and academics, spanning several decades. These pioneers of quality movement systematically examined what ailed a company's performance, what needed to be done to eradicate the ills, and developed many path-breaking tools and techniques to give effect to their recommendations for overcoming the deficiencies in the approach to maintain quality in all spheres of company activities. They all identified "Quality" as the key driver for superior business performance, and established "total quality" as the means to business excellence. This unit will attempt to provide some background of "why and how" of the quality concept that was developed over the years by these quality pioneers, and how it was integrated into the modern business process as an essential tool for success.

6.3 QUALITY AND BUSINESS

It is said that a business exists for its customers, and not vice-versa. Therefore, a cardinal task of the business process is to take care of the needs and expectations of its customers. From previous discussions, it would be clear at this stage that the means of winning and retaining customers is nothing less than assuring the quality, utility, affordability and availability of a product or service, which, in turn, involves integrating and assuring quality in all related business processes–direct or indirect. Business processes are not independent entities; they are *interrelated* with each other and none of the processes can stand alone to serve any interest of a company. For example, the purchasing department is related to Production for meeting the schedule of production, which in turn, is related to Marketing as per their ability to sell; finance is related to the collection of money from the sales proceeds and other sources to ensure timely availability of this resource for funding projects, expansion, paying wages, meeting materials bills, etc. For timely and appropriate meeting of the needs of customers and other stakeholders in the company, it is not enough for these functions to act in a traditional and co-ordinated manner; they have to act unitedly by forming cross-functional processes with focus on customers and fast response to customer needs. This is the core concept of modern quality management, which total quality management philosophy has propagated.

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Role of quality in achieving superior business performances was demonstrated by several studies in USA, leading them to adopt total quality as a means for resurgence of American industries in the 1980s. In recognition of this necessity, the *Malcolm Baldrige National Quality Award* was instituted in USA in 1987 for encouraging industries to adopt total quality in their business process management. With the success of Japanese industries in a competitive market, it was fully established that quality drives the market share of the business. The Japanese adopted a total quality culture from the beginning of the 1960s, leaving all others in the race for industrial growth. As quality improves, so does cost, market share and ultimate profitability that leads to further investment and growth. Thus, quality serves the very purpose of a business, which is creation of wealth and welfare for all of its stakeholders–namely customers, employees, suppliers, shareholders, society, government etc. Examples of such business success due to quality are many now in India, namely Maruti Udyog Ltd., Infosys, TCS, Tata Steel, Tata Motors, Hero-Honda and many others. Figure 6.2 presents a bird's eye view of the influence of quality in improving business operations, whose primary aim is to improve profitability for growth.

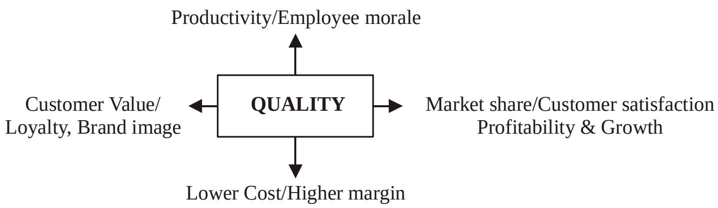

Fig. 6.2 *A Bird's Eye View of Quality and Profitability*

However, achieving these multifaceted advantages of quality needs maintaining quality in all functions, processes and activities of the business, which sums up to "total quality" in the organization. However, quality is not a static landmark; as the customers become more demanding and competition grows, quality also has to continue to improve in order to retain or further acquire the market. Hence, the special characteristic of total quality programme is to encourage and engage in the drive for continuous improvement in all business processes.

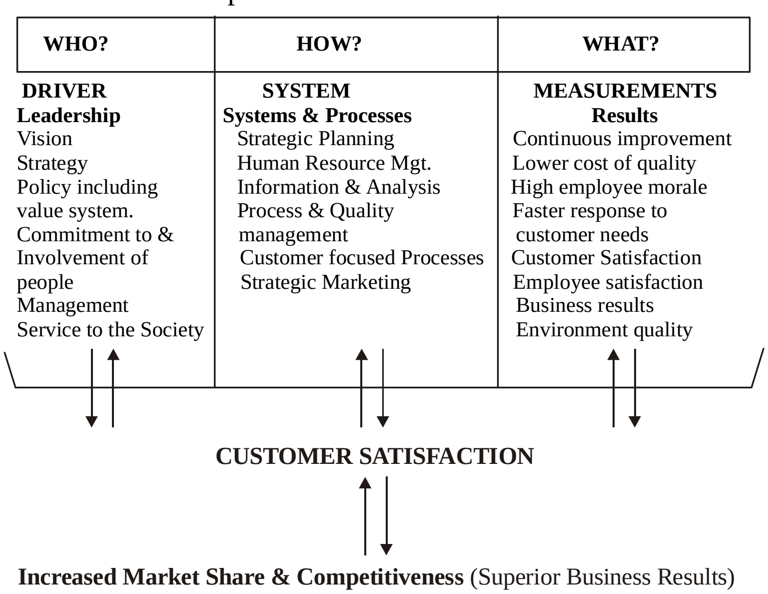

Fig. 6.3 *Process Chain for Total Quality Management*
(Adapted from IBM's Market Driven Quality Programme Framework)

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The value of a product or service in the market place is influenced by its quality characteristics. Improvements in performance, features, reliability and maintainability will differentiate the product or service from the rest. Hence, quality makes the best business sense by improving the company's reputation, changing the customers' perceived value for the product or service, creating brand, and increasing profitability. Examples of beneficiaries of such quality philosophy are: Sony Corporation, Toyota Motors, Microsoft, Infosys, etc. It is not uncommon to find that customers today are basing their purchasing decisions on value for the money that a product provides. And, this value comes from the commitment to quality and continuous improvement.

Managing competition is the challenge to modern business organizations. The most effective means to manage competitions is meeting and exceeding customer expectations by managing continuously improved quality. There are several quality related dimension of a business that differentiates it from the competition. For example:

- Superior product design
- Continuous improvement
- Outstanding service/Customer care
- Higher flexibility in operations and variety
- Faster response to customer needs

Managing business processes using a traditional functional structure and quality set-up is often inadequate to meet this challenge. Pursuing total quality – that involves quality in every aspects of the business – helps improvements in all these dimensions simultaneously. Addressing these quality related dimensions of a business through a "total quality programme" has changed the way of doing business. The traditional method of managing business processes by functional structuring has changed to cross-functional processes that run horizontally across all related functions. The purpose of such quality orientated process structuring is to serve the customers better and build efficiency for faster response and flexibility in the organization. Figure 6.3 presents a view of who, how and what drives the modern business process and systems for gaining customer satisfaction and superior business results.

Arrows in Figure 6.3 would indicate that customer satisfaction is central to the total quality management system, which is derived from the leadership quality, systems and processes of the organization. They must be directed or designed to serve the customers and customer satisfaction through enhanced and improved quality, which in turn, results in increased market share and improved business results.

It should be noted at this stage that this approach to superior business results through process restructuring, cross-functional process teamwork and focus on customer satisfaction, equally apply to both manufacturing and service sectors of industries. Because, business of any type – be it manufacturing or service – has its own set of customers, and satisfying the needs and expectations of those customers is essential for the success of the enterprise. Thus, a total quality approach in business processes of either manufacturing or service has become the order of the day. With the rapid growth of service sectors in a developing economy (as in India), more and more service sector companies are adopting the total quality approach by recasting their business processes in line with TQM practice. Prominent service sector companies – like the IT sectors, financial services, telecommunication services, healthcare, retail business, etc. – are redesigning (or recreating) their business processes as per the principles of total quality in order to win over the customers by providing value added products and services in a fiercely competitive market. (Products in service sector mean the offerings of a package of facilities, enabling software, etc.). Adoption of total quality approach helps them to keep the customer needs in focus, and design their business processes to satisfy those needs – be it the quality, timeliness or cost. Recognizing the significance of total quality approach in a competitive business, IT giants like the Infosys and TCS in India quickly adopted TQM in their business operations and soon became the global leader in the field of providing world-class IT services. Both these companies were recognized and awarded for their quality excellence in India and abroad. Therefore, the total quality approach to business process is not confined to manufacturing sector only; it is being found equally (if not more) relevant and applicable to all service sectors where the customer demands and expectations are more diverse (than the manufacturing sector) and critical for the success of the business. Thus, quality (i.e. total quality) is no longer a functional approach to business management; it has to be made an integral part of any kind of business process that has customers at either ends of the process chain (either internal or external customers) and satisfaction of those customers is at the centre of the success of the business.

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6.3.1 Quality Policy

TQM is a top-down culture in an organization, requiring the commitment and involvement of the top management for its success. It is the vision of leadership (i.e. top management) that guides the organization and its people in the course of total quality. Top management in a TQM organization is responsible to promote a set of *values, vision and mission* of the company, upon which a Quality Policy for the entire organization is framed and followed. The vision, mission and values, as set by the leadership, provide the direction for quality planning, which, in turn, acts as the foundation for all quality management activities and systems. Therefore, they are the basis for formulating Quality Statement or Quality Policy by the management.

Quality policy is a statement of intent, describing the overall intention and direction of the company as regards the quality management system of its products and services. Since customer satisfaction is the focus of the modern quality management system, this statement should relate to the needs and interest of customers and continual improvement of products and systems as a means of satisfying and exceeding the expectations of customers. One of the features of a good quality management system (highlighted in the introduction) is the involvement of people in attaining quality goals. Therefore, the quality statement should be inspiring to the people of the organization to draw their involvement and commitment.

A typical Quality Policy statement could be:

“The company will strive to produce and deliver superior quality goods and services to its customers by benchmarking the quality levels with world-class leaders, investing in latest technology, and training its workforce for developing high-class skills and competence.

A committed and skilled workforce, teamwork, customer-first work-culture, and innovation will be the means of accomplishing the quality goals, and the motto will be customer satisfaction and delight at any cost”.

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It should be noted that the quality policy statement has the component of intent (e.g. customer satisfaction and delight by delivery of superior quality of goods and services), and means (e.g. by benchmarking, latest technology and training of people, teamwork, innovation etc.) Such a statement helps the organization to set its course of actions and processes for attainment of goals. Therefore, a quality policy statement should satisfy these features for guidance and clarity.

Since values, vision and mission are important components of the process of formulating quality policy, they need to be understood in the context of quality strategy.

Values: Values are the core beliefs about what is important to an organization and what should drive success in the journey towards vision of the company. Values guide what should be the attitude towards and policies for customers, employees and other stakeholders, and they should be followed throughout the organization, and lived up to by example by all employees of the organization, irrespective of rank and designation. Some important values are: integrity, professional ethics, transparency in dealings, customer-first attitude, credibility, trustworthiness, etc. Values provide the means to decide how the course of a journey towards the vision should be undertaken, i.e. a value-based company will not trample the professional ethics or integrity or customer's interest to set up a new business or penetrate a new market. The choice of values and their propagation in the organization's work culture is essential for implementation of total quality culture, and this is the role of leadership in the organization. Quality policy should adequately demonstrate the values by which the company intends to accomplish quality goals. For example, customer-first work culture and teamwork in the quality policy statement reflects the value system.

Vision: Formulation of the vision statement is fundamental to the functioning of leadership. The vision statement should clearly point to organization's focus in its functioning, idea about its destiny, where it wants to go and how. The purpose of vision statement is to bind and inspire all people into a common objective, transform all activities into focused goals, and create enthusiasm in the work environment. Therefore, in designing vision, leadership should have the foresight for the future, respect for the quality culture, and understanding of human psychology and forces of competition. A typical vision statement can read as:

> We shall be the industry leader in the country in our chosen field of business by 2010 through new market penetration, launching of new and contemporary products, and providing world-class goods and services to the customers with assured satisfaction. Value addition, customer care and continuous improvement of products and services will be our hallmarks.

A vision statement should be clear about what, when and how; it should be exciting to the people in the organization, and should link to the needs of customers. Since a vision statement should bind people together for future direction, it should be clearly communicated and explained to all the people in the organization.

Mission: The mission statement defines the purpose of the company and the role it wants to play in broader social, economical, national or environmental perspectives. Sometime mission is also referred to as "purpose" of the company, because it outlines what business it wants to be in and why. Therefore, the mission statement will differ widely as per the nature of business.

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For example: a Bank may state its mission as, To be in financial services business, and provide competitive financial services to its customers, promote economic prosperity of the society, and contribute to overall national development. Whereas, an educational institution may set its mission as, To foster national progress through development of professional skills and entrepreneurial spirit.

However, both statements contain what business they want to be in and why, and relate their purpose to a national or social cause.

Both vision and mission lay the milestones for the quality policy to provide direction and quality goals. They provide the foundation upon which the quality policy should be framed and worked out, and this quality policy becomes the starting point for the journey to total quality in the organization. Setting the vision, mission and quality policy that motivates and enthuses the people in the organization, is the task of leadership.

6.3.2 Continuous Improvement

Continuous improvement is the main vehicle of a total quality system for meeting and exceeding the customer needs and expectations. Many may claim that continuous improvement is a one amongst many tools for improvement, but, in reality, it is a philosophy that is deep routed in the concept of total quality. All quality management systems of the modern era advocate a continuous improvement programme as a part of quality system e.g. TQM, ISO-9000, QS-9000 etc. Continuous improvement has come to be recognized by the industries and business as the main vehicle for growth in a customer sensitive competitive marketplace. It implies a system of planned and uninterrupted activity for carrying out further improvements and development with a belief that there is no end to improvements. For both planning and carrying out improvement programmes, a number of quality planning and statistical tools are available, and the work involves extensive uses of these tools.

Continuous improvement represents a process of (1) identifying areas of operations that need improvement, (2) systematically determining and isolating root-causes of the observed deficiencies in performance, (3) remedying the performance problem by eliminating the root-causes, (4) stabilizing the system by standardization of the new parameters and practices so that the system functions effectively to hold to the gains established by the programme, and (5) continue to look (or work) for new opportunities for improvements. What a continuous improvement cycle implies is that the process chain does not stop at attaining a one-time improvement; it continues to look for new opportunities for further improvement and follow-up actions continually. It should be noted that these philosophical steps of continuous improvement have their routes in the principles of Deming's P-D-C-A cycle and Juran's Quality Trilogy (these will be discussed in the next chapter). However, working out a real problem for continuous improvement will involve use of many statistical tools and improvement techniques. For example, the process capability study of a manufacturing line by following the control chart technique of statistical methods would be essential for improving quality capability and reducing the cost of poor quality. Similarly, application of the histogram and Pareto diagram would be necessary to pinpoint the root causes from amongst many.

The system of continuous improvement applies to all processes and activities of the organization i.e. it is not confined to product or process quality only. If there is a

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lack of human quality or leadership quality or necessity for improving cash-flow management, a continuous improvement programme can be launched and worked for. It is a critical requirement in all activities of the organization for ensuring quality of operations, total customer satisfaction (considering that there is a customer for any activity in the organization who derives some benefits from the actions), and gaining competitive advantage. The essence of continuous improvement is the belief that improvements in any area are a never-ending chain of activities for doing better and better, time and again. Therefore, for the success of continuous improvement programmes, an organization must train its people to think outside the box and promote creativity and innovation in the workplace. The aim of this step is to create a work environment that leads to changing the mind-set of working people and creation of a new work culture where commitment to improvements and orientation towards continued thinking and working becomes a part of daily life. Creative thinking and an innovative approach to problem solving is essential for continuous improvement.

The benefits of continuous improvement philosophy are many; some are visible and some are not. Some visible benefits are:

1. There will be enhanced customer satisfaction and customer loyalty through value creation in improved products and services
2. Reduced errors, defects, wastes and unnecessary costs, and cost of servicing
3. Development of new understanding and opportunities during the course of work
4. Promotion of all-round improvements in the systems, efficiency, communication, resource utilization, etc.
5. Improvement of skills and creativity of people
6. Realization of lower-cycle time of production and services
7. Improving the company's performances

But, invisible benefits are of greater consequence; they change the company's total work culture and develop in-built strength into the organization through quality of people, management, processes, and attitude. These indirect benefits truly enable the organization to grow and sustain in the competitive business environment. Therefore, all modern quality management systems – like the TQM, ISO-9000, etc – make continuous improvement an essential part of the system. Continuous improvement is a part of principles by which total quality is practised in modern organizations, and it has become a part and parcel of strategic management philosophy for superior business results.

Important areas of applications of continuous improvement are:

- Improving quality levels of products and services
- Reducing waste, errors and defectives, leading to improvement in costs
- Improving cycle time of performance and lead time for response to customer requirements
- Improving customer satisfaction

- Developing a new understanding about the changing market and customer preferences for a competitive edge
- Improving the company's cost and financial performances for fulfilling corporate responsibilities and obligations to different stakeholders
- Developing the skill and competence of people in the organization

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There are number of ways by which an organization can put continuous improvement into practice, but the basic steps of a continuous improvement process are: (a) systematically determining and isolating the root-causes of quality or performance deficiencies hindering improvements or desired results, (b) remedying the performance problem by eliminating root-causes, and (c) stabilizing the system or the process by standardizing the improved practice so that the system functions effectively to hold to the gains. Obviously, analysis of these steps would require considerable uses of different statistical tools, some of which will be discussed later.

While creativity, innovation and teamwork are common denominators for continuous improvement programmes, some of the important techniques for continuous improvement are: Deming's P-D-C-A Cycle, Kaizen Quality Circle, Just-in-Time Manufacturing (JIT), Poka-Yoke (Mistake Proofing), Zero-Defect Programme, Taguchi's Quality Loss Function, and 5-S Programme. Some of these tools will be discussed in Units 5 and 6.

An important aspect of the continuous improvement programme is to measure and assess improvement for deriving information for future improvement. As a basic rule, a company should select and set performance measures and indicators that best represent the factors that lead to improved customer satisfaction, operational efficiency and financial performance. A comprehensive set of measures and indicators representing the interests of customers and company performance requirements provides a clear basis for aligning all processes and activities of the company with its goals, objectives and vision, which is the purpose of TQM. Measurements provide data and information about the processes, their outputs and results. This data and information need to be analyzed using sound statistical techniques for projecting trends and inferring cause-and-effect relationships between operating parameters. Hence, knowledge of statistical techniques for data and process analysis is essential for a member in a continuous improvement team.

6.3.3 Implementation of Total Quality Control

The total quality perspectives as reflected in the Malcolm Baldrige National Quality Award model suggest several requirements for effective implementation of TQM. The implementation process requires:

(1) Statement of quality policy, (2) Strategic planning of quality objectives, key processes and implementation plan with due regard to internal capability, market environment, customer demands, and suppliers' capability, (3) An approach/deployment plan (action plans) for implementation, (4) Measurement and monitoring plans for results and performance in each process category under MBNQA, and (5) Plans for continuous improvement and adoption of suitable strategies like benchmarking, process re-engineering, and other quality improvement methods

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The first challenge in the implementation of TQM is that the TQM system has to be implemented by managers and employees of the organization, who are obsessed with their own mind set, complacency and cultural habits. This has to be changed by the leadership by defining new roles of employees in valuing customers' needs, empowering them with knowledge, skill and understanding of the process of TQM by extensive training, and facilitating performance improvement (continuous improvement) throughout the organization.

A road map for TQM implementation is illustrated in Figure 6.4. The implementation starts with the culture of putting the customer first in any planning of process or activity. This culture must be cultivated amongst the senior executives and managers first – as they are the leaders for general employees, and they must act as change agents. These executives and managers should be able to motivate and inspire people for total quality and fulfilling customers' needs by transparent communication, counselling and facilitating required actions, paying attention to critical processes for the success of TQM, and by removing the barriers to total quality. This is the most difficult part of TQM implementation, which involves changing the people and motivating them towards accomplishment of total quality goals.

To achieve and sustain market leadership, organizations must empower people, institute 'quality improvement programmes' (QIP), and set quality goals in all spheres of activities, preferably by benchmarking with the best in the industry practice. Planning measures for improvement and measuring the actual performances in all process categories are important steps in the implementation of total quality. The purpose of this exercise is to identify gap areas and take necessary corrective and improvement measures for superior business performance.

Develop: Culture of listening to the voice of Customers

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Set: Clear Strategic Plans: Values, Vision, Mission and Goals with focus on Customer satisfaction and future growth

↓

Communicate: The need for the journey to all employees and draw people together to the common goals; introduce the system of 'internal customer' within the company

↓

Identify: Key Processes and Restructure them with customer-focused horizontal processes

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Focus on People: motivate, build teams, train, empower and encourage participation

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Cultivate: Culture of customer care, Creativity, Innovation and Teamwork for Continuous Improvement

↓

Set: Measures and measurement points and targets for verification, monitoring and improvement

↓

Introduce: Total Quality Tools for Improvement and value creation, Benchmark

↓

Manage: Processes and Quality outcomes for continued customer satisfaction

↓

Measure Business Result, identify gaps and initiate improvement actions

Fig. 6.4 *Road Map for Implementation Stages of Total Quality*

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TQM models – like the MBNQA – prescribe that each process category under MBNQA system should be split into different "items" and "areas under each item" are to be separately addressed for building quality into the process during implementation. The purpose of this approach is to ensure that the issues and problems are addressed in totality, and not in parts by parts. TQM is to be implemented throughout the organization and in all its processes and functions. Dividing each process category into items and areas helps to establish TQ in a better way. Organizations are required to approach the implementation of TQ principles in each of these items and areas by appropriate, effective and innovative measures. Measures and actions for addressing these items and areas of concern may vary with the industry specific needs, but they have to be addressed by suitably deploying actions, measures and resources, and measuring results for each. Hence, every process and action in the TQM system must have its own set of objectives for managing and measuring the progress.

TQM is a company-wide quality management system with a view to achieving total customer satisfaction and superior performance. Performance improvement is the ultimate goal of a business, and its means is the customer satisfaction by total quality process. Performance is, however, an outcome of the quality of managing the processes as envisioned in the MBNQA model and their effective integration. This is the task of leadership. Leadership has to deploy the spirit of total quality in all areas of operations and business in a manner that the organization achieves its strategically planned objectives and vision. Therefore, in the implementation of a TQM system, the processes described under MBNQA have to be carefully itemised by incorporating all items that are critical for attaining the organization's goals and objectives.

6.4 STATISTICAL APPROACH TO QUALITY CONTROL

Central to all information is data. So, data must be presented in the form in which it is capable of giving appropriate information and create knowledge. Data should be reliable, representative, and should be presented in the right form. This requires statistical thinking and approach to the collection, compilation, presentation and analysis of data for process and quality management. As per Deming, the central task of quality management is to identify the causes of variability from the target quality and controlling the same by corrective and preventive actions. This involves using statistical tools that permit root-cause analysis, establishing correlation between controlling factors, and systematically applying those knowledge and information for control, correction or prevention. For improvement, on the other hand, one should know where to act and how to act. There are statistical tools – like the histogram, Pareto diagram, Cause-and-effect diagram etc – that permit analysis of statistical data (i.e. data collected and compiled by following the statistical rules of sampling, grouping, and validation) to arrive at the points of action i.e. where to act. Determining how to act requires knowledge of the process, people who are running the process, and specialized tools and techniques for quality planning and continuous improvements that include statistical tools like Statistical Process Control (SPC), Taguchi's Quality Loss Functions, Six-Sigma practice etc. Thus, by combining the use of statistical tools for segregation and analysis of data facilitates identifying what had gone wrong, what could go wrong, how to control and correct the situation, and finally, how to approach for quality improvement.

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Experts believe that widespread adaptation of statistical tools and techniques in day-to-day quality management and other industrial practices was the primary reason for turnaround in Japanese industries after World War II. Following the Japanese success story, industries the world over have nowadays adapted this practice of using statistics for decision-making, and made statistical thinking and applications of statistical tools an integral part of conducting the business processes for superior performance. Since superior performance is the aim of total quality management, all modern quality management systems attach special importance on the uses and applications of statistical tools for quality improvement and problem solving. Uses of statistical techniques for parameter planning, process out-put measurement, and analysis for decision-making are key to continuous improvement efforts. Some of the areas where statistical techniques and approach can be used towards this purpose are:

Customer satisfaction measurement	Benchmarking
Root cause analysis	Variance analysis
Sampling and Testing	Inventory control
Product cost analysis	Cycle time optimization
Process capability study	Service cost analysis
Cost of Quality measurement	Defectives and Defect analysis
Make or Buy decision	Down time analysis
Buy or Sell investment decision	Forecasting

The list could be longer, and the scope of application of statistical tools depends upon the way one makes use of various available techniques. It is said that applications of statistics in business is not limited by the depth and breadth of the subject, but by the limitations of managers' vision and creative approach. Extension of process capability study (Cpk) to develop the concept of Six-Sigma practice by Motorola Inc., USA to excel in quality, cost and productivity is an example of the scope of statistics and statistical thinking.

1. Common statistical tools

Statistical tools for industrial applications like quality management could be grouped under four categories according to their primary purpose. These four categories are:

(i) Data collection and compilation

(ii) Data preparation and presentation

(iii) Data analysis

(iv) Drawing inference for decisions

The objective of using various statistical tools and techniques is to solve problems and effect improvements. The chosen tool should fit the particular problem or situation; though, many a time, there may not be only one right way for a problem analysis. A variety of analytical tools may be needed in conjunction with each other for some problems, depending upon the situation, complexity of the problem and interactive behaviour skill of the team members under a quality improvement set-up. Common statistical tools for these purposes are:

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A. Collection of data

(a) Flow diagram

(b) Check sheets

(c) Sampling and surveys

However, for collection of data, it has to be defined or decided from where the data should be collected. For a process, this is best done with the help of a simple technique called "Flowcharting", which attempts to define the process through the stages of its various sub-processes.

B. Presentation, analysis and display of data

(a) Charts, such as run charts, bar charts, pie charts

(b) Histogram

(c) Scatter diagram

(d) Pareto diagram

C. Data Analysis and Conclusion

(a) Cause & effect diagram

(b) Pareto analysis

(c) Correlation / interrelationship diagram

(d) Control charts, and process capability studies

Any of these tools can be used, either singly or in combination, for analysis and solution of a problem. Quality management is about solving problems for improvement, and these tools are an essential aid towards these efforts. Common tools used for problem solving and quality improvement are popularly known as **seven simple tool of statistics** introduced by Ishikawa. They are:

1. Check Sheets 2. Charts (Bar, Run and Pie) 3. Histogram 4. Control Charts 5. Correlation or Scatter Diagram 6. Pareto Diagram and, 7. Cause-and-Effect Diagram.

Some lists include Flow Diagram as one of the seven tools. Flow diagram is used to define the process steps and their boundaries. This step is often necessary to identify improvement actions through other statistical means. These tools will be discussed here with their main features and purposes. A general outline of the utility of statistical tools in the field of data collection, presentation, display and decision-making in quality management functions is shown in the box below:

1. Process mapping:	Flow Diagram
2. Data Collection:	Check Sheets, Sampling and Survey
3. Analysis and Display of Data:	Bar Chart, Run Chart, Pie Chart Histogram, Pareto Diagram, Scatter Diagram, SPC: Control Chart, SPC: Process Capability
4. Analysis of Cause-and-Effect:	Cause-and-Effect Diagram (also known as Ishikawa diagram or Fishbone diagram)

Before any further discussion on statistical tools, it would be necessary to appreciate the importance of sampling and its role in any statistical analysis. Any analysis is only as good as its base data, and the means of collecting reliable and bias-free data in statistical analysis is "sampling".

2. Sampling and Sampling Fundamentals

No statistical discussion can start without the appreciation of the role and purpose of sampling. Sampling is used to obtain information about a large group (called the population) from a smaller representative group (the sample). To reflect the true characteristics of the larger population, sampling must be done very carefully to represent the characteristics of larger lot without any error or bias. In effect, sampling is a cost-effective means of collecting representative data that yields vital information for decision-making. Samples can be collected from a specific lot (a finite population) or a continuous process involving infinite population. Whatever could be the source of sampling, the process of sampling must satisfy four criteria, namely: validity, reliability, timeliness, and economy. Sampling methods and the size generally determines fulfillment of these criteria in a given sample lot.

Depending on the event being considered for sampling, there could be two types of situations: (1) the event follows the law of probability i.e. the event will occur in random pattern with certain degree of probability, and (2) non-probability events i.e. does not follow the probability rule. As far as quality control and management is concerned, we are concerned with the probability events related sampling where populations fit the normal distribution of occurrence. And, in this group, there are number of types of sampling based on the methods used. They are:

Random Sampling:
The one in which each and every unit of the population has equal chance of being selected into the sample lot

Random Sampling: This is also called 'simple random sampling'. Random sampling is the most common method of sampling, and it is widely used in industries for quality management. A simple random sampling method is the one in which each and every unit of the population has equal chance of being selected into the sample lot. This method should, therefore, be so followed as to ensure equal opportunity for any unit of the population to be a part of the sample i.e. should be free from any bias. The purpose is that all representative characteristics of the population should be present in the sample lot, which is much smaller in number than the population they are sampled from. To determine which units are to be sampled, random numbers are required. Random numbers can be obtained from "random number table" – a published universal table, or by busing computer generated random number, or by drawing randomly from a lot as in the lottery system. For example:

Taking samples from a running process line at 8.10 a.m., 8.40 a.m., 8.53 a.m., 9.25 a.m., 10. a.m., 10.35 a.m. etc (obtained as minutes after 8.0 am from the random number generator) to measure the process out-put or quality.

However, obtaining true randomness in a real situation may be very difficult and expensive. Hence, very often, few other types of sampling are used under the category of Restricted random sampling.

Under restricted random sampling, there are:

Systematic sampling:
Method where a first sample is picked up in random and then subsequent samples are drawn in a predetermined fixed pattern or time interval

(1) **Systematic sampling** method where a first sample is picked up in random and then subsequent samples are drawn in a predetermined fixed pattern or time interval. This is a variation of random sampling technique, but extensively used in day-to-day quality control jobs where population from which samples are drawn is not very large. For example:

Taking first sample at any random time and then sampling at a regular interval of 15 minutes from the initial time for checking the quality output from a line.

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(2) Another method is the cluster sampling. In this method, a cluster or a sub-group of the population is used as a sample lot. This sampling method is permissible only when the population is stable i.e. there is no variation from lot to lot or from one sub-group to another. For example:

Sampling and checking in a continuous production line – say assembly line of an automobile company – by sampling the car produced at 1 p.m. in the morning shift or 7 p.m. in the evening shift or 4 a.m. in the night shift. In this system, it is assumed that the car produced at the given time is representative of the shift.

(3) There is yet another sampling method, and that is two-stage sampling. This method is typically applicable when the number of production is large. In this sampling method, samples are first taken from the large population by following a random or systematic method, and then sampled again by following a random sampling technique in order to obtain a smaller sample group, referred to as 'secondary sampling'. The secondary sample is then considered the representative of the original population.

(4) Another type is stratified sampling. In this type, the entire population is divided into a number of homogeneous groups called 'strata', and then a simple random sampling technique is followed for each stratum to ensure total coverage of the population. Example: customer satisfaction survey in a company. First, customer population is divided into homogeneous groups – may be region-wise, metro-wise or economic background wise. Then, by following the simple random sampling method, each homogeneous group is sampled and the survey of satisfaction is carried out. Very often, the simple random sampling method resorts to using a "lottery method" only (and not generated random number from table or computer) for drawing samples for randomness.

To summarize, for most quality control purposes, random sampling or a variance of it is used to collect samples from a lot that follows the normal distribution pattern. Such sampling allows a conclusion to be made about a large group from a much smaller one, thus saving cost and time of checking and analysis. This is the most practical way for statistically deducing conclusions from a lot or a process or an event. However, sample size and sampling technique are very crucial for accuracy of results. The greater the degree of precision required in the results, the higher is the number of samples (i.e. larger sample size) required for analysis. Factors that influence the sample size and sample numbers are: (1) consistency of the process, (2) difficulty of gathering data, (3) cost of gathering data, (4) impact of making error of judgement, (5) preciseness of results required, (6) severity of the problem for which samples are being taken, and (7) the size of the population.

As far as quality control for incoming and outgoing quality is concerned, generally random sampling technique is used, but sample plans and their interpretations are subject to some rules for making decisions from the sample results. They are:

(1) Lot Acceptance Sampling Plan (LASP)

LASP is to be made regarding what sampling scheme should be followed and rules for making decisions. For example, the decision can be based on counting the number of defectives in a sample, and then decide about the acceptance or rejection of the lot, or even for going to multiple or sequential sampling schemes to take the final decision. Types of acceptance plan to choose from under LASP are:

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Single sampling plans: One sample of items is selected at random from a lot and the disposition of the lot is determined from the resulting information. These plans are usually denoted as (n–c) plans for a sample size *n*, where the lot is rejected if there are more than c defectives.

These are the most common (and easiest) plans to use although not the most efficient in terms of average number of samples needed. Example: Choose any three samples at random from a homogeneous lot, and reject if any chosen sample shows any defect.

Double sampling plans: After the first sample is tested, there are three possibilities:

1. Accept the lot
2. Reject the lot
3. No decision

If the outcome is 3, a second sampling is done. The procedure is to combine the results of both samples and make a final decision based on that information. Example: Taking another set of samples at random from the same lot, and checking. If there is more than one defect and the nature of the defect is minor (i.e. not impairing the functionality of the product), the lot can be accepted, provided the user has agreed for double sampling plan.

Multiple sampling plans: This is an extension of the double sampling plans where more than two sampling steps are needed to reach a conclusion. The advantage of multiple sampling is smaller sample sizes i.e. one can draw lesser number of samples in each step.

Sequential sampling plans: This is the ultimate extension of multiple sampling where items are selected from a lot one at a time and after inspection of each item a decision is made to accept or reject the lot or select another unit.

(2) Acceptance Quality Level (AQL) & Lot Tolerance Percent Defective (LTPD)

What sampling should be followed will, however, depend on the purpose and quality level one is seeking for. Therefore, two more terms are relevant for understanding of sampling and testing for decisions; namely: Acceptance Quality Level (AQL), and Lot Tolerance Percent Defective (LTPD). They are defined as:

Acceptable Quality Level (AQL): AQL is a percent defective that is the base line (minimum) requirement for the quality of the producer's product. The producer may accordingly design a sampling plan such that there is a high probability of acceptance of a lot, but with defect level less than or equal to the AQL fixed by the purchaser.

Lot Tolerance Percent Defective (LTPD): LTPD is a designated defect level that a process output can tolerate and higher than that would be unacceptable to the consumer. The consumer would like the sampling plan to have a low probability of acceptance a lot with a defect level higher than the LTPD.

However, any sampling plan may have two risk factors, which are termed as "Producer's Risk", and "Consumer's Risk". Producer's risk is the probability of rejecting a good lot (i.e. defect level equal to AQL) by following a given (n–c) sampling plan. Consumer's risk relates to the probability of accepting a lot with higher defect level (i.e. defect level equal to LTPD) by following the same (n–c) sampling plan.

(3) Operating Characteristic Curve (OC)

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Therefore, quality control personnel often have to take decision by plotting Operating characteristics curve (OC – curve). This curve plots the probability of accepting the lot on Y-axis versus the lot fraction (or percent) defectives on X-axis. The plotted curve displays the characteristics and properties of LASP that were followed, and shows the risk involved in accepting a bad lot with increased fraction defective production.

Figure 6.5 exhibits the associated risk of producer and consumer with reference to AQL and LTPD.

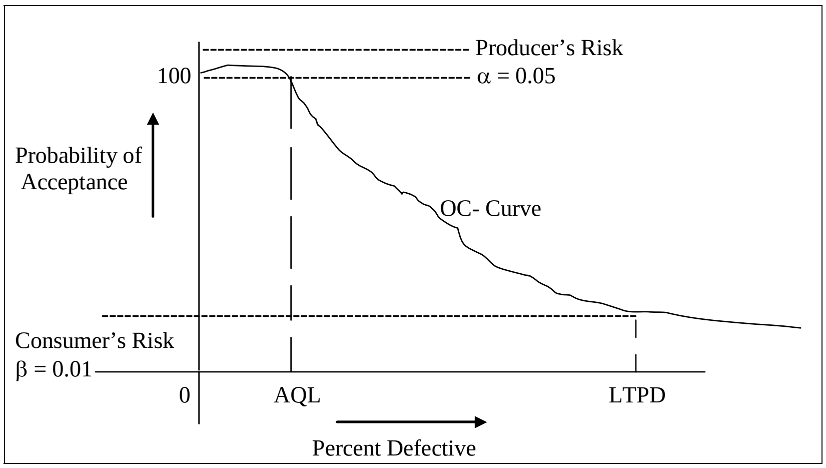

Fig. 6.5 *Associated Risk of Producer and Consumer*

(4) Average Outgoing Quality (AOQ) and Average Outgoing Quality Level (AOQL)

The task of quality management is to reduce the risk of accepting defectives in a lot, but at the same time ensuring that no unnecessary cost is added up or loss is incurred. Long-term solutions lie in reducing the variance of the process and improve process capability, but many a time they have to resort to re-checking and 100% inspection of rejected lot for rendering them acceptable. This poses the problem of how to ensure Average Outgoing Quality (AOQ). Therefore, along with normal sampling as per originally decided LASP, 100% inspection of rejected lot is undertaken for replacing the defectives with good units. But, what has been measured as good also runs the chance of being defective as discussed earlier. Hence, Average Outgoing Quality (AOQ) concept is used which refers to the long-term defect level for this combined LASP (original) and 100% inspection of the rejected lots from the process. If all lots produced come with a defect level of exactly 'p' – the probability of occurring a defect – and the OC curve for the chosen (n–c) sample of LSAP indicates a probability of (p_a) of accepting such a lot, then over the long run the AOQ can be shown to be:

$AOQ = \dfrac{P_a p(N - n)}{N}$ = where N is the lot size, and p and p_a as mentioned earlier.

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(5) Average Outgoing Quality Level (AOQL)

Average Outgoing Quality Level (AOQL) of the process is obtained by plotting the AOQ values at the Y-axis versus the 'p' of incoming lots. The curve will start at 0 for p = 0, and will come back to 0 at p = 1, where every lot is inspected and rectified by replacing defectives with good ones. In between the graph will rise to a maximum. This maximum is the worst possible scenario for long term AOQ, and this value is called the Average Outgoing Quality Level (AOQL).

Thus, it would be evident that the task of QC personnel is to design the sampling plan, test plan, and decision-making system in order to ensure minimizing the risk of accepting any defectives in a given lot. For this, one should have the knowledge and appreciation of the sampling techniques and the rules that are generally followed in the statistical analysis. Sampling in quality control and management is associated with any study involving:

- Estimation of the average number of defectives, errors or other failures produced during the production run.
- Estimation of distribution of total defectives, errors or failures in production line or in service.
- Decision for acceptance or rejection of a lot either produced in-house or at a supplier's end.
- Estimation of various process characteristics.
- Determination of the state of process control.
- Evaluation of performance with process specification or quality with the standards / specifications.
- Decision-making for process improvement.

Seven Tools of Statistics

1. Check Sheets

Check sheets are used to track the frequency of occurrence of specific events that occur during a sampling period or in a study period or in a given span of time concerning a problem. Check sheets plot the data as they occur within the given period, and plot them in the form of a check sheet as shown in Figure 6.6. Check sheets are used to record data in the form of a matrix chart in which one variable is the sampling period or frequency and the other is the event being studied. From the frequency of occurrence, information about the "vital few" factors influencing the problem can be easily obtained. Thus, a simple plot of data in the form of check sheets helps to distinguish between "facts" as observed in the check sheets and any preconceived opinion or perception about the problem, which we often have. Check sheets enables taking appropriate actions for control based on the facts and data for a given event.

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No. of complaints in week

<table>
<tr><th>Causes</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>Total</th></tr>
<tr><td>Colour distortion</td><td>||</td><td></td><td>|</td><td>|</td><td>~~||||~~</td><td></td><td></td><td>||</td><td></td><td>~~||||~~</td><td>17</td></tr>
<tr><td>Picture not stable</td><td></td><td>|</td><td></td><td>||</td><td></td><td>|</td><td>|</td><td>|||</td><td></td><td>|</td><td>9</td></tr>
<tr><td>Poor sound control C</td><td>|</td><td></td><td></td><td></td><td>|</td><td></td><td></td><td></td><td>|</td><td>|</td><td>4</td></tr>
<tr><td>Remote not working</td><td></td><td>|</td><td>|</td><td></td><td>|</td><td></td><td></td><td>|</td><td></td><td></td><td>4</td></tr>
<tr><td>Frequent picture distortion</td><td>|||</td><td>|</td><td>||</td><td>|</td><td>||||</td><td>|</td><td>||</td><td></td><td>|||</td><td>~~||||~~</td><td>22</td></tr>
<tr><td>Total</td><td>6</td><td>3</td><td>4</td><td>4</td><td>11</td><td>2</td><td>3</td><td>6</td><td>5</td><td>12</td><td>56</td></tr>
</table>

Fig. 6.6 *Check Sheet for Customer Complaints of a CTV Brand*

Functions of check sheets are:

- Compiling data to prove or disprove opinion and perception
- To provide data on events and their relative frequency—for identifying where to focus for corrective actions
- To provide an easily understandable picture of a process and its problems
- To facilitate comparison in various categories of data relating to different time, cost etc.

A typical check sheet for study of customer complaints for a consumer electronic product is shown in Figure 6.6. In check sheets plot, bars are drawn (conventionally, the fifth bar appear as diagonal to the others four bars in the group) in the respective column as the "event" occurs during the study period. This type of plot immediately reveals the vital few causes for customer dissatisfaction in the given case. In this plot, frequent picture distortion, colour distortion and unstable picture emerge are the vital few causes for concern, and this fact should lead to further actions for quality improvement.

Some important applications of check sheets could be:

Defect cause isolation, Confirmation checks, Production process quality checks, Defective item checks, Customer complaint analysis, Improvement status etc.

Check sheet is basically a data collection tool, so is sampling and survey–the other two tools that are used for data collection. Data collection often starts with check sheets, which are then followed up by analysis of the observations by using other statistical tools – like the Histogram, Pareto Diagram etc. The main purpose of check sheets is to spread the data on a format that helps to focus on the apparent root causes of the problem.

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Flow Diagrams: Graphic representations that display and define the processes through the sequential flow of operations

2. Flow Diagram

Flow diagrams (also known as Flow charts) are graphic representations that display and define the processes through the sequential flow of operations. The primary purpose of a flow diagram is to provide understanding as to what to measure and control at what point of the process. A flow diagram is generally used with other statistical tools and techniques, such as process capability study or quality improvement projects.

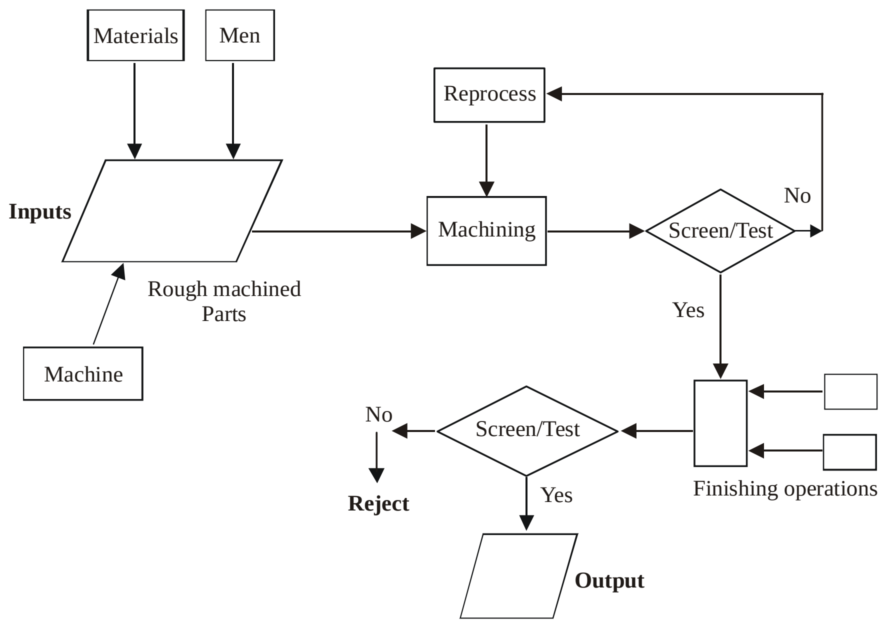

Fig. 6.7 A Simple Flow Diagram of the Movement of Processes and Control Points

A flow diagram can be constructed to indicate the followings:

- A map of the system, showing sequential flow of process activities, what goes into the process and when to measure
- Input and output products or services i.e. what inputs are needed for certain outputs
- Responsibility locations, and customer-supplier relationship involved in the process
- Costs and value addition points for control and improvement
- Process time, actual and estimated
- Potential data requirements and improvement opportunities

Flow charts can range from macro level to micro level. Example of a macro level flow diagram is shown in Figure 6.7, depicting the process map for achieving quality output for customer satisfaction.

A micro level flow diagram represents more detail of the steps necessary for the process of improvement, which can incorporate customer needs, quality issues and the process of handling those issues for satisfactory end results. In a macro level flow diagram, activities necessary to achieve a process objective are listed. This can be the process for meeting the quality specification, or customer satisfaction or quality improvement programme. Macro level flow diagrams are often done before attempting construction of micro level flow diagrams. Micro level flow diagrams chart work processes to identify not only the sequence of work activities and decisions, but also the responsibility, location for performing activities and making-decisions. A simple flow diagram of a manufacturing process is illustrated in Figure 6.7, which shows inputs, activities and their locations, measurement and control points, and outputs with final rejection stage.

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In a flow diagram, the number of key steps and the number of activities should be kept limited in order to keep the focus on a "vital few" activities. "Vital few" are those factors or points in the flow diagram that contribute most to the problem or in its solution. Data collection and compilation in the form of check sheet allows to identify "vital few" points in the data. These "vital few" are then explored further for quality improvement.

3. Charts

Charts are graphic displays of data for easy understanding of a relative position that is not always possible with descriptive words or numbers. Type of charts commonly used in business data presentations are Bar, Pie, and Run chart. Histogram and Pareto-Diagram also have some common characteristics with a bar diagram, and that's why they are sometimes considered as a special type of vertical bar diagram. Similarly, a control chart, mentioned earlier, is a specialized form of a run chart, where there are statistically determined control limits. This will be discussed in more detail subsequently. Features and purpose of the main chart types, namely Bar, Run and Pie will be discussed here.

(1) **Bar charts.** The bar chart is commonly used for presentation of qualitative data. The data can be continuous or discrete data, which is plotted against discrete intervals. A simple type of vertical bar chart is shown in Figure 6.8.

This is a vertical bar diagram (also called bar chart) where the length (or height) of bars represents the numerical value of the event or measurement. Width or gap between the bars is no significance to bar chart data, but they should be uniform in a diagram. Bars can also run horizontally, and have many formats like component diagrams, multiple bars, etc. A component bar diagram is used to represent the fraction contribution (or share) of different sources to a particular element or event, and this is plotted by proportioning each bar as per the share of contribution. A component bar diagram can be used for presentation of customer complaints in quality management for showing the contribution of different types of failure. Bar diagrams can also be presented by multiple bar columns for a given period, where such bar columns represent a data set of a particular interest.

A bar diagram (as shown in Figure 6.8) can be effectively used in quality management practice to represent quality levels over a period of time in order to understand the consistency of quality of the production processes. Based on the observations from bar diagram, further improvement actions can be taken for those periods of deviation or fluctuation by using other statistical tools like cause-and-effect diagram, SPC etc.

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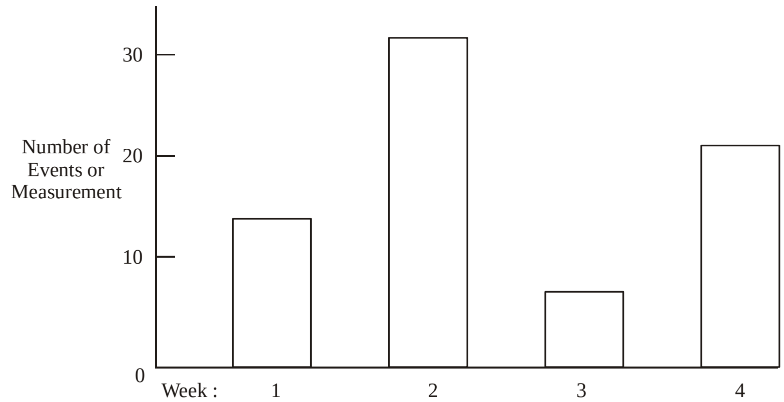

Fig. 6.8 *Vertical Bar Diagram*

(2) Run Charts: Run charts show the trends of data for a process over a period of time. The horizontal axis (X) represents interval and vertical line (Y) represents measured data, which can be continuous or discrete. Figure 6.9 illustrates the features of a single line run chart, where measured values have been plotted on scale (indicated by x) on time axis.

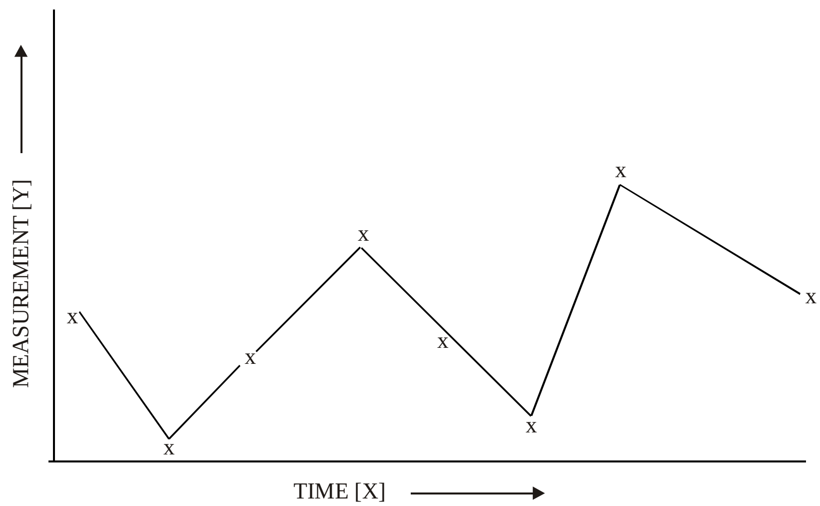

Fig. 6.9 *Run Chart of the Measurement of a Characteristic over Time. The characteristic could be the dimension of a part or productivity from a line or variation of room temperature etc.*

A run chart is simple to construct and lends itself to easy visual perception of how the process is running with the time i.e. lends to observe process variation over a time or trend. This, however, does not indicate whether the process is under control or not. Utilization of a run chart is limited to: (a) denote the presence of trends, and (b) denote sudden shifts in the process. It has very limited capability to indicate any problem in the process, and the nature of the problem. Hence, a run chart is often used in combination with a histogram or control charts for further analysis of problems and corrective actions. Nonetheless, run charts are extensively used in quality control activities of a manufacturing line in order to identify how the process is running, and if there is any wild departure at any point of time. If a point shows wider departure than normal, products of the line produced in between the time intervals can be set aside and segregated for quality; though stopping the machine as early as possible and taking corrective measures is the right action. Many a time, shop supervisors put a upper line and bottom line in the run chart (which are not necessarily the upper and lower specification limit, and very often set by the quality supervisors based on the capability of the machine being followed by run chart) in order to identify if any point in the measurement is going outside the set limits. This prompts the supervisor or operator to take immediate corrective action.

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(3) Pie Diagram: Pie charts are circle graphs that display 100% of data as circle. The circle is divided into proportionate slices that represent categories whose size is defined by the percentage of a category in the total. Figure 5.5 shows a typical pie diagram for customer complaints of a car due to various problems.

Pie diagram is very suitable for presenting various business results and quality issues, such as analysis of company earnings from various heads, causes of products and service complaints, cost build-up etc. Pie diagram and bar diagram may be used for similar presentations, but pie diagram is not amenable for presentation of data over different periods in the same diagram. For this latter purpose, component bar or multiple bar diagrams are more suitable.

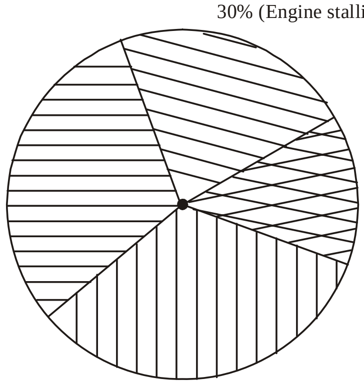

Fig. 6.10 *Pie Diagram. The diagram should be levelled with the notation of each category along with the respective percentage. Alternately, the diagram should indicate the percentage of each category within its body*

Pie diagrams are very useful for comparison purposes, especially when there are only few heads under which the data is compiled or problem is being studied. Pie diagrams are very popular with economists who often deal with data from one time survey.

4. Histogram

A **histogram** is a special bar chart that displays the frequency of occurrence of a measure or characteristic of data from a process. In a histogram, data is plotted in the form of a series of rectangles, where vertical axis (Y) represents the frequency and horizontal axis (X) represents the measurement or characteristic data, either in continuous or in discrete scale. Figure 6.11 illustrates the features of a histogram.

Histogram:
A special bar chart that displays the frequency of occurrence of a measure or characteristic of data from a process

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Unlike a bar diagram, a histogram is a two dimensional presentation in which both length and the width of the bar are meaningful. Therefore, their unit dimensions should be decided and maintained. For example, if one is plotting a histogram of dimensions of a lot received from a supplier, X-axis should show the unit of expression of the dimension (e.g. inches, mm etc), and Y-axis should show the number of times one band of dimension occurs upon checking the lot. Thus, width of the rectangle on X-axis covers a range or band, which is often termed as 'class interval'. Histograms clearly illustrate the patterns of variation in process and help in understanding the process. A histogram provides:

- Easy to understand means of displaying the variability of data
- Distribution pattern of data i.e. normal distribution or skewed
- Understanding of causes of variation, like common cause or special cause, when used with control charts

A histogram shows the frequency or number of observations of a particular value, and in effect shows the frequency distribution of a specific data set. Thus, it provides an easy-to-understand means of displaying data and their distribution over a range of values. The shape of distribution within a specified range can often provide information that may not be evident from control charts alone, such as acceptability of product or characteristic values, within a range or specification. However, histogram does not provide the trend analysis, for which run chart or control chart should to be used.

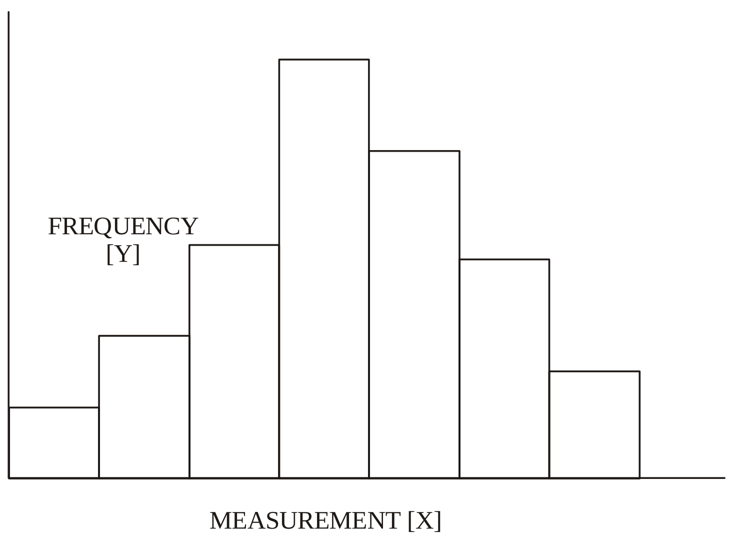

Fig. 6.11 *A Histogram Displaying the Frequency of Occurrence of Measurement with a Range*

5. Correlation or Scatter Diagram

Scatter diagram provides a graphic plot of two variables, and the purpose is to show if any correlation exists between the variables. Correlation determines the strength of a relationship between two variables, like cost and demand growth, employee training and increased productivity, fluctuation in room temperature and machining accuracy etc. This technique is often used in conjunction with regression analysis. A near perfect

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line going through maximum data points indicates good correlation. Figure 6.12 shows a scatter diagram plot between variables A and B. The line fitted in this diagram indicates good correlation between variables A and B.

The larger the number the data points, the better it is for establishing correlation. For example, the line fitted through 3 points always run the risk of accuracy compared to the line fitted through 4 or 5 points. If the data points are haphazardly distributed and cannot be joined by a straight line, the correlation is assumed to be poor or nonexistent. To fit the data point, regression analysis is generally used, but that is beyond the scope of the present book (this a special statistical technique, which uses equation of a line or curve determined by the mathematical relationship between variables for fitting a line to the data points). When data points are plotted on a log or semi-log scale, they show better correlation than what was not apparent on a simple plot. Scatter diagram can indicate whether additional analysis is required to determine the exact nature of cause-and-effect relationship i.e. it is capable of providing clues on how to improve the process.

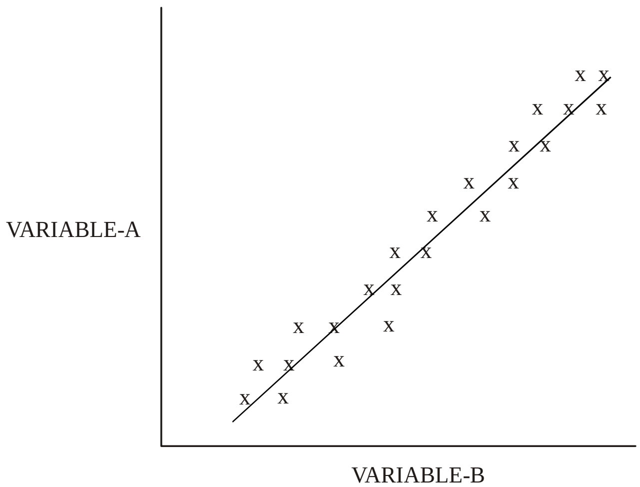

Fig. 6.12 *Scatter Diagram of Two Variables Showing Good Correlation*

The pattern of the scatter diagram could be linear or non-linear, and relationship could be either positive (i.e. when both variables increase together) or negative (when one increases and the other variable decreases). The plot finds frequent applications in determining whether a cause-and-effect relationship exists between two variables, and whether or not two process variables are related to one another (like temperature and precision machining).

6. Pareto Diagram

A Pareto diagram is a special type of vertical bar diagram that displays the relative frequency of various categories of problems or events. To display the frequency, bars are arranged in descending order of magnitude from left to right. As a result, the “vital few” categories (or items) that contribute to the maximum of the problem, or condition of the events being analysed, stand out. Pareto diagram is usually accompanied by a cumulative percentage line showing the cumulative frequency of items, starting from most frequent category. Figure 6.13 depicts a Pareto diagram of problems faced by customers with respect to a product e.g. car.

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Pareto diagram immediately reveals the vital few causes and helps in selecting improvement efforts. In other words, the plot shows the immediate improvement opportunities. Typical applications of Pareto diagram are: displaying causes of problem in order of importance, verifying root causes of problems following cause-and-effect analysis, and comparison of data for checking results after taking process improvement actions.

Pareto was an Italian philosopher who used this technique to study the population characteristics. From his study the "80-20" rule evolved, which stated that 20% of population holds 80% of wealth of the society. This rule has been found applicable to many areas of economic and industrial studies of modern era. Illustrations of 80-20 rule are:

- In industries, 80% of problems are caused by 20% of products or process.
- In marketing strategy, 80% of sales volume comes from 20% of customers.
- In operations, 80% of inventory value lies in 20% of the inventory items.

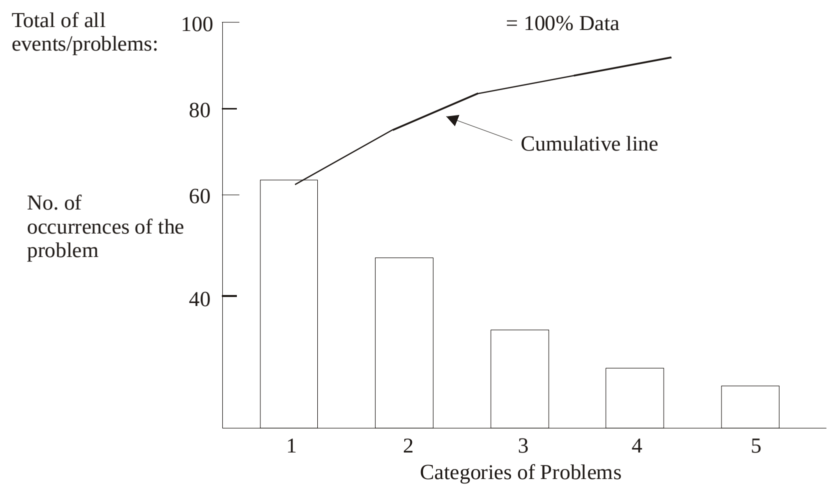

Fig. 6.13 *Pareto Diagram with Cumulative Frequency of Problems in the Functioning of a Car*

To summarize, a Pareto diagram helps to separate out the vital few from the trivial many in deciding which of the problems to work out first. Thus, Pareto analysis allows prioritization of improvement work by differentiating between "vital few" and the rest. With reference to Figure 6.13, 80% of problems of the car lie with the first two categories of problems. Hence, these two areas are the vital areas for further investigation and quality improvement.

7. Cause-and-Effect Diagram

A Cause-and-Effect diagram is a graphical representation technique used to identify and relate possible causes with effects. An illustration of a Cause-and-Effect diagram is shown in Figure 6.14. The diagram is developed by examining categories of causes that help in focusing attention beyond symptoms to root or primary causes. The structure so developed resembles a fishbone. Hence, some also call it "fishbone diagram". Dr K. Ishikawa of Japan first used the cause-and-effect diagram in 1950 for statistical process control, and after his name, this technique came to be known as Ishikawa diagram.

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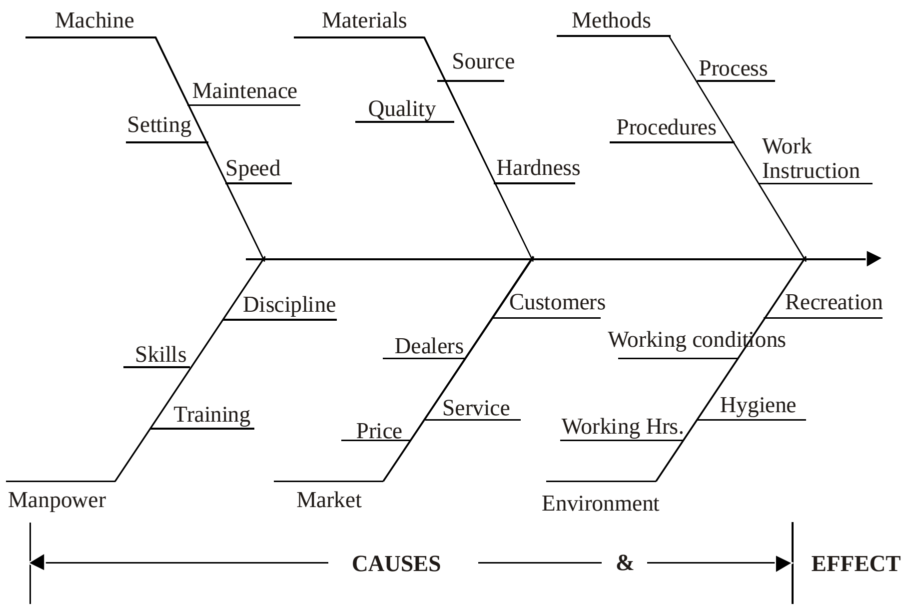

Fig. 6.14 *Cause-and-Effect Diagram for Root-cause Analysis*

The Effect under analysis can be either a current state of the problem that needs to be corrected or it can be with respect to seeking an improvement. For example, "effect" under analysis could be "inconsistent quality out put from a machining line" or it could be "improvement of quality level in a line". Cause-and-effect diagram should show all the factors that can influence the design or process or their outcome, be it in manufacturing or service. Causes and their probable effects are listed from the results of brainstorming sessions, which are a critical part of constructing this diagram. Then, the causes are broken down into their smallest parts, and each of the categories of causes and their parts are critically examined to establish how the causes can occur and interact. This is a very useful tool for identifying the causes of a problem or to understand those factors that influence a process for the "effect". Its strength in analysing relationships lies in the structured way in which it is developed by using categories of causes and their components, which helps in focusing to root rather than symptoms.

Development of the cause-and-effect diagram requires a team approach to the issue, where brainstorming is used as principal tool for listing out the causes and their components. Therefore, this technique is considered a very effective tool for problem solving, where a team approach is always beneficial. The technique is used not only for analysis of causes of any current quality problem, but also for getting clues for improvements. The cause-and-effect diagram is used for: identifying major and minor reasons for a specific problem, identifying root-causes for an effect, and getting ideas about how select additional data for the solution of a major problem or project. As such, this is a very frequently used tool in all continuous improvement programmes.

These statistical tools play a pivotal role in quality management by facilitating data segregation, grouping, analysis and presentation, identifying possible causes, root causes, and focusing on a "vital few". In todays' quality practice, use of these techniques either for data presentation or data analysis for identifying where to act and how have become a common practice.

6.4.1 Quality Planning and Improvement Tools

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The other kinds of quality tools are quality planning and continuous improvement tools (also known as management tools). Examples of quality planning tools are: QFD (Quality Function Deployment), FMEA (Failure Mode Evaluation and Analysis), Concurrent Engineering, Taguchi's Quality Loss Function analysis, etc. These quality planning tools are used by companies at the beginning of a product (or service) launching or for correcting/enhancing the product or service quality in terms of market demands and competitions. Continuous improvement tools are those that were developed (or adopted from other disciplines) for continually enhancing quality standards and promoting quality culture in the organization by increasing involvement of people and system orientation for "first-time right" work culture. Examples of continuous improvement tools are: Deming's P-D-C-A cycle, Kaizen, Quality circle etc. Customer satisfaction and providing value to the customers are at the core of quality planning and improvement tools. Some of the major areas of applications are:

- Launching of new products for meeting and exceeding customer expectations
- Product development for meeting the changing needs of customers
- Value creation for customers and providing cost-effectiveness
- Continuous improvement of processes for reduced variability and consistency
- Measurement and analysis of business results and decisions about improvements

It must be appreciated at this stage that statistical tools are supporting tools for all kinds of management decisions, be they quality planning, performance improvements or investment decisions. Thus, these quality tools are often used in conjunction with each other, and they need to be understood in that larger context for applications.

1. Quality Planning Tools

The broad objective of quality planning tools is to ensure marketing of products and services with attributes that will satisfy current needs and future expectations of customers. Steps for this quality planning process are: (a) identification of market and customer group for understanding the current needs and future expectations, (b) converting these needs and expectations to specific product and service specifications, and (c) enabling the manufacturing and service delivery processes of the enterprise to meet these needs and expectations for customer satisfaction.

Some popular quality planning tools are: Quality Function Deployment (QFD), Concurrent Engineering, Design of Experiment (DOE), Taguchi's Quality Loss Function, Failure Mode Evaluation and Analysis (FMEA), Fault Tree Analysis, and New Seven Management and Planning Tools. Of these, QFD and FMEA have been discussed in Unit 1 as part of quality of design and conformance.

Quality Function Deployment (QFD) is a methodology to ensure that customer needs and expectations are attended to and fulfilled throughout the processes of design, operations and delivery of the products or services. In other wards, QFD is a methodology to translate the voice of customers into actual reality of designing, manufacturing and delivery of products and services to customers. **FMEA** is another popular technique for incorporating the customer's voice into the design and manufacturing for conformance to quality. If customers are to be satisfied with the product, then manufacturers have the responsibility to ensure that the product does not fail in service and cause inconvenience and irritation. This is gaining more importance

FMEA: Popular technique for incorporating the customer's voice into the design and manufacturing for conformance to quality with the stricter product failure liability clause of many countries. Therefore, in the quality planning of a product or for new product development, it is necessary to check out thoroughly that the product will not be liable to failure, and cause inconvenience, loss or risk to personal safety. The failure mode and effect analysis matrix provides a structured means of determining the impact of different modes in which a product may fail in service. Information gathered while completing or computing the FMEA, serves as useful inputs to modify the design of the product or the process involved. Application of FMEA often calls for design support from QFD. Hence, these two techniques have been reported in Unit 1 together under quality of design i.e. meeting the customer needs and expectations through quality design of products and services.

NOTES

(1) Concurrent Engineering (CE) is an another quality planning tool that replaces the traditional product development process with the one in which tasks are done in parallel, and there is an early consideration for every aspect of a product's quality attributes and the required development process. It is product development strategy for faster market response with correct quality and value. This strategy focuses on the optimization and distribution of a company's resources to ensure effective and efficient product development process. The approach involves linking up the activities with clearly identified responsibilities to be performed by all major functions that contribute to design, development, production and marketing of products or services. This means that under the concurrent engineering approach, all agencies concerned with the product development become involved and responsible from "concept through sales" of a product, and they have to act in parallel for cutting down the lead-time and cost. This approach helps to avoid conflicts between the agencies (like design, manufacturing and marketing) with regard to their own limited goals, and helps to fulfill the Company's overall goal of customer satisfaction at least cost. Naturally, concurrent engineering has to be a team approach, and the team has to be multi-functional i.e. cross-functional team drawn from different expert areas of the company. The Objective of Concurrent Engineering approach is to ensure that customers get the quality and service what they want and in time. Cross-functional teams of experts drawn from different areas of the company have proved to be extremely beneficial for developing competitive products at significantly lower lead-time and lower cost. This approach is in line with the modern concept of restructuring and realigning of functions into customer-focused processes for ensuring customer satisfaction under TQM practices.

Concurrent engineering is also termed as "Simultaneous engineering", because as the name implies, a number of processes related to product development are carried out simultaneously in order to shorten the "cycle time" by as much as possible. If steps shown in Figure 6.15 for product development are performed sequentially and consecutively in the traditional way, the cycle time for design and production will be long, uneconomical and delayed for the market penetration. Concurrent engineering pulls together all the functions which have any stake in the development work and make them work together concurrently in teams. The team should have continuing product development involvement and responsibility from original concept through sales. The purpose of concurrent engineering is aggressive product development that is functionally efficient, easy to manufacture, and fulfills the needs of customers. Concurrent engineering has emerged as a way of bringing rapid solutions to product design and development processes. Essential steps for concurrent engineering are shown in Figure 6.15. Functions of multi-discipline concurrent engineering teams include:

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- Distinguishing the characteristics of product for establishing appropriate design and production methods, which includes ease of service, repair and maintenance.
- Analyzing functions of the product so that all design decisions can be made after full understanding of how the product works in end application. All members of the team should understand the functions well for making their own contributions.
- Relating product function to production method capability. This can be facilitated by computer-aided design tools, which can simulate product performance by varying assumptions.
- Performing tests and review of manufacturing capability to examine if design can be simplified without affecting the performance or can be improved for value addition.
- Ensuring design compatibility of each part, its quality and assembly method for ease of production and preventing generation of defectives.
- Designing manufacturing system fully involving people who will run the system, operate on minimal inventory and compatible to suppliers' capability.

Many companies have made use of cross-functional concurrent engineering team drawn from different areas of operations for developing globally competitive products at significantly lower cost. Collaboration amongst individuals, groups, departments, and separate organizations within the firm is a must in concurrent engineering approach. Therefore, it may need re-looking into the organization structure for effective integration of people and the process. A firm must be dedicated to the long term implementation, appraisal, and continuous revision of a concurrent engineering process and results. It would be apparent that concurrent engineering and QFD have some commonality in approach. In fact, concurrent engineering technique makes frequent use of a number of popular tools. QFD, Failure Mode analysis, Design of Experiment, Benchmarking, etc are some of those tools.

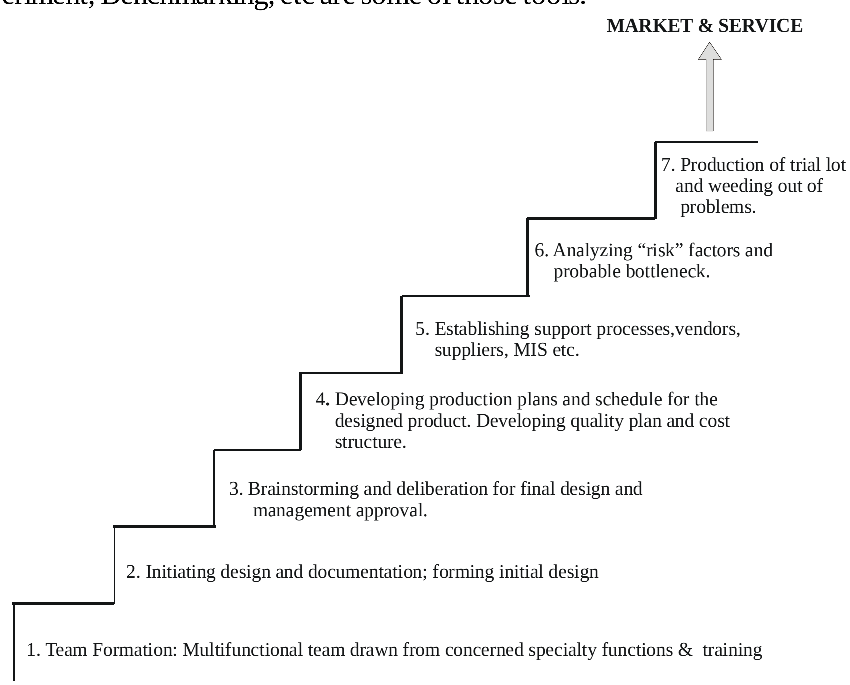

Fig. 6.15 *Seven Essential Steps of Product Development by Concurrent Engineering*

It is to be appreciated that majority of a product's costs are committed very early in the design and development process. Therefore, application of concurrent engineering should be at the onset of a project concerning product development. There are several applications in which concurrent engineering may be used. Some primary applications include product research, design, development, re-engineering, manufacturing, and redesigning of existing and new products. In these applications, concurrent engineering is applied throughout the design and development process to enable the company to reap the full benefits of this process. There are several benefits that concurrent engineering can accomplish, such as improving quality and cost, delivery time of a new product, identifying and weeding-out design problems at the early stage of design and production, and ensuring the practice of doing first time right. The process has, therefore, come to be recognized as an essential step of business process strategy for ensuring customer satisfaction and market leadership.

(2) Design of Experiment

'Design of Experiment' (DOE) is a structured statistical method for determining the relationship between factors (Xs) influencing a process and the output of that process (Y). The concept was first introduced by Sir Ronald A. Fisher as a method for testing certain hypothesis in 1920s. Taguchi, the famous Japanese statistician, further improved the technique in 1950s, for engineering applications. Taguchi introduced the technique for incorporating the effects of uncontrollable factors in the DOE experiments. The broad objective of the DOE is to study the influence of a 'subject factor' while the effects of other influencing factors are also taken into account. The technique is built on the method of analysis of variance by using modeling where the observed variance is partitioned into components due to different factors. This is a technique that uses formal statistical experiments, and facilitates conducting and analyzing controlled tests to evaluate the factors that control the values of a parameter or a group of parameters. In DOE, factors are varied simultaneously by suitable experimental design (like the Random design, Factorial design, Latin square design etc) instead of one at a time as in the conventional method of experimentations. DOE technique substantially reduces the number of tests compared to conventional testing where collecting large number of data, holding each factor constant, takes a very long time to establish the variations and influence of different interacting parameters of a process. The technique is widely used as a part of modelling process with an aim to establish a relationship between different factors influencing the process and the output quality. Most software packages dealing with mathematical modelling have an in-built programme for DOE where indeterminate measurements of factors and interactions between them can be accurately analyzed by feeding in methodical variations in the model. Following this technique, DOE can be successfully applied in the field of quality management to determine the best combinations of product and process parameters that could lead to high quality and low cost.

Design of experiment is a specialized, statistically designed, test programme, which calls for thorough planning before undertaking the test runs. Highlights of DOE process are:

1. Planning of the tests i.e. objective of the tests, how data is to be measured, nature of improvements aimed for, identification of variables, etc.
2. Decision on data analysis approach with clear focus on the objective of the experiment.

3. Factors are varied simultaneously, and not one at a time, by adopting a suitable experimental design – popularly orthogonal array experiments.
4. Statistical approach in variance analysis and modelling.

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It is an efficient method for organizing experimental work for optimization or screening which factors are most influential in the experimental results. For example, in the machining of a precision component with very close tolerance level, there could be 'n' number of factors that influence the result, namely: material, material hardness, cutting speed of the machine, depth of cut, nature of cutting tools, coolant grade, coolant feed, machine sturdiness, operator skill, temperature of the machining-room, etc. Varying each of them independently to find out the ideal condition of machining will be very time consuming. Hence, the conditions can be best identified by orthogonal array experiments as a part of DOE process. In order to identify what parameters are important in the study, the Herringbone or Ishikawa Diagram (to be discussed later under statistical tools) can be plotted first and probable contributions of each parameter can be examined. Based on the Ishikawa diagram analyses, significant factors or design variables can be picked up and tests for DOE, by using factorial design of experiment, can be planned with clear focus. The technique of orthogonal array is at the core of design of experiments. This is a specialized technique based on statistical probability. Once the project is identified, the objectives and factors – along with their levels – are determined by group discussions in the planning meeting. There are a number of ways to set the experimental design based on the nature of the project and its objectives. Orthogonal arrays are one such popular technique used for facilitating design of experiments. Putting it simply, orthogonal array is a number table consisting of rows and columns where rows of the array represent the experiments or tests to be performed, and the columns correspond to different variables whose effects are being analyzed.

DOE dramatically reduces the number of tests required to establish optimum conditions or design, which is essential in the present-day competitive market for faster development of quality product and services. To facilitate its application, a number of computer software (DOE software) are available nowadays, which are programmed to deal with a large number of variations and constraints in the proposed model or experiment. To put it simply, the technique calls for defining variable ranges and applying constraints by using process data and engineering knowledge, and thereafter establishing the optimum conditions or design by suitably varying the optimum criteria, removing specific design points and optimally modifying the existing designs or process parameters with additional points. Some common steps in the DOE are:

1. Define the project or the problem, set objectives, and plan the tests.
2. Decide on evaluation criteria and quality characteristics.
3. Identify factors and levels of those that are to be included in the study.
4. Gather data and knowledge about the possible interactions of the factors included in the study.
5. Identify uncontrollable factors (Noise factors) and how they should be treated.
6. Identify the design variables and the range for each.
7. Decide which range to hold constant.
8. Select the measured response variables to be included in the study.

9. Select a statistical test design.
10. Run the tests for collecting significant data.
11. Analyze data (variance analysis) by using computer software and develop statistical models.
12. Interpretation of results with respect to improvements sought for e.g. optimization, performance, etc.
13. Decide on the design parameters.
14. Test robustness of the design.
15. Build the pilot lot of the designed product, and verify the design validity.

Important steps in the process of the DOE set-up are to identify design variables and response variables. **Design variables** are the variables we have control over. **Response variables** are the variables we cannot control but can measure. Typically, we want to achieve certain values of response variables by manipulating the levels of design variables. Examples of design variables include weight, size, process settings such as time/cutting speed, temperature etc. Examples of response variables include strength, dimensions, acceptance standards, cost, % of rejects, etc. At times, it may be difficult to distinguish between design variables and response variables due to high correlation between two variables, which cannot be varied independently. In such cases, it would be better to choose one as a design variable and measure the other as a response variable. The influence of controlled design variables on measured variables can take linear, interactive or quadratic effects, depending on the nature of variable effects in the designed experiment, and the results can be deduced accordingly. The result of this DOE experiment can then be used in the empirical model for system optimization. To sum up, the process involves:

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Design Variables: Variables we have control over

Response Variables: Variables we cannot control but can measure

- Knowledge of the process and parameters, and clear objective of the experiment,
- Planning and designing of the tests by considering the design variables and response variables, and
- Statistical modelling by expert knowledge based on a theoretical model involving design and response variables or using the results of DOE as described above.

DOE is used for three primary objectives, namely:

1. To establish which factors are most influential and over what range
2. To find optimum parameters, taking into consideration different demands based on the observed response of the experiment
3. To test the robustness of proposed solutions or design

Types of experiments will, therefore, depend on the objectives of the test. For example, two-level orthogonal arrays can be used to design experiments to suit several experimental situations to know the machine setting ranges in a machining process for performance consistency. DOE not only reduces time to establish the right process or product design, it also results in substantial reduction in cost. Many claim that the cost of developing a new product through DOE can lead to over 50% cost saving for a company. DOE has been applied to many functional areas like:

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1. Research & Development: For quantifying interrelationships between variables and/or screening a large number of variables to find out the critical ones.
2. Quality Assurance: For setting quality specifications and acceptance levels in a manufacturing set-up.
3. Product Development: For new product development, product optimization based on customer preferences or re-designing for coping with changes in market place.
4. Manufacturing: For establishing optimum machining conditions, casting conditions etc.

DOE is especially useful when making decisions involves a lot of unknowns. For example, during the development of a new product, there are usually lots of unknowns about how to design the best product but keeping the cost low. DOE can turn the unknowns into accurate estimates of the effects of variables that can lead to the right choice of design of the product under development. In quality management, the analysis of process parameters is often done by DOE, which relies on the preparation of orthogonal arrays that clearly show the impact of changes in process parameters on the output of the process.

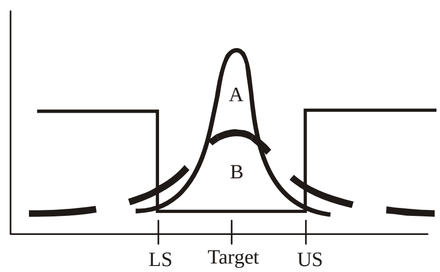

Fig. 6.16A *Situation 1*

(3) Taguchi's Quality Loss Function

Noted Japanese Quality philosopher, Taguchi, has developed a unique technique called Quality Loss Function analysis, which establishes cost (or financial implications) due to user dissatisfaction with a product's performance as it deviates from a target value. Taguchi pointed out that both, average of the process and variations, are critical measures for quality. This led him to formulate a technique to establish what should be the "target" value of a product or process that would result in no loss either to the company or to the customer. The analysis focuses on the controllable variations for making the process more centred with respect to the target value.

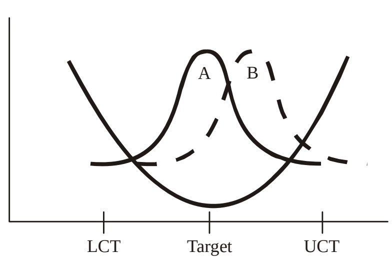

Fig. 6.16B *Situation 1*

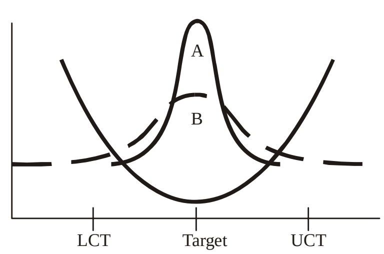

Fig. 6.16C *Situation 1*

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To understand the implication of the concept, let's considers three situations as represented below:

(1) **Situation 1** shows a situation where both curves A & B are centred on the target, but the spread of B (i.e. viriations) is more than A. It means that process B will be less relaible to produce quality on target, and will cause some economic loss.

(2) **Situation 2** shows that both processes A & B are equal in variations, but process A is closer to target value. Hence, it will be preferred by customers.

In these figures (6.16A,B,C), LS and US refer to lower and upper specifications, but figures 2 & 3 refer to LCT and UCT, which are lower and upper customer tolerance levels beyond which customers become dissatisfied. The task of Taguchi's loss function analysis is to find out the optimum target value that will not cause customer dissatisfaction as well as not cost the company more than what is required to be done.

Taguchi's Loss Function is plotted with Loss in the Y-axis (vertical) and Target value in the X-axis (horizontal) – vide Figure 6.17.

(3) **Situation 3** shows these situations superimposed on the Loss function curve, where the processes may be on target as per visual estimation but B has more variations, which must be corrected to get the optimum value from the design.

The Quality Loss Function gives a financial value for customers' increasing dissatisfaction as the product performance goes below the desired target performance. Equally, it gives a financial value for increasing costs as product performance goes above the desired target performance (see Figure 6.17). In the words of Quality Master Deming, Taguchi's loss function goes to prove: "A minimal loss at the nominal value, and an ever-increasing loss with departure either way from the nominal value." Thus, determining nominal value (i.e. target value) is a critical factor in the decision for designing a product or a process. Determining the target performance value is generally made by an educated guess, based on customer surveys and feedbacks. The quality loss function attempts to make this guess more scientific by introducing a method of statistical analysis for controlling variations. Loss function analysis entails evaluating both variance and the average of a process, and provides a single metric for comparison. In this respect, Taguchi's method can be considered as a combination of statistical and engineering approach to arrive at the optimum target value for minimum potential loss. Figure 6.17 shows an illustrative curve pertaining to Taguchi's Quality Loss Function.

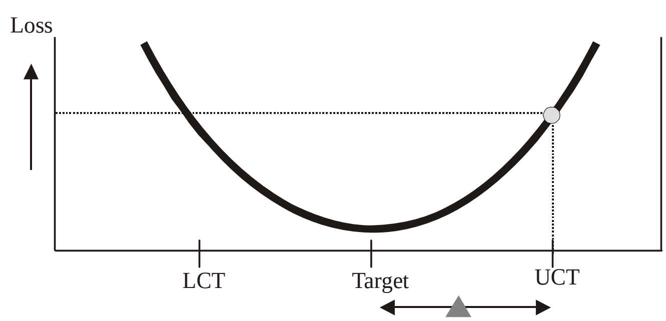

Fig. 6.17 *Taguchi' Quality Loss Function Curve*

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The quality loss function allows decisions to be made at the design stage itself regarding how to minimize loss (i.e. save cost) by controlling variations while aiming to achieve a target performance value.

Technically, Taguchi's Quality loss Function can be defined as: A parabolic representation that estimates the quality loss, expressed monetarily, which results when quality characteristics deviate from the target values. The cost of this deviation increases quadratically as the characteristic moves farther from the target value in either direction. Loss due to performance variation can be calculated from the following equations:

(1) Loss at a point $L(X) = k\ (X–t)^2$,

where k = Loss coefficient
X = measured value
t = target value

(2) For: Average Loss of a sample set: $L = k\ .\ [s^2 + (pm–t)^2]$

where, s = Standard deviation of the sample, pm = Process mean, and t = target value.

This would translate: Total Loss = Avg. Loss × Number of samples.

To work out the loss, measure data from a process line producing a part, data should be collected for about 30 or more parts, and also collect '*Failure cost' per part* from the filed. Then:

Calculate *average of the measurements*, and the *standard deviation* by checking the spread and dividing the same by 6.

Find k (a constant for the process) from the formula (1), using L(X) = failure cost obtained from the field, and the target value (t) set for the process.

Next, calculate *average loss per part* in this set by using formula (2).

Quality managers often come across cases where parts have been produced as per the specification band and okayed by QC, but some of them are not fitting to the next assembly point requirements. As a result, the parts not fitting which cost money to the company should be either rejected or reworked. Taguchi's method allows the company to design the process or the product by following this analysis, and then taking measures to control the variations. The more precision, the more likely is the chance of facing such problems in a company.

For effectively handling this situation, Taguchi considered that both average performance and variation are critical measures of quality capability, and they have to match each other. In this regard, he classified the causes of variations into: controllable and uncontrollable. He called the latter category noise factors. He recommended that selecting a product design or a manufacturing process that is insensitive to uncontrolled sources of variation improves quality, but major source of loss are due to controllable variations. Applying Taguchi's concept entails evaluating both the variance and the average for arriving at a best solution. For a dynamic situation, where the performance level depends on some conditions of usage or applications, he used the concept of signal factor and adjustment factor. His method suggests adjustment of "adjustment factor" in such a manner that the relationship between signal and adjustment factors becomes insensitive or less sensitive. A simple example is the design of a ceiling fan. Noise from running the fan causes customer annoyance, and this can be controlled by adjusting the quality of bushes (it could be for other reasons, but considered for this example) in a manner that noise level does not change any further after some bush quality improvement. For further improvement, another signal factor to be taken – for example, heat generation during running – and the armature quality should be adjusted till the temperature rise becomes insensitive to the armature quality. These improvement actions can go on till a satisfactory product has been designed. Thus, improvement actions during the design stage itself can be taken to ensure a product that does earn customer dissatisfaction and at the same time does not lead the company to make improvements in the parts beyond a level where there is no return of investment.

Taguchi recommended use of "orthogonal arrays" as a technique to simulate the results of various factor combinations to reduce the number of experiments otherwise necessary to complete the design. This is necessary to coming to a balanced solution. Taguchi's loss function analysis goes to show that though many times the guess work for target value setting may work in the industry, but for ensuring value to customers by producing the satisfactory product at optimum cost, it should not be left to chance, because of the gap between average and variations inherent in a process (see Situations 1 to 3 mentioned earlier). Variations must be controlled to minimum level by systematic analysis and corrective actions, and Taguchi's method provides an answer to this problem. The system can be used in the application of QFD technique for designing of product features or for benchmarking the quality output of a process.

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(4) Value Engineering

Value Engineering (VE) is a technique for analyzing functions of an item or process to determine "best value" or the best relationship between "worth" and "cost". By "Best value", means that an item or process consistently performs the required basic functions and has the lowest total cost. **Value Engineering** can be defined as an organized effort directed at analyzing the functions of systems, equipment, facilities, services, and supplies for the purpose of achieving the essential functions at the *lowest life-cycle cost* consistent with required performance, reliability, quality, and safety. Value Engineering (VE) was first developed by Lawrence Miles as a research activity at the General Electric Corporation, USA, during World War II, and since then got widely used in industries and Government bodies to take advantage of its benefits. The efforts pertaining to VE can be performed by both in-house personnel and by experts from outside the organization. Value engineering contributes to the overall management objectives of the company by improving quality, reducing cost, streamlining operations, and promoting a creative work culture. The technique is variously known as value analysis, value management, and value control. The primary purpose of the technique is to accomplish all the required functions of an item or a process at the lowest total cost through a process of elimination, combination, substitution or simplification of design parameters or process steps. In the present day competitive business environment, VE has a vital role as a proven tool for reducing cost and improving product quality and process performances.

Value Engineering: An organized effort directed at analyzing the functions of systems, equipment, facilities, services, and supplies for the purpose of achieving the essential functions at the lowest life-cycle cost consistent with required performance, reliability, quality, and safety

Value engineering is a customer centric process, and, as such, it focuses on functions of an item or process for the analysis. When the technique is applied at the design or engineering stage, it may be called value engineering (VE), and when it is applied at the later stages of manufacturing or during the life cycle of the product, it is called value analysis (VA). However, many subscribe to the idea that a VE project

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should start with value analysis (VA) first and then should be appropriately designed and engineered to add value to the product. The objective of these processes is to ensure that the desired value (i.e. value what a customer requires for its applicability and is prepared to pay for the same) is not compromised at all at any stages, namely design, engineering planning, process planning, or manufacturing. Since value of an item lies in factors like the quality, maintainability, repairability, aesthetics, longevity, etc, efforts of functional analysis must direct to all these factors, and quality alone. Thus, value engineering is a function based strategy to accomplish the desired functions of a part at least cost or desired features of an article at lowest life-cycle cost. The process of VE is, therefore, multidisciplinary and follows a specific methodology. In brief, the VE process breaks components of a project into functions, and the VE team identifies solutions that will satisfy the functions. In a manufacturing organization, VE team formulates the solutions into workable recommendations and the design team implements the valid recommendations into the design. To ensure that systematic VE improvements are achieved, the following process steps for value engineering are recommended:

1. Designating a management official to monitor and coordinate the VE efforts in the organization.
2. Developing criteria and guidelines for both in-house and outside experts to identify programmes / projects with most potential to yield good savings from the VE application. VE process should recognize that potential savings are greatest during the planning, designing and initial phases of the programme implementation. Guidelines should cover:
   a. Minimum threshold value for selection of a project;
   b. What is acceptable under the prevailing regulations for the product, environmental standards and energy regulations;
   c. Providing training in VE techniques to the staff assigned for developing, analyzing, reviewing and carrying out VE proposal and evaluations;
   d. Documenting the projects, programmes, systems and products that meet the criteria for carrying out VE studies. Also, documenting the reasons for not implementing recommendations by VE teams;
   e. Developing annual plans and reporting systems on VE activities in the organization.

Methodology of VE study involves the following stages:

- *Selection (Pre-study)* – this involves selection of right projects, processes or systems.
- *Investigation* – this stage involves gathering background information and data, and carrying out functional analysis by the VE team. The team compiles all information pertaining to customers' needs and ranks them in a relative scale.
- *Brainstorming* – for identifying creative alternative proposals. This stage is the most crucial and involves (a) identifying primary functions of the product, (b) breaking down the primary functions into sub-functions – secondary, tertiary etc, and (c) estimating costs for providing the desired features in the product.

- *Evaluation* – this involves analyses of alternatives and life-cycle costs in order to establish an optimal set of product functions that meet the requirements of the customers at least life-cycle costs.
- *Development* – involving technical and economical justifications with supporting data of the chosen set of functions that offer the highest value at the lowest cost.
- *Presentation* – to the management with recommendations and team findings.
- Implementation (Post-study) – involving fair evaluation of the proposal, working out of the implementation plan, identification of resources, and implementation.
- *Audit* – involving review of the accomplished results, and awards.

Though cost saving is the result of a VE project, it primarily aims at providing essential features and functions of a product to customers at the least life-cycle cost. In this respect, it has some similarity with the QFD objectives and a matrix very similar to the one used for QFD analysis can be used for VE also. A typical spreadsheet for VE study should consider:

(1) Primary functions of the assembly or the product.

Functions of each part that goes into the aggregate–including listing of subfunctions of each part.

(2) How the functions and sub-functions are synchronized to achieve the primary functions, and the cost of this synchronization.

(3) Special features of the function, and value or importance of the functions expressed in terms of index or % of value being attached by customers.

(4) Cost of the parts as % of total cost.

(5) Any other features that add value to the product.

Value analysis and working out of alternatives have to be carried out based on these functions and costs analysis by the VE team.

VE is not only recognized but also acclaimed as one of the best Value Improving Practices that management can employ. It is being successfully applied to new product development, improvement of existing products, quality improvement, improvement of customer satisfaction, and the process of planning, manufacturing and constructions for maximizing businesses. Some major benefits of VE are:

- Reduction of product and operating costs
- Effective utilization of resources for better businesses
- Reduction of waste
- Clear direction of work philosophy, and resultant employee involvement
- Cost competitiveness for gaining strength in the market place.

It must be borne in mind that VE is not simply cost reduction; it is about teamwork that is focused to give best value for money to the customers at large. To achieve this goal, more and more companies are now collaborating with the suppliers and customers alike by cutting down the barriers of organizational boundaries. They are all working as a team for cutting down waste and building real value that serves the customers best.

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(5) Fault Tree Analysis

There are many products where the cost of failure could be very high e.g. break failure of a car, failure of domestic LPG gas cylinder valves, passenger lifts, escalators, etc. Such failures often entangle product liability cost, which could have a telling effect on the company's performances. The fault tree analysis is an effective means to know in advance the list of undesirable events that the design team must take care of in terms of more robust and reliable design or incorporation of other fail-safe methods. As the name implies, the fault tree analysis involves systematically arranging in the form of a branching out tree of different causes that may be responsible for the failure of a part that is being studied for improvement. The technique is best used in the design of a mass-producing new product where the hazard of failure may affect the product acceptability or harm the users.

The fault tree diagram attempts to interlink the probable causes of failure of an event through the representation of branches of a tree. The branches are linked together by means of gates, as in logical circuit, indicating if the event can occur as an "either-or" event or as a "this and that" event. Example of a fault tree analysis of axle failure of an automobile is shown Figure 6.18.

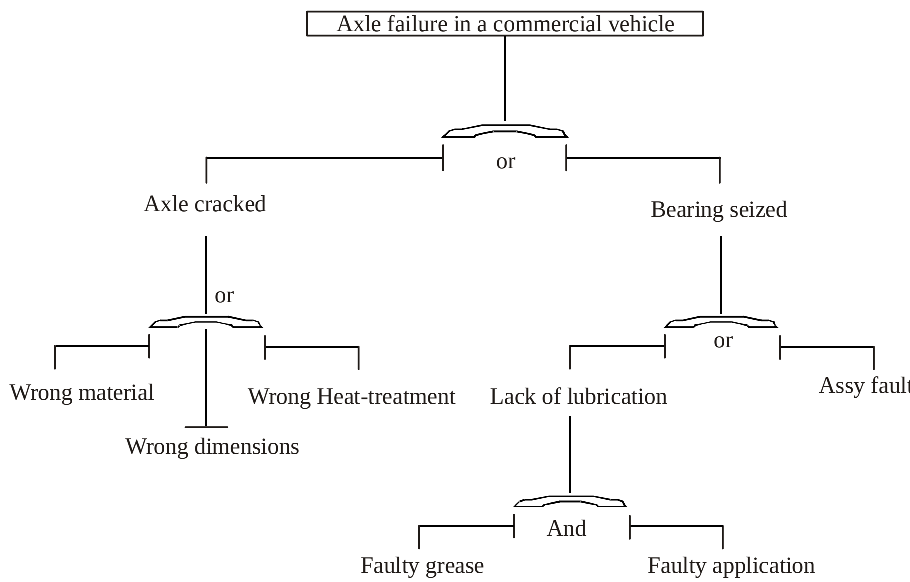

Fig. 6.18 *llustration of fault tree analysis – showing the inter-linking causes of failure of an automobile axle. [Only some of the probable causes have been shown; other causes can be built into the diagram]*

In fault tree analysis, relative seriousness of the event (failure) is indicated by assigning "class of hazard" under four categories:

- *Class* I: Negligible hazard – those cases that will not result in personal injury or other product damage. Example: Failure of an electric bulb.
- *Class* II: Marginal hazard – those that can be controlled without injury to personnel or major product damage. Example: Failure of a bi-cycle tube.
- *Class* III: Critical hazard – those cases that will cause personnel injury or major product damage. Example: Earlier stated axle failure of a commercial

vehicle. This class of hazard needs immediate attention for corrective actions for product survival.

- *Class* IV: Catastrophic hazard – that will cause severe injury to personnel or product loss. Example: Failure of break of a running vehicle.

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Generally, a numerical value is assigned to the above hazard categories, and a numerical value assigned to the possibility of failure and the overall risk involved. For instance, hazard categories can be assigned: Class I = 0, Class II = 1, Class III = 5, and Class IV = 10, and the possibility of failure with respect to causes shown in Figure 5.5 could be out of 100: Wrong material = 10, Wrong dimension = 5, Wrong heat-treatment = 20, Faulty grease = 10 etc. The latter values will depend on the set-up and environment under which the manufacturing is being carried out. The primary aim of such a system of assigning numerical values is for actions by the design and control team to minimize the chance or risk of any type of failure that may endanger human lives or heavy damage to the property.

It may be appreciated that use of the fault tree analysis technique calls for accurate data and information about field conditions in which the component has to work, the nature of accidents or failures in the field, customer complaint data, competitors' product capability, laws and regulations relating to the safety and serviceability of the product etc. As such, the process demands an accurate data gathering system, record keeping and elaborate information management system in the organization. Where there is a paucity of information and data relating to the modes of failure, elaborate field trial and testing of sub-assemblies/assemblies may be needed to acquire knowledge. Elaborate designs of information system, field trials and assembly testing facilities prevalent in automobile manufacturing companies are some examples of steps for fulfilling this necessity. An effective system in this respect helps to understand, design and mitigate the factors that may cause product quality deficiencies in the field operations.

(6) New Seven Management Tools

There are a number of other tools that can be used for quality planning, and the one that is gaining popularity is "The New Seven Management and Planning Tools". These tools are not exactly new to the industries, but were made popular in US and Japan since mid-1980s for improving the effectiveness of their quality planning and improvement efforts. These new tools are especially useful for structuring some unstructured ideas, making strategic plans and organizing complex projects. The "New Seven Tools" are:

1. Affinity Diagram,
2. Interrelationship Diagram,
3. Tree Diagram,
4. Matrix Diagram,
5. Matrix Data Analysis,
6. Process Decision Programme Chart (PDPC), and
7. Arrow Diagram.

Some of these tools have already been mentioned in this section. These tools are basically drawn from "Operations Research" methodology, and discussing them in details is out of bound of this volume. Hence, only the salient features would be mentioned here.

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(1) **Affinity Diagram**: It is a technique of gathering and organising large number of data or ideas, opinion and facts relating to a problem or project, and to identify natural patterns or groupings in the information. This technique is a team approach and applied on broad issues that affect the organization's business performance, such as customer dissatisfaction, causes for high cost of poor quality, etc.

Once the issue has been identified, the team (generally 6 to 8 persons) is formed, which then brainstorm on the selected issue and note down each response. Thereafter, the ideas, which are generally put forward at random during brainstorming sessions, are grouped according to their "affinity" or relationship to each other. This helps to systematise the ideas and guide to the measures for solution. The "affinity" relationship can be suitably displayed in a flow-chart pattern by further brainstorming with creative approach (i.e. looking differently and creatively) to the problem for optimal solution.

(2) **Interrelationship Digraphs**: This is a technique where a central issue is chosen and then logical or sequential links are developed among related category of problems, in order to get a clear idea about what leads to the central problem. This is also a team approach and encourages lateral thinking in problem solving, like downtime analysis, failure cost, etc. The key points are: (1) it illustrates interrelationships between many ideas, (2) identifies major factors or causes affecting the issue, (3) enables problems to be examined from broad perspective, (4) determine the order or sequence in which the issues should be addressed, and (5) eliminates any bias in solution due to preconceived ideas that most frequently creep in into any problem-solving process. This technique is often used in conjunction with "Affinity Diagram", after the latter technique has established clear focus to the issues at hand. The aim of this technique is to take the central idea (say from affinity diagram study) and then map out logical or sequential links among related issues. For each issue at hand, the team members are encouraged to come out with more than one solution in order to lead to the more optimal solution. Figure 6.19 illustrates an "Interrelationship Digraph" for a machine downtime (only few typical causes are illustrated). Figigure 6.19 only points to the possible issues; linkages between the issues for right solution should be carried out by the team members by brainstorming, cause-and-effect analysis, etc.

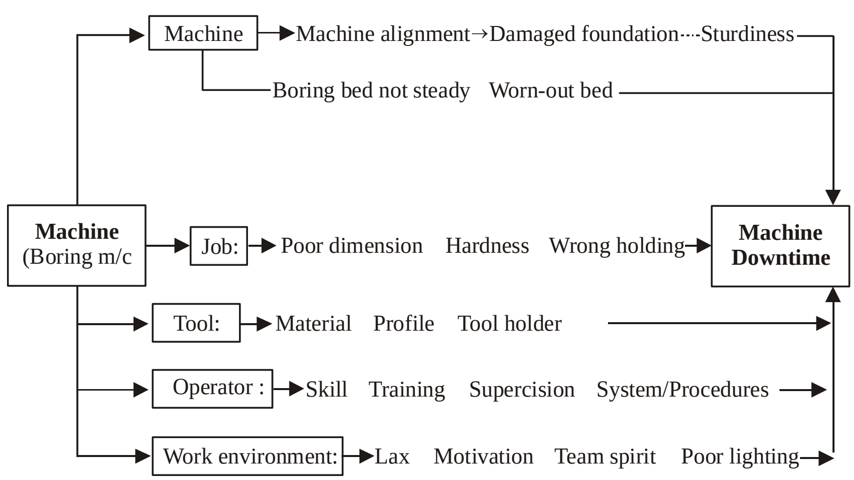

Fig. 6.19 *An Illustrative 'Interrelationship Digraph'*

The idea is to join together by all process owners to brainstorm and zero in to the causes of a problem, and ensure that the systems and methods are correctly placed for effective quality management.

(3) **Tree Diagram:** This is an analytical planning tool that is used in breaking down issues and ideas until actionable items and points are identified. The tool is primarily used for operational planning steps after the initial diagnosis of issues and problems have been made. The technique calls for a clear statement of the problem from where a team starts looking into the process steps required to arrive at a final conclusion. The tree diagram can also be used for process step identification with a view to producing correctly and efficiently. A common example of use of tree diagram for charting out process steps is the assembly of individual parts to sub-assemblies and then to final assembly in a car plant. The chart, showing steps form the base problem to the sequential development of process or activity steps till the final conclusion, looks more like an inclined tree. In this context, readers are referred to "Fault Tree Analysis", which is a variant of tree diagram for decision-making – also known as "Decision Tree".

The typical steps in tree diagram analysis are:

1. Choose the project or issue to be solved or goal to be achieved, and develop a clear goal statement for focus.
2. Identify major "heads" under which the issue is to be analysed. For example, analysis of customer needs, competitions, process capability, supplier availability, budget and inventory constraints, etc. for new product development. (These feedbacks are generally generated from Affinity Diagram, Interrelationship Diagram or by Brainstorming).
3. Organise all tasks logically in order to arrive to the set goal by asking questions and brainstorming. Put them in order under each head.
4. Review the diagram to ensure that all tasks have been included in logical sequence.
5. Plan the process and actions to resolve the issue as per goal.

(4) **Matrix Diagram:** It is a method of graphically displaying relationship between characteristics, functions and tasks in such a way so as to establish a logical connecting points between the factors being considered. "House of Quality" as shown under QFD discussion is an example of this approach. The aim of this technique is to help identifying the features of a product or service that would satisfy the function and task at the filed of applications, and then proceed to use that information for quality planning and improvement.

(5) **Matrix Data Analysis:** Matrix data analysis is a statistics-based "factor analysis" technique. The process takes data from matrix diagrams and then attempts to arrange it quantitatively to display the degree of relationship among the variables. For daily work, this technique is too quantitative. Therefore, some prefer to use an alternative approach – prioritization matrix – for simplifying the issue and to apply in daily work.

(6) **Process Decision Programme Chart (PDPC)**: The PDPC is a management and planning tool that is used to create a detailed implementation plan by including all possible problems and unfavourable events that may occur during the

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implementation. It maps out all possible events that can occur when moving from a problem statement to possible solutions. In practice, PDPC takes each branch of a tree diagram, anticipates possible problems and provides alternative measures that will prevent the deviation from occurring or not to be affected by the deviation. An example of PDPC is shown in Figure 6.20.

(7) **Arrow Diagram:** This involves planning and constructing the essential steps from start to finish of a project or problem solution, where the steps are connected by arrows to indicate the flow of events or activities. This technique has been widely used in the form of CPM or PERT.

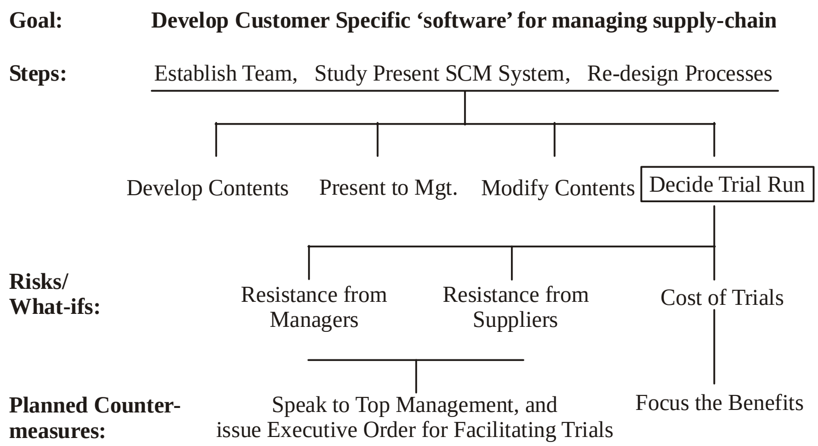

Fig. 6.20 *An Illustrative Process Decision Programme Chart*

These management and planning tools are often used conjointly, and considered useful to promote participation of managers in improving the quality of decisions through teamwork and active involvement of individuals. As will be appreciated from later discussions of 'Statistical Tools', many of these new tools have their concept drawn from 'seven simple tools of statistics'.

6.5 CONTINUOUS IMPROVEMENT TOOLS

As the title implies, it is a specially designed process of activities in a company for continually achieving further improvements in quality and value in products and services. The aim of this improvement progrrame is accomplishing higher customer satisfaction and superior business performances. Continuous improvement is a part of principles by which total quality is practiced in modern organizations, and it has become a part and parcel of strategic management philosophy for superior business results. It is not only a part of product or service quality improvement programme alone; but it embraces all systems and processes in the organizations for customer satisfaction and superior business results. As such, continuous improvement programmes must cover all areas of operations in an organization concerned with the customer satisfaction and superior business performance. This process is at the core of total quality management practice.

The important areas of applications of continuous improvement include:

- Improving quality levels of products and services
- Reducing waste, errors and defectives, leading to improvement in costs

Check Your Progress

1. What do you understand by quality of a product or service?
2. What does the mission statement of an organization define?
3. Define Acceptable Quality Level.
4. What is a check sheet?
5. What is a Pareto diagram?

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- Improving cycle time of performance and lead time for response to customer requirements
- Developing new understanding about the changing market and customer preferences
- Improving the company's overall performances for fulfilling the corporate responsibilities and obligations to different stakeholders, and
- Developing the skill and competence of people in the organization.

There are number of ways by which an organization can put continuous improvement into practice, but basic steps of a continuous improvement process are: (a) systematically determining and isolating the root causes of quality or performance deficiencies hindering the improvements or desired results, (b) remedying the performance problem by eliminating the root causes, and (c) stabilising the system or the process by standardising the improved practice so that the system functions effectively to hold to the gains. Obviously, analysis of these steps would require considerable use of different statistical tools; some of which will be discussed in this unit. These steps of analysis are similar in practice as mentioned under the *Deming's P-D-C-A cycle*, and *Juran's quality improvement programme*. Continuous improvement drives are a never-ending cycle of activities for doing better and better, time and again. The process demands the belief that there is no end to improvements, and the main barrier to recognise the need for improvement is the fixed mind-set of people working in the concerned areas. Thus, teamwork, creativity and innovation are a part and parcel of all continuous improvement programmes, because they help in overcoming a fixed view and mental barrier, and also help in finding out the best alternative solution to a problem through creative thinking and innovative approach to the problem solving.

While creativity, innovation and teamwork are common denominators for continuous improvement programmes, some of the important techniques for continuous improvement are: Deming's P-D-C-A cycle, Kaizen, Quality Circle, Just-in-Time Manufacturing (JIT), Poka-Yoke (mistake Proofing), Zero-Defect Programme, Taguchi's Quality Loss Function, and 5-S programme. Majority of these tools can be also used for quality planning and for special strategic purpose. Taguchi's Loss Function analysis has been discussed earlier, because the technique is unique for quality planning of improved products. Quality circle and 5-S programme would be discussed under 'Participative Quality Improvement' techniques. A brief description of other techniques is also provided in this unit. The subject of quality planning and quality improvement tools is so vast that they are generally covered in special, purpose-dedicated books on this subject. The coverage of such detailed treatment is outside the scope of this book. The discussions given here are aimed at providing the scope and elements of each of these techniques, and their relevance to total quality management.

1. Deming's P-D-C-A Cycle

Deming's P-D-C-A (Plan-Do-Check-and Act) cycle underlies the basic approach in problem solving and improvement projects. What it implies is that for solving a problem, one must understand why it is important to undertake the improvement programme of the problem area and then *plan* what to do, *doing* as decided from the data set and analysis of the planning step, *checking* if the results achieved are adequate or what

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one wanted it to be, and then *acting* for implementation and standardization of the practice. The important steps in this process are:

(i) PLAN: (A) Identify the problem/improvement area with justification for why –based on facts and data, and not perception or hunches. (This phase of work is called Proof of the Need in Juran's approach).

(B) Study current situations by: (a) collecting present data, (b) deciding data on competitions or desirability, and (c) determining goals to be achieved by the study.

(C) Analysis of the problem for planning the action points from present data. The steps involve are (a) identifying possible causes, (b) shortlisting most probable causes, and (c) isolating the root cause(s).

(Steps B and C are known as Diagnostic Journey in Juran's approach).

(ii) DO: Implement solution for the root cause(s) by analysing: (a) list of possible solutions, (b) selecting preferred solution with justifications, and (c) implementing preferred solutions in the process or problem areas. (This step is called Remedial Journey in Juran's approach).

(iii) CHECK: This step involves checking, measuring, analysing and continuous monitoring of results. The aim of this step is to ensure that the developed solution or the process can produce the desired result.

(iv) ACT: This step is known as 'Holding to the Gains' by (a) standardising the process of improvement achieved by the programme, (b) reviewing the whole process to plug any loopholes, and identifying future work.

These are the basic steps for systematic approach to continuous improvement in total quality practice. In fact, the P-D-C-A approach – alongwith S-D-C-A cycle – has come to be recognised as a powerful tool for problem solving in industries. S-D-C-A stands for 'Standardize-Do-Check-and-Act. S-D-C-A cycle helps in bringing about the needed standardization in the practice in a manner that eliminates the possibility of the problem recurring again in the system and leads to the consistency in the higher level of performance or quality. Figure 6.21 shows an illustration of how P-D-C-A and S-D-C-A cycles can be combined together for accomplishing step-by-step improvement, which is the characteristic of any continuous improvement project.

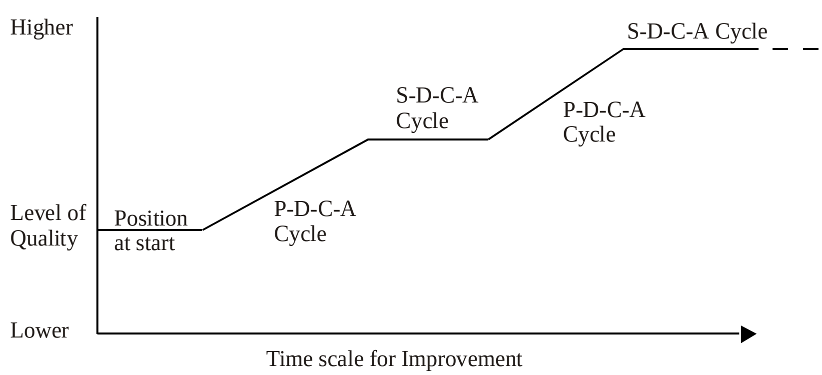

Fig. 6.21 *The Combination of P-D-C-A and S-D-C-A Cycles in Work for Achieving Step-by-step Performance Improvement*

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As Figure 6.21 indicates, while improvement is brought about by P-D-C-A cycle, the system has to be brought to a stage of stable control by the application of S-D-C-A cycle. These steps in the improvement work are termed as "freezing" of the result at a new level, and "unfreezing" the system from the said level for improvement to take it to a higher level. Thus, S-D-C-A cycle is a continuous cycle that has to be perpetually rotated in order to work for a higher level of performances. Application of S-D-C-A cycle helps in ensuring the effectiveness of the new system after the implementation and standardization of the planned solution. This is the essence of any continuous improvement study where one improvement result serves as the take-off point for another continuous improvement study. In sum, continuous improvement is a process linked with unbroken chain of following activities:

(i) Systematic determination and isolation of root causes of performance deficiencies in any area of the business, namely production, quality, supply-chain, finance, etc.

(ii) Remedying the performance problem by eliminating the root causes by appropriate measures in the company.

(iii) Ensuring stabilization of remedied measure in the organization's systems or practices so that solutions are effective and provide the desired benefits.

(iv) Thinking and working out for the next opportunity for improvement, and keep on repeating this cycle.

In continuous improvement programme, it is not enough to take actions alone, it must also be ensured that the 'actions taken' have yielded the desired results that are effective enough in the context of the organization's business situations.

2. Juran's 'Quality Trilogy'

Juran's 'Quality Trilogy' has been another powerful approach for quality improvement, and being successfully practiced globally under the guidance of Juran Institute. This has been discussed in some details in unit 1; the purpose of repeating the same here is to emphasise the fact that this philosophy has been subsequently developed as a full-fledged technique for quality improvement in many organizations. This approach is often termed as Juran's 'project by project' improvement technique, because Juran recommended handling of any improvement work in 'byte-by-byte' manner (i.e. systematically) as in a project and following the guidelines of his 'Quality Trilogy'. Briefly, the steps involved in his 'Quality Trilogy' are:

	Identify the customers.
	Determine the needs of those customers.
Quality Planning	Translate those needs into your language.
	Develop a product that can respond to those needs.
	Optimise the product features so as to meet your needs and customer needs.
Quality Improvement	Develop a process which is able to produce the product.
	Optimise the process.
Quality Control	Prove that the process can produce the product under operating
	conditions with minimal inspection.
	Transfer the process to operations.

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Juran suggested that all improvement work must be carried out by following the above sequence, and the improvement programme should be handled as a project with cross-functional project team. This cross-functional team should be formed only for an identified project, and then disbanded after the project has been completed and gains from the project have been held. Different cross-functional teams should be formed for different improvement projects. Thus, while Deming's P-D-C-A cycle starts with the planning of the programme by top management (e.g. Quality Councils/ Sub-Councils, or the Steering Committee responsible for quality in the organization). Juran's approach is very much people driven and system based.

The journey for improvement in the scheme of things by Juran starts with properly identifying a project, which involves analysis of data and information to determine the areas of opportunity or where the deficiencies lie. The purpose of analysing data is to frame the proof of the need for improvement, and thereafter define the project and its objectives in clear measurable terms. The next steps in the journey are to analyse possible causes and identify root causes, and finally move from the root causes to the remedies. Remedial journey is not complete unless the solutions have been implemented, checked, measured and analysed to determine if desired results have been achieved. If not, root cause analysis and remedies should be re-examined and re-evaluated. Once the results are satisfactory, the technique recommends that the process of achieving the set results be standardised in practice for holding to the gains. Broadly, the process can be divided into 10 systematic steps. They are:

A. *Proof of the Need*:

(1) Identify improvement opportunities

(2) Understand why the problem has to be addressed

(3) Clearly state the problem and plan the desired results (target)

B. *Root Cause Analysis*:

(4) Seek Cause-and-Effect relationship

(5) Collect relevant data and analyse

(6) Isolate root cause(s)

(7) Identify and implement preferred solution(s)

C. *Remedial Journey*:

(8) Check and monitor results

(9) If goals are met – adopt the solution in practice; if not, repeat steps 4 to 8

D. *Holding to the Gains*:

(10) Review the whole process to plug any loopholes, and standardise the new process for practice.

There are lots of commonalities between Juran's and Deming's approach, but Juran's approach is more customer specific. Juran is the first one who explicitly introduced "customers" as a focus for any quality improvement scheme, and had designed the quality management techniques towards that end. He emphasised customer satisfaction more than Deming did and focussed on management and technical methods rather than worker satisfaction. In fact, Juran's approach is more applicable where the objective of the improvement work is to achieve a 'breakthrough' improvement in the organization with the help of management interventions and creative technical actions. And, to make the breakthrough possible, Juran advocated the use of "80:20" rule of Pareto, which emphasises on concentrating on the 'vital few' sources of problems, and not to be distracted by 'trivial many' i.e. less important ones.

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Kaizen: A japanese word, meaning 'continuous improvement'

3. Kaizen

Kaizen is a Japanese word, meaning 'continuous improvement'; 'Kai' means continuous, and 'zen' means improvement. Kaizen calls for never-ending efforts for improvement involving everyone in the organization–be they managers or workers. It is a people—centric process, and people's involvement and commitment to improvement is a must for successful Kaizen project. Kaizen principles believe that everything can be improved – increment-by-increment – leading to the accomplishment of much higher goals, be that in personal life or in business. In business management, Kaizen – the most powerful tool of Japanese origin for performance improvement – is now widely used internationally. A part of this technique has been discussed while describing the contributions of its originator—Masaaki Imai–the father of 'Kaizen'.

The basic tenet of Kaizen is that a large number of small improvements over a period will result in substantial improvement in organizational performance. The cumulative effect of these small incremental improvements, in turn, leads to quantum improvement in the areas of operations and performance. As a result, Kaizen culture changes the vision of the company and morale of the employees, which are essential for superior performances. Kaizen involves looking into the problems with a fresh eye, and aims to ensure effectiveness of a system or business by restructuring and organising every aspect of their operations and practices in the workplace. This does not mean that whatever is ongoing in a company should be changed or tinkered with. The change, which always accompanies a successful Kaizen process, has to be made after detailed study and thorough analysis, including views and suggestions of the people working in the respective areas of operations or business. It is a very "people-centric" process, and is based on the five primary elements:

- **Teamwork**: Kaizen aims to establish teamwork in the company, and make the employees and management to look at each other as member of the team with a common goal. A Kaizen company pulls together all its employees towards the common goal.
- **Personal Discipline**: Kaizen believes that each member of a team must have high morale and discipline in thinking and behaviour to make the team effective. A team cannot succeed without each member working in unison and seeing each other as a competitor rather than support.
- **Improved Morale:** Kaizen believes that high moral amongst employees is essential for achieving long-term results. Therefore, Kaizen process is designed to take care of employee morale by people to people touch and effective communication system.
- **Suggestion for Improvement:** Seeking improvement is the aim of Kaizen. Therefore, Kaizen process calls for feedback and open communication from each member of the team and people concerned with the area or problem. The idea is to proactively act before things are late.

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- **Quality Circle:** Quality circle refers to voluntary groups in the workplace who meet to discuss quality levels concerning pre-identified areas in the company. This is an essential tool for giving effect to the Kaizen concept in an organization, and is being widely used by many industries.

Kaizen is not a process that looks at radical measures to create drastic changes and immediate improvements; it is a process of continuous, long-term approach to improvements with the help of people involved with the jobs. Kaizen believes that improvements continually unfold in a set up, and the activities of Kaizen team are accordingly designed to take long-term continuous improvement approach.

Kaizen, as a process, demands standardization of as many aspects of a business (or a manufacturing process) as is possible, removing all bottlenecks for quality and productivity. Since frequent pitfall in quality management is lack of internal infrastructures, systems and proven procedures, Kaizen approach often starts with analysing, organising and restructuring every aspects of a system to ensure that it functions at peak efficiency. This approach can be split into two functions, namely (1) establishment and maintenance of the standard operating procedures (sop), and (2) continual improvement of the same. Once the standard operating procedures have been established and mastered through a combination of discipline and human resource development, the next step is to seek to establish higher standards, i.e. improvements. The areas of improvements can be of two types, necessitating innovation for drastic improvement involving large investments, and Kaizen type small improvements to be brought about by continuous efforts of the teams of employees. As has been mentioned earlier, Kaizen principle believes that everything can be improved, increment-by-increment, leading to the accomplishment of much higher goals. Kaizen encourages small improvements day after day, continuously. It is a never-ending improvement process that follows gradual improvement method as opposed to drastic change by scrapping everything and starting anew.

The first step in Kaizen implementation is to check the current working standards and procedures in order to estimate the current performance and scope for further improvements. Once the scope has been defined, the next step is to "go to *GEMBA*"—*Gemba* means the real place where the real action takes place. This is often the work-place, i.e. shop floor. At the shop floor, two kinds of actions need to be taken: (1) to involve the people working in the area, and (2) to introduce 'good housekeeping' through *5-S principles* for bringing discipline, orderliness and creative thinking amongst the people working in the shop floor. Kaizen involves both, working on the improvement of people concerned in the areas of work as well as on improving the systems and procedures for setting higher standards for better results. As such, Kaizen is a strictly controlled action plan; it does not allow anybody to change any design or system without thorough analysis and committee approval (Kaizen Committee). In Kaizen practice, everybody in the improvement group, regardless of rank or position, is encouraged to put up "suggestions" for improvements, which are examined in details by the committee. One of the critical tasks of Kaizen committee or improvement groups is to eliminate **MUDA**, i.e. wastes. Wastes are often the major source of potential revenue loss in the business. The best way to tackle *MUDA* is to identify the "non-value added" activities and eliminate them one by one. Examples of *MUDA* are: frequent movement of people to and fro from a place for getting the jobs done, searching

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for tools of work, excess inventory, over production, idle running of machines, lack of free flow of movement of goods, etc. The most common example is re-writing the address of a receiver on envelope in addition to the letter inside. System of using window envelope for such purpose is an outcome of *MUDA* solution. All types of *MUDA* fail to add efficiency to the process, and are sources of direct loss of revenue. Therefore, elimination of *MUDA* is an essential step for Kaizen process. A generalised approach to Kaizen is shown in Figure 6.22.

6	Look for new opportunities & plan for further improvements
5	Set new standards/procedures & new 'standard operating practice'
4	Carry out improvement tasks, implement, review results, tie up ends
3	Form Kaizen team, resort to MUDA/5-S, training of people etc
2	Plan for Kaizen by identifying areas, and means, of improvements
1	Check / analyze current standards & systems, identify weak links

Fig. 6.22 *General Order of Kaizen Activities*

As would be evident, Kaizen approach makes extensive use of different kinds of organization tools, statistical analysis and creativity techniques. Kaizen is not a stand-alone process. It is free to adopt any technique that would lead to improving the situation, such as 'Zero-defect', Just-in-time, Total Productive Maintenance (TPM), 5-S principles, etc. The main tasks of the Kaizen process are: to identify the areas of improvement, form the Kaizen team, set improvement goals or objectives, set up review committee, define do's and dont's, analyse and evaluate results, solve the remaining performance issues, and establish the new standards and procedures for improved results. These steps should be followed by actions in the organization to institutionalise the Kaizen process so that Kaizen becomes a way to work, i.e. to bring about the ultimate change in work culture as an enabler for positive thinking and continuous improvement. One of the objectives of Kaizen is to set the right mind-set of personnel in the organization for creating a good work environment that supports all continuous improvements programmes. In sum, key Kaizen practices manifests into the following characteristics:

- Work procedures become process focussed rather than result focus
- Working objectives become "customer-driven" rather than profit driven
- Problem-solving approach becomes cross-functional and team based with co-operative approach amongst people working in related areas
- Encouragement in the organization for suggestions, quality circle, small group activities, and orientation for quality improvement in all spheres of activities by promoting work environment for creativity and innovations
- Wide practices of improvement tools – like JIT, Kanban, Zero-defect, TPM, etc., and
- A culture of 'quality first' in the organization.

Thus, Kaizen is not a method by itself; it is a cultural change and promotion of work culture where all usual methods of quality improvements, creativity and innovations are to be faithfully practiced. Kaizen is about changing the outlook and practices in an organization from the level of 'acceptable' to 'excellence'. It aims to accomplish excellence in results, and the means are by setting right mindset and creativity amongst people at the workplace. The process broadly encompasses: (1) making worker's operations more productive, safe, less tiring and efficient, (2) improving equipment quality, machine layout and materials flow, etc., (3) promoting creativity and innovation in the workplace, and (3) improving or changing methods, systems and procedures at higher levels.

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4. Zero-Defect Programme

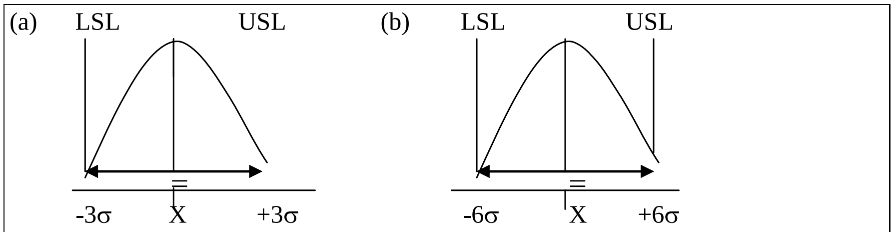
Spirit of Zero-Defect: Prevention of defects by doing it right first time and every time

Crosby first introduced this concept in his absolutes for quality management. The purpose of the system is to eliminate identified defects by prevention of occurrence to a maximum extent, if not completely. The **spirit of Zero-defect** is prevention of defects by doing it right first time and every time. This leads to minimization of defects to bare minimum and tending to zero with drive for continuous improvement. Crosby described Zero-defect programme as the absolute standard of performance, which should be the constant aim for achievement. This does not necessarily mean that defect level must be brought down to absolute zero to start with. What this programme achieves is continual lowering of defect level by following different improvement tools. Japanese industries successfully used this technique as a strong business driver in their global competitiveness.

However, one may fear that with decreasing level of defects, cost may tend to rise geometrically. One way of countering this apprehension is to add value to the products, which can offset any extra cost of controlling the defects. An outstanding example is the Six-Sigma movement of Motorola, which aims to continually decrease the defect level in the process to three to four parts per million and yet gain considerable cost, product and performance superiority over the competitors. The important direction is not what one does but how he does it. The aim of zero-defect programme is to continually bring down the defect levels in a process or a product to near zero value. The programme does not bind the company about the process of lowering defects, but demands commitment and resource planning to achieve this goal by following any suitable improvement process. The system recommends that every company should periodically observe a "zero-defect" day in order to bring about awareness amongst the employees. This is a programme and not a technique, but practicing "zero-defect" programme is essential for successfully pursuing continuous improvement.

5. Six-Sigma Practice

Six-Sigma is a quality metric that counts the number of defects per million opportunities (DPMO) at six levels. The higher the sigma-level, the better is the quality level with lower DPMO. For example, a sigma level of 3.5 means that a process has the chance for producing 22,700 DPMO, but a sigma level of 4.5 means 1350 DPMO at a shift of process mean to ±1.5s. A perfect six-sigma would mean defect level of only 3.4 DPMO even at a shift of process mean to ±1.5s. This is achieved by drastically reducing process output variations by ensuring that the process is made capable such that the specification tolerance is at least equal to 12 times sigma (i.e. ±6s, s being the 'standard deviation' – a measure of quality variation. In contrast, the traditional quality measure hitherto followed defines a process capable if the specification tolerance is at least 6 times sigma (i.e. ±3s). This situation is illustrated in Figure 6.23.



(USL = Upper Specification Limit, and LSL = Lower Specification Limit)

Fig. 6.23 *Six-Sigma Graph*

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Graph (a) represents traditional quality level, where the process is considered capable if (USL – LSL) is > 6s, whereas for six-sigma quality level, it has to be ³12s. This means that standard deviation (a measure of maximum allowable variation) of the process (sigma) has to be improved to 1/12th of the specification spread in case of six-sigma quality process, i.e., process variation has to be drastically improved.

The significance of this improvement by following the six-sigma practice is considerable in today's industries and business processes. For example, with traditional 3-sigma process, having a shift of process mean of ±1.5s, the process is likely to give out 66,807 defects per million opportunity, which is far from world-class quality, whereas in six-sigma process, having a shift of process mean of ±1.5s, the process would give only 3.4 DPMO at sigma level six. It has been experienced that with 3-sigma process, it would be very difficult to conduct business in a globally competitive market, especially in service sectors, because defect generated would be too large and at that high-defect level virtually no modern computer can function with the required reliability.

To understand the significance of six-sigma statistically, let us consider the following:

Conventionally, Process Capability (Cp) = (USL – USL)/6s, where s is the standard deviation of a process. Now, assume that required Cp of a process for a given USL/LSL is 1.5. Then, as per "six-sigma" concept:

$\sigma L = 1.5$, where L = Sigma level between 1 to 6.

Thus, when $L = 3.5$, $\sigma = 1.5/3.5$ ———— (a)

when $L = 6$, $\sigma = 1.5/6$ ———— (b)

This implies that "standard deviation" (s) of the process (b) is much lower than that of process (a). In other words, with increasing sigma level, standard deviation, which is the measure of dispersion (i.e. variations), significantly comes down for a process.

Thus, "six-sigma" concept for controlling variations results in significant improvement in quality, be it process or a product. This original statistical concept has been further driven by Motorola (who first introduced this concept), GE (General Electric), Allied Signal and others as the basis for improvement in all spheres of management and as a long-term business strategy to gain superiority over other competitors. A simple illustration, as given below, will highlight the scope of work under six-sigma practice.

Illustration: Say, a machine has to cut 1-meter long bar at a speed of 10 pieces per minute with the tolerance limit of 1M ± 0.1mm.

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This means that if the machine cuts at times any piece with length more or less than ±0.1 mm, those pieces will be defective, and cause loss of value, machine time and rework cost.

Traditionally, each cut bar can be inspected, defect corrected or taken out of the lot for making supply to customer, but that would be very expensive, time consuming and not fool-proof, i.e. risk of defectives being accepted will remain.

Six-sigma process will take a different approach to this issue. It will examine why the process is cutting differently at times, plot control charts to identify the cause(s), and go for analyzing how the process can be brought within the tolerance level all the time without any deviation. If this statistical approach does not work, six-sigma process will then call for re-designing the product or re-engineering the process in a way such that occasional variations do not cause any error or defect. These will require management involvement and commitment for resources, and may require quality improvement steps of few other associated factors – like the system, people, work environment, etc.

Thus, Six-Sigma technique identifies the faults, track them back to their origin, re-design the product or the service, wherever necessary re-engineer the process and changes the infrastructure, to make the systems and processes more capable, consistent and precise.

Therefore, it is no wonder that "six-sigma" is now being used as "management initiative" rather than "quality initiative" to bring superiority in business performance, especially with respect to cost and quality.

Six-Sigma practice was pioneered by Motorola Inc. of USA. A brief outline of their six-sigma practice will perhaps demonstrate what should be the primary approach to this technique. Motorola started the six-sigma movement with an aim of achieving "near zero-defect" level in their manufacturing competence. They defined 'near zero-defect' as 99.999% defect-free manufacturing capability. This defect level was then translated into DPMO at six different sigma levels. At "six-sigma" level, DPMO value is the lowest, i.e. 3.4 only at a process mean shift of ±1.5s, which is an astonishingly low defect level in the process compared to what was prevalent in manufacturing industries (see Table 6.1). However, it should be appreciated that higher sigma level cannot be achieved in one single go; companies have to take up improvements step by step.

Motorola had approached this six-sigma movement in phased manner. In their second phase of six-sigma movement, their objective was not only to move closer to "zero-defect", but also improve all levels of customer satisfaction by 'Total Customer Satisfaction' (TCS) movement. This necessitated identifying areas that are most important to customers, and then set out for improvement by six-sigma approach in these areas first. They called this approach as "critical to quality opportunities" (CTQ), where defects must be avoided if customers are to be made happy. Hence, their starting point for six-sigma campaign became these CTQ areas. Motorola had devised "six steps to six-sigma" practice, which was more to deal with the quality aspects of non-manufacturing activities and areas of subjective decisions, e.g. planning, budgeting, human resource management, maintenance, etc. Because it was realised early that improving process capability to six-sigma level entails not only addressing the direct quality capability issues, but also areas of management that are integral to work culture and attitude for perfection in process execution. Purposes of these steps are:

- **Steps I and II** involve determining the products to be made, customer segment to be served, what is to be served and how to do that.
- **Step III** involves in making the organization look at the needs for suppliers' support to meet the target quality, and focus on developing suppliers' quality capability.
- **Step IV**: This is the step where all processes being carried out by the company should be mapped out, and needs and means for process improvement should be determined for fulfilling the mission.
- **Step V:** This step involves critical evaluation of the process to be upgraded, and elimination of all non-value added steps, activities and sources of errors.
- **Step VI**: This is the step for establishing measurement criteria, analysis of data, and driving the process with a spirit of continuous improvement.

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An improvement drive in six-sigma practice calls for usage of all tools of total quality improvement – including re-engineering – with focus on the means for reducing the process variability to bare minimum and establishing consistency in the new process. Six-sigma technique identifies sources of faults, tracks them back to the origin, eliminate them, takes steps to make the process or system more capable by reducing the dispersion and variation, and then provides measures for maintaining consistency. A CTQ process with a capability level established at a given time by six-sigma technique may not be quite suitable for customers of different period; hence processes need continuous evaluation, re-working and improvement. The improvement may be brought about in stages from a lower sigma level to a higher sigma level, but it must be pursued for getting the full benefits of "six-sigma" movement. Though the term "sigma" is a statistical term to denote statistical capability of a process, "six-sigma" is just not a statistical tool; it is a tool encumbering both manufacturing and non-manufacturing areas for ensuring superior quality, minimising cost of poor quality, and gaining customer satisfaction and loyalty in a competitive market. A major part of the benefits of six-sigma movement come from reduction in the cost of quality (also referred as cost of poor quality). The impact on the 'cost of quality' vis-à-vis six-sigma level of performance can be seen from Table 6.1.

Table 6.1 *Cost of Quality Variation with Six-Sigma level*

Sigma Level	Defect per Million Opportunities	Cost of Poor Quality
1	-	Not Available
2	308,537 DPMO	Not Available
3	66,807 DPMO	25 to 40% of Sales
4	*6,210 DPMO	15 to 25% of Sales
5	233 DPMO	5 to 15% of sales
6	3.4 DPMO	Less than 1% of Sales

* Level 4 with 6,210 DPMO is reported to be the industry average

Six-sigma methodology employs the following road map: Define – Measure – Analyze – Design – Verify (DMADV) cycle or Define – Measure – Analyze – Improve – Control (DMAIC) cycle. Both the cycles involve intensive data analysis using a

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range of statistical tools, which are also employed in total quality initiatives. However, DMADV cycle is used (a) when a product or process is to be developed in the company anew, and (b) the existing product or process has been optimised but still does not meet the level of target for customer satisfaction or sigma level. DMAIC cycle is used when a product or process is in existence but it is not adequately meeting customer satisfaction or the set performance standard.

In the above cycle, Define – refers to setting project goals and customer deliverables, where customer means both internal and external customers. Measure – refers to customer needs and specification setting, and process measurement to determine current performance. Analyze – refers to process options to meet customer needs, root cause of the problem and identification of solution. Design – refers to designing of process for customer satisfaction. Verify – refers to analysis of results to determine if the performance is meeting customer needs and specification. Improve – refers to process improvement by eliminating defects and errors. Control – refers to identifying measures to control the process for future performance at the improved level.

Thus, Six-sigma practice is based on the premise of how to better the design of products and processes so that defects and errors never arise in the first place. One of the steps for success stories of General Electrics of USA was the adoption of "six-sigma" by Jack Welch, the legendary Chairman of the company, as a strategy for changing the organization's focus. It has been proved to be an invaluable tool for reducing direct cost and adding to the bottom line of the company. Application of six-sigma technique has been very advantageously used in many new products development or improvement. Notable example is the development of Light Speed CT Scanner by GE Corporation of USA, which was designed by drawing customer into the process, using all of the CTQ (critical to quality) performance features that customers (hospitals in this case) wanted in that product, and then subjecting those CTQ features to the rigors of what GE called "Designed for Six-Sigma" (DFSS) process. This approach enabled GE to develop a new light speed CT Scanner where scanning time came down from earlier 3 minutes to only 17 seconds for a chest scanning. As a result, hospitals gained much higher utilization of machine time, could handle more number of patients, and cost of scanning came down for the patients.

6. Just-in-Time Manufacturing (JIT)

Just-in-Time (JIT*)* is defined as "a philosophy of manufacturing based on planned elimination of all waste and on continuous improvement of productivity". It is a system of manufacturing with the objective of producing the right part in the right place at the right time, i.e. in other words, "just in time". Shigeo Shingo – the well-known industry philosopher and visionary of Toyota Motors Japan, is known for this creative approach of manufacturing. JIT is not only a cost-effective manufacturing process, its operational philosophy helps to continually build quality into the process and products, otherwise the whole system falls through.

Just-in-Time manufacturing (JIT**)** is a special tool developed in Toyota Motor Co., Japan, in 1950, in an attempt to improve the quality and performance of various workstations during the production and delivery of goods. The initial idea of this system was to avoid building up queues of inventory at a workstation in order to eliminate the need for storing work-in-progress inventories without allowing any workstation to run out of stock of working materials at any stage. But, the potential benefits of the process from saving cost by waste reduction and bring an overall excellence in the production system was soon realised by the industries in Japan. This led to the widespread adoption of this technique in manufacturing sectors in Japan and USA. Because of its multi-faceted benefits, the system soon became a buzz in the manufacturing sectors, and is considered as the most powerful tool for managing productivity (a term that includes quality) and cost in today's manufacturing business.

JIT applies primarily to **repetitive manufacturing** processes in which the same products and components are produced over and over again. The general idea is to establish the flow of processes (even when the facility uses a jobbing or batch process layout) by linking the workstations so that there is an even, balanced flow of materials throughout the entire production chain. The aim of the system is to accomplish the goal of driving all inventory buffers toward zero, and cut down any generation of waste. For this reason, JIT is sometimes called lean production or stockless production system.

Philosophically, this system changes the material flow from "Push" process to "Pull" process. "Push" process allows a workstation to produce what it can and then push it to next station. Next station may then require storing the items as inventory and plan to produce by matching parts. This will frequently lead to process-yield imbalance, in addition to holding inventory and the cost of it. JIT technique changes this from "Push" to "Pull" system, where parts are pulled or called up when required for continuing production by the next-in-line workstation. The station orders the parts from the previous operations as per their exact requirement in a manner so as to arrive just when the parts are needed. This system compels the stations to work responsibly so that productions are as per the call, and defectives are not produced to hold back a line. Therefore, production line has to be continuously fine-tuned to avoid or minimise defectives, which is a major objective of TQM. It would now be obvious that to support a system like the JIT manufacturing, systems like TPM as a part of manufacturing system is unavoidable, because that type of system implementation can only guarantee the sustained availability of machine time for each workstation.

It is amazing to know how simple the concept is, but it requires a meticulous planning of machine capacity, process capability for quality consistency and precise dimensions, materials planning, input quality planning, and materials balancing for each station. Hence, networking of JIT-systems with suppliers and each workstation is essential for quality. Such a partnering and networking of systems allows the vendors and suppliers to be linked to JIT manufacturing of the parent company, and facilitates maintaining near-zero inventory. By following the JIT manufacturing system, Japanese industries have been able to virtually eliminate the in-process inventory of materials and components due to timely manufacturing of exact quality and quantity.

The key factors for successful implementation of JIT-manufacturing are the planning of production flow, balancing the load of each workstation, installing required level of process capability, and training of the people about the critical measures of the process. Therefore, the steps for JIT implementation are:

1. Stabilise daily production schedule by creating uniform and steady load at each workstation. Work out model and method of dealing with any fluctuation of schedule due to unforeseen reason by considering end-item inventory rather than by allowing fluctuation in the line.

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Repetitive Manufacturing: Processes in which the same products and components are produced over and over again

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2. Eliminate or reduce setup time for a product by redesigning product features and dimensions, process equipment features, and quality planning. For example, use of CNC machining may require pre-machining of jobs (better still close-dimensional jobs) to reduce setup time. This may necessitate vendor partnering and capability.
3. Reduce lot size and delivery time to cope with next-in-line workstation demands. This would require supplier co-operation and information networking for efficient management of supplies.
4. Take measures for reducing wastes, i.e. any action or step that does not add any value to the processed job. Examples of waste are: unnecessary movement of materials to and for the line, use of redundant methods, unnecessary movement of personnel, time delay due to off-on support services, need for rework and rectification, etc.
5. Create continuous flow of materials from one station to other by reducing lead time, applying the concept of cellular manufacturing, reducing queue length, improving process capability, and bringing the concept of 'internal customer' for team building and cooperation amongst operators.
6. Install TPM (Total Productive Maintenance) system for improved availability of machine working hours.
7. Promote multi-skilling amongst work force (this can be apart of TPM exercise). In general, JIT requires teams of competent, empowered employees who have more responsibility for their own work.
8. Pay attention to "suppliers' quality capability" for getting correct jobs at source with an aim for "zero-defect" supply.
9. Train people in the process measures and methods of control, establish communication network amongst people.
10. Ensure movement of materials only through "pull" system by adopting card system of Kanban technique for controlled operations in the manufacturing line.

Kanban is another Japanese system for JIT manufacturing – is a slight modification of conventional JIT practice. In Kanban system, a card or a marker is used to control the movement of in-process materials through the sequential process stages of manufacturing. It relies on an information system to communicate the material needs by a customer unit to its supplier unit by the card system. Two cards are used in the system; p card, meant for production signal, is used to authorise a workstation to produce one specified lot of a part, and m card, meant for movement signal, authorises the movement of the lot from the workstation to the customer unit. Originally, Kanban method of production control system was used by Toyota Motors. Like JIT, this technique can also be used for control of movement of materials between customers and vendors.

Though these two processes are frequently equated together and the purpose of both JIT and Kanban may appear the same, they are not the same technique. JIT manufacturing system can be implemented on its own, but Kanban implementation requires JIT manufacturing for complete success in holding to the goals of inventory management. As has been discussed earlier, JIT brings along many other attendant benefits with its implementation. Implementation of JIT manufacturing can lead to many advantages, and some important ones are:

- Lean manufacturing system
- Virtual elimination of inventory, unlocking the expensive capital for other productive work
- Reduction of waste and non-value added process steps
- Saving of warehousing cost
- Improved quality and delivery compliance, and
- Improved process capability/reduced process variability, which leads to decrease in cost of poor quality.

Practicing JIT/Kanban system for inventory control has become easier with the scope for computer networking of vendor station to manufacturer's workplace or from workstation to workstation. When the daily/weekly demand is high, many vendors are also willingly setting up warehousing facility near the manufacturer's unit in order to be a "preferred supplier" and develop long-term business relationship. In fact, in today's competitive business environment, more and more supply-chain management and associated function of inventory control is being shifted to the "sellers", i.e. suppliers. Organizations are tying the suppliers with long-term commitment for specific delivery schedule and exact quality. Suppliers and vendors have become a part of the supply-chain management in order to serve the customers by delivery of value-added products of right quality at right time.

7. Poka-Yoke (Mistake-proofing)

This is another brilliant idea of Shigeo Shingo. This is a simple mistake-proofing process in manufacturing or in the service. Poka-Yoke makes use of automatic devices or simple methods that help to avoid common human errors. Poka-yoke focusses on two aspects:

(i) Prediction or recognition that a defect is about to occur, and then providing signals or warning.

(ii) Detection or recognition that a defect has occurred and then stopping the process so that no further defect can be produced.

Poka-yoke techniques are often very simple, like flashing of light signal when the automatic or manual sensor detects the signal of malfunctioning or generation of defects. However, successful approach to this mistake-proofing needs creative thinking. At times, Poka-Yoke comes out with suprisingly simple method of ensuring that mistakes are not made or an error gets into the system. Therefore, Poka-Yoke solutions can range from simple colour coding of cables to prevent any mistake during jointing to very complex mistake proofing system of passenger aircraft controls. Poka-Yoke technique can also be applied in the designing of products where safety hazard of the product is very high, e.g. passenger lifts, conveyor belt, certain chemical plant equipments, etc. Examples of common Poka-Yoke products are: Car Alarms, Fire Alarms in tall buildings, automatic overload switch off, limit switches, machine vibration alarm systems, etc.

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8. Benchmarking

No quality improvement discussion can be complete without discussing 'Benchmarking'. Robert C. Camp first coined the term Benchmarking in 1980, while engaged in studying the improvement programme at Xerox Corporation in USA. According to Camp, meaning of benchmarking is finding and implementing best practices in the business. This does not imply that benchmarking is copying the best practice of an industry; it is about understanding "what, why and how" of a superior process or a method, and then adopting it in one's organization for improving performance to a higher level. The essence of benchmarking is the endeavour to analyse and understand the process, products or services of a world-class company in order to learn how they achieved that superior results, and then set up one's own internal measures and steps to meet or surpass them. Juran described this as practice for managerial breakthrough. The need for benchmarking is to enable the organization to set-in world-class practices in the management, resulting in much improved business results, customer confidence and competitive advantage.

The process of benchmarking makes an organization look outside to identify a business leader in the field for knowing and understanding the way to their success. The key to the success of benchmarking process is in understanding of *what, why, how* and *when* of the success story. It is a method of identifying new ideas and new ways of looking at things for improvements. For example, "customer complaint resolution time" of Rank Xerox Corporation was once benchmarked across the industry for better services to customers by gathering ideas from their approach to customer problems, data acquisition system, analysis of the problem, and empowerment of employees to take decisions.

Good benchmarking exercises produce two types of information: (1) quantitative data that can be used to measure current performance and set future targets (this is prevalent in most financial exercises and setting targets for return on investments), and (2) qualitative information on the approach to design of products and services, and adoption of 'key success factors' that explains how the benchmarked company became the leader in that function or business (this is prevalent in manufacturing and electronic industries for launching new products and service features).

(i) Plan: What to be benchmarked, identify critical success factors, form teams, document processes, set performance measures.

(ii) Search: Identify partners and establish partnership.

(iii) Observe: Understand and document the partner's process, procedures and practice.

(iv) Analyse: Gaps in performance and find out root causes.

(v) Adopt: Choose "best practice", adopt to Co.'s own condition.

The key factors for successful benchmarking are: believing that it is a better way of doing things, there is a need for change and improvement from the present level, determining what should be improved and changed to make impact on company's performances, acceptance of the fact that another company's solution can be better, and developing a vision of what it should be after the change. To translate these into actions would broadly involve:

- Gap analysis between own and other superior practices.
- Understanding the prevalent "best-practices" in industries to identify what must be changed or improved.
- Identifying the most appropriate "benchmarking partner" and study their best practices methodology.
- Implementing benchmarked practices at one's own unit to achieve set goals.
- Reviewing of results and outcomes to determine "where you are" after the change, and what needs to be done further.

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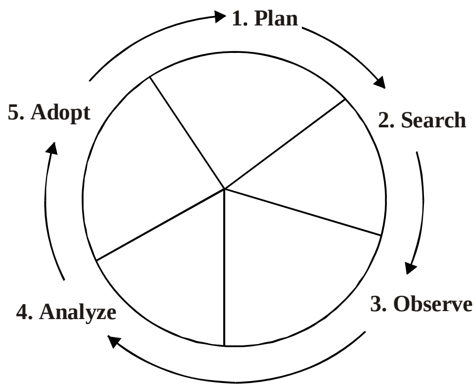

Fig. 6.24 *A Sequential Benchmarking Process Cycle with Tasks for Each Stage*

Benchmarking process steps can be grouped under the cycle: Plan → Search → Observe → Analyze → and Adopt. These steps are illustrated in Figure 6.24.

In a step-by-step practice, this mean following a systematic sequence of steps in following order:

1. Identify the function to be benchmarked and form teams.
2. Identify "best-in-class" company in that function.
3. Identify the key performance variables to measure and collect data.
4. Establish benchmarking partnership with the chosen company and function
5. Ensure that types of data being collected are amenable to accurate comparison with the benchmark partner's data.
6. Analyse and compare the data for understanding the measures taken by the partner. In addition to the collection of quantitative data, identify the management approach that differ between the companies, and identify the critical factor that led to the success of the partner.
7. Prepare enablers from the study of partner's technique and management actions.
8. Set new goals or levels of performance in the chosen function (benchmarked level).
9. Establish functional goals for the benchmarking team, and allow analysis of how the goals can be accomplished in the situations of the company.

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10. Allow team to make presentation and recommendations about how the company must act and improve to reach to the new goals. Make management review in terms of resource and facility requirements, and finalise target and actions.
11. Communicate and share the findings and goals with the people of the organization to build understanding, commitment and motivation to work for the goals.
12. Develop action plan for implementation, covering all related areas.
13. Implement actions and monitor progress, share the improvement outcomes with the partner and people of the organization.
14. Review and recalibrate the benchmarked goals and levels.
15. Periodically re-evaluate the benchmarks to ensure that they are valid for current data and business situation, and aimed at best targets.
16. Benchmarks should be re-evaluated at periodical intervals to ensure that they are valid for current data set, business situation and aimed at best targets.

One of difficult steps for benchmarking is the choice of benchmarking partner and getting their approval for sharing data and information. This is particularly so when partnering is sought with a company within the same business and in competition with each other. However, many enlightened organizations have come to the understanding that exchange of information and data with a serious and well-organized company may be of mutual interest by learning from each other's experiences. Therefore, the success in this regard depends on the approach and attitude of the partnering companies. Benchmarking partner can also be sought from outside the industry having superior process in some generic areas, e.g. customer support systems, market research and analysis, supply-chain management, etc. Generally, partners can be chosen from four common sources of superior practice. They are: (1) Direct Competitors, (2) Functional Leaders, (3) Internal Operations, where superior practice of one unit can serve as guide to the other, and (4) Generic Processes—where similar functions of one company can be used for benchmarking study of the other, irrespective of the nature of business, e.g. customer complaint resolution process of a Health Care Co., with the one in hospitality management.

Obviously, benchmarking exercises often become somewhat long-drawn due to difficulties in getting partner approval and also in exchanging and understanding data and information, which may involve visits and exchanges of communications. The focus of benchmarking study of a partner is mainly on how to adopt actions and measures for improving processes and practice for superior performance in the parent company.

Benchmarking is a strategic tool for quantum improvement in business results, which is the pressing need of a business under competitiveness. The improvement can only occur if companies understand the need to change, are willing to change, and have vision about what could be the outcome after the change. Benchmarking sets a self-developed target that should be achieved by creative and analytical approach to the solutions.

Major benefits of benchmarking are:

- Adoption of new practices that help overcoming previous perception and barriers about possibilities and improvements; thus, bring about a change of outlook, work culture, and approach for superior results.
- Acquaintance with diverse and innovative approaches and process design to achieve "breakthrough" improvement of performance.
- Acceleration of the rate of growth and performance in the company.
- Creation of a work environment that promotes employee involvement and creativity.
- A system of working through facts and figures, and empowered team, and
- Achievement of competitive advantages due to superior performances.

Significant benefit of benchmarking is in creating an attitudinal change for managing the business through diverse thinking and creative approach. When benchmarking practice is used correctly, it can considerably influence the operating practices of a company. Care is necessary to correctly understand the process and objectives of benchmarking. Benchmarking is not a quick fix for performance gap in a competitive environment. Benchmarking cannot work unless there is an environment of openness in the organization, creativity, commitment and involvement of people, and the recognition that there is always a scope to learn and improve. Therefore, it is no wonder that benchmarking requires a preconditioning of the organization by a strategy like TQM to make the organization process focussed, people driven and committed to continuous improvement for performance excellence. Benchmarking is not copying or imitating, it is about understanding the 'best-of-industry' practices. If the organization is not prepared with cultural reorientation of total quality, an attempt at benchmarking may not be successful, and may even lead to confusion and disruption in the existing practices. To reap the full benefits of benchmarking, organizations have to go through certain reorientation and cultural changes that are characteristics of a total quality organization. Else, it may lead to following pitfalls:

1. Failure to relate the benchmarked process improvement to the company's vision and strategic positioning.
2. Failure to get people involved and committed to benchmarking as a process.
3. Failure to perceive benchmarking as an ongoing process for improvement, and not a one time effort.
4. Failure to visualise what the company should be after the implementation of benchmarking.
5. Likelihood of management resistance to change, and
6. Failure to garner creativity and innovation in the organization, without which benchmarking efforts are seldom successful.

For making the benchmarking an effective tool for superior performance, organizations must create a work environment where teamwork and all out management support for continuous improvement drives the processes.

Benchmarking exercise should be objective specific with measurable outputs – like manpower productivity, capital productivity, quality consistency, preciseness of a process, timeliness of services, cycle time for supply-chain management, return on

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investment etc. With reference to a manufacturing industry, this would mean benchmarking in the following areas:

1. **Products and Services** – like product features, service features, customer service system, complaint resolution time, etc.
2. **Work Processes** – like process of design, product development cycle, supply-chain cycle, etc.
3. **Cost, Quality and Productivity** related issues.
4. **Planning and Strategy related areas** – like planning process, determination of short-term and long-term strategy, etc., and
5. **Support Functions** – like financial practices, HRM practices.

The list of probable areas for benchmarking would largely depend on an organization's specific needs and the demands of competition. Every activity of an organization that produces a result or has a measurable outcome can be benchmarked for improvement. Benchmarking activities in a company generally starts with products and services, and then with time and cultural changes, it graduates to process benchmarking—including management processes. Perhaps, process benchmarking with world-class leaders in the industry has the greatest impact on an organization's efficiency and performance. As per impact of the benchmarking exercise in an organization, many tend to hierarchally group benchmarking under the following heads:

- **Performance Benchmarking** for key output measures, and key performance measures and indicators. They are irrespective of areas of operations; sole consideration is how that impacts the organization's performance.
- **Process Benchmarking** for process improvements, cycle time improvement, efficiency, process quality outcome, inventory level, etc.
- **Best Practice Benchmarking** for mastering 'best-practice' from the industry leaders by understanding, sharing and adoption at one's own company in order to achieve a new heights of performance in the organization.
- **'Best Practice' modeling** for modeling of best practices for organizational restructuring in order to improve organizational capability for superior performance and meeting the challenges of competition in all spheres of business.

Figure 6.25 shows the benchmarking process maturity of a company in terms of gaining organizational excellence.

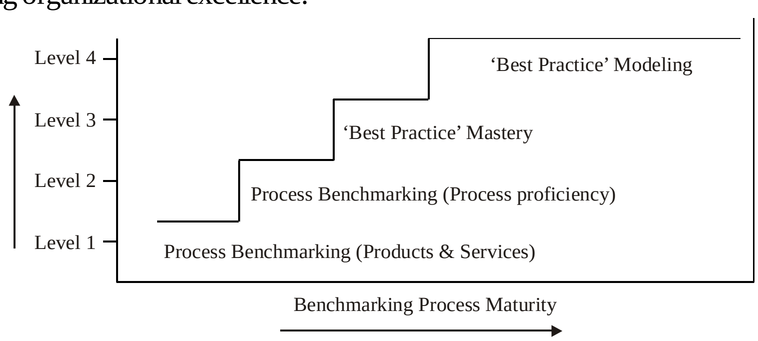

Fig. 6.25 *The Steps in Benchmarking Process for Gaining Organizational Excellence in Performance*

Majority of companies initially starts benchmarking exercise by focussing on product and services, then goes on to focus on process benchmarking either through an external or internal process partner, but potential reward of benchmarking process lies in graduating to adopt higher-level benchmarking process, such as mastering and modeling of "best practices" by partnering with a world-class industry.

Partnering with the world-class "best-practice" companies is critical for the success of higher-level benchmarking practice in order to have organization wide effect. It involves not only the adoption of best practices, but also modeling the organizational culture and processes in line with the best in class. This change in culture, thinking and orientation of work planning in terms of achieving the best possible level of performance in all aspects of the business is the ultimate goal of benchmarking process. It helps to reach a new height of performance level leading to organizational excellence. However, benchmarking should not be confused with "competition analysis"—a technique often used in industries to know the strength and weakness of competing companies. The purpose of competition analysis is to take pre-emptive steps for safeguarding the business or work out a strategy of doing better in a competitive business. The purpose and methods of benchmarking are different; benchmarking study is focussed to an identified area of operation with an aim to improving the process and its management to world-class level, and very often by partnering the process with a leader in the filed (i.e. a competitor). Benchmarking is a focussed study in strategic areas for radical change in the way a company should work to become globally competitive.

6.6 SUMMARY

- The demands of customers and competitive business environment make it necessary for modern quality management systems to address not only the quality characteristics, but also the cost, delivery, maintainability, reliability and attractiveness of features of products and services.
- As a consequence of this change in the marketplace, modern quality management concept had to undergo considerable changes from the era of inspection and quality control and embrace the concept of total quality.
- The Japanese first showed the power of quality as the business driver in the midst of global competition by adopting a total quality culture in manufacturing and services.
- Inputs like a statistical approach, process control, focus on quality rather than quantity, training and skill improvement of people, commitment of management, etc., became the guiding vision of this new quality system.
- Quality goals should meet the needs of customers at a minimum combined cost. The product should be designed by capturing the voice of customers by employing techniques like QFD and FEMA as discussed in the text and these quality goals should be achieved by maximizing the uses of existing operating conditions.
- This calls for strategic planning for quality designing, production and conformance in the organization, involving quality in all related activities and processes in the organization.

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Check Your Progress

6. Fill in the blanks with appropriate words.
   (a) _________ variables are the ones we have control over.
   (b) The technique called Quality Loss Function analysis was developed by ________.
   (c) Value engineering is a ________ centric process.
   (d) _____ _____ is known as the father of Kaizen.
7. State whether the following statements are true or false.
   (a) Six-Sigma is a quality metric that counts the number of defects per million opportunities (DPMO) at six levels.
   (b) Kaizen is a method by itself.
   (c) Good benchmarking exercises produce two types of information: quantitative and qualitative.
   (d) A pie diagram shows the frequency or number of observations of a particular value and in effect, shows the frequency distribution of a specific data set.

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- Quality cannot be a stand-alone system in an organization; it must be an integral part of the total business operations involving quality in all business processes and activities, which is the tenet of total quality management. Addressing these quality related dimensions of a business through a total quality programme has changed the way of doing business.
- The traditional method of managing business processes by functional structuring has changed to cross-functional processes that run horizontally across all related functions.
- The purpose of such quality orientated process structuring is to serve the customers better and build efficiency for faster response and flexibility in the organization.
- The concept of total quality control was first developed by Feigenbaum in 1961, based on various recommendations of Quality Masters – like Deming, Juran and Crosby.
- Keeping in view the new dimension of quality prescribed by the Quality Masters, Feigenbaum emphasized the need for a holistic view of quality management system involving all functions and functionaries of the organization. This new and more comprehensive approach of quality management came to be known as Total Quality Control (TQC) and this acted as the pioneer of the present-day Total Quality Management (TQM) system.
- The tools and techniques used in quality management have been grouped into two categories, which are also known as management tools:
    - o Statistical tools
    - o Quality planning and improvement tools
- In this unit, the important tools in these categories have been discussed and their importance in quality management has been highlighted.
- Central to all information is data. So, data must be presented in the form in which it is capable of giving appropriate information and create knowledge.
- Data should be reliable, representative and should be presented in the right form. This requires statistical thinking and approach to the collection, compilation, presentation and analysis of data for process and quality management.
- The central task of quality management is to identify the causes of variability from the target quality and controlling the same by corrective and preventive actions. This involves using statistical tools that permit root cause analysis, establishing correlation between controlling factors and systematically applying the knowledge and information for control, correction or prevention. For improvement, on the other hand, one should know where to act and how to act.
- There are statistical tools – like the histogram, Pareto diagram, Cause-and-effect diagram, etc. These permit analysis of statistical data (i.e., data collected and compiled by following the statistical rules of sampling, grouping, and validation) to arrive at the points of action, i.e., where to act.
- Determining how to act requires knowledge of the process and people who are running the process and specialized tools and techniques for quality planning and continuous improvements that include statistical tools like Statistical Process

Control (SPC) and improvement tools like P-D-C-A, Kaizen, Taguchi's Quality Loss Functions, Six-Sigma practice, Benchmarking, etc. Keeping these aspects of quality management in view, various tools and techniques in quality management have been described.

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6.7 ANSWERS TO CHECK YOUR PROGRESS

1. Quality of a product or service means the features or characteristics, or some attributes of a product or service or similar offerings.
2. The mission statement defines the purpose of the company and the role it wants to play in broader social, economical, national or environmental perspectives.
3. AQL is a percent defective that is the base line (minimum) requirement for the quality of the producer's product. The producer may accordingly design a sampling plan such that there is a high probability of acceptance of a lot, but with defect level less than or equal to the AQL fixed by the purchaser.
4. Check sheet is basically a data collection tool, so is sampling and survey–the other two tools that are used for data collection.
5. A Pareto diagram is a special type of vertical bar diagram that displays the relative frequency of various categories of problems or events.
6. (a) Design

   (b) Taguchi

   (c) centric

   (d) Masaaki Imai
7. (a) True

   (b) False

   (c) True

   (d) False

6.8 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is the difference between vision and mission of an organization?
2. Which are the important areas of application of continuous improvement?
3. What are the functions of check sheets?
4. What are some major areas of application of quality planning and improvement tools?
5. What do you understand by brainstorming?
6. List the five primary elements of Kaizen.
7. What are the six steps to six-sigma practice?
8. Which are the two aspects which Poka-yoke focuses on?

9. What are the major benefits of benchmarking?
10. With reference to the manufacturing industry, which areas are focused upon by benchmarking?

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Long-Answer Questions

1. Write a detailed note on quality concepts held significant by organizations.
2. Explain the significance of quality in business.
3. Discuss the process of implementation of total quality control.
4. Give a detailed account of the seven tools of statistics.
5. Evaluate Taguchi's Quality Loss Function and explain its implications.
6. Write a note explaining value engineering.
7. List and discuss the seven tools of management.
8. Explain the salient features of continuous improvement tools.
9. Paraphrase the systematic sequence of steps of benchmarking.

MODEL QUESTION PAPER

MBA Degree Examination

Third Semester

Time: 3 Hours **Maximum: 100 Marks**

PART A (5 × 8 = 40 marks)

Answer any FIVE of the following:

1. Define the functions of production management
2. Explain the importance of capacity planning
3. Define Work measurement.
4. Explain the concept of materials requirement planning.
5. List the advantages if 'Just in Time'.
6. List the five primary elements of Kaizen.
7. Explain how value - addition can be done in a transformation process.
8. Write a short note on the importance of selecting appropriate production process.

PART B (4 × 15 = 60 marks)

Answer any FOUR of the following:

9. Planning for manufacturing proceeds through product development. In this context explain process design and selection.
10. Discuss the various types of production systems.
11. Explain the relevance of 'flexibility in process selection' in details.
12. Describe the long and short term methods of capacity planning.
13. Discuss the different types of forecasting methods used in business.
14. Describe the modules of MRPII process.
15. Explain the concept of Six Sigma and discuss its relevance to businesses.