PRODUCTION AND OPERATIONS MANAGEMENT
M.B.A
First Year, Semester-II, Paper-IV

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FOREWORD

Since its establishment in 1976, Acharya Nagarjuna University has been forging ahead in the path of progress and dynamism, offering a variety of courses and research contributions. I am extremely happy that by gaining 'A+' grade from the NAAC in the year 2024, Acharya Nagarjuna University is offering educational opportunities at the UG, PG levels apart from research degrees to students from over 221 affiliated colleges spread over the two districts of Guntur and Prakasam.

The University has also started the Centre for Distance Education in 2003-04 with the aim of taking higher education to the door step of all the sectors of the society. The centre will be a great help to those who cannot join in colleges, those who cannot afford the exorbitant fees as regular students, and even to housewives desirous of pursuing higher studies. Acharya Nagarjuna University has started offering B.Sc., B.A., B.B.A., and B.Com courses at the Degree level and M.A., M.Com., M.Sc., M.B.A., and L.L.M., courses at the PG level from the academic year 2003-2004 onwards.

To facilitate easier understanding by students studying through the distance mode, these self-instruction materials have been prepared by eminent and experienced teachers. The lessons have been drafted with great care and expertise in the stipulated time by these teachers. Constructive ideas and scholarly suggestions are welcome from students and teachers involved respectively. Such ideas will be incorporated for the greater efficacy of this distance mode of education. For clarification of doubts and feedback, weekly classes and contact classes will be arranged at the UG and PG levels respectively.

It is my aim that students getting higher education through the Centre for Distance Education should improve their qualification, have better employment opportunities and in turn be part of country's progress. It is my fond desire that in the years to come, the Centre for Distance Education will go from strength to strength in the form of new courses and by catering to larger number of people. My congratulations to all the Directors, Academic Coordinators, Editors and Lesson-writers of the Centre who have helped in these endeavors.

Prof. K. Gangadhara Rao
M.Tech., Ph.D.,
Vice-Chancellor I/c
Acharya Nagarjuna University.

204EM24: PRODUCTION AND OPERATIONS MANAGEMENT

COURSE LEARNING OUTCOMES (CLOs):

On successful completion of the course the learner will be able to:

1. Provide students with a foundational understanding of Operations Management
2. Educate students about the obligations and duties of various organisational environments for operations managers
3. To increase students self-assurance in handling production and operational tasks in the industrial and service sectors
4. To define an operations system's boundaries, and know how it connects to other functional sections of the company and its surrounding surroundings.

Unit-I: Introduction to Operations Management: Nature, Importance, Scope and Functions of Operations and Operations Management - Evolution of Operations Management - Types of Production/Operations Systems. Design of production processes Allocating resources to strategic alternatives. (Numerical types of LPP)

Unit-II: Capacity, Location and Layout planning: Capacity planning – Framework and Types; Location Planning – Location Decision Factors and Planning methods (Numerical); Layout planning – Planning and Principles of Layout, Classification of Plant Layout; Production Planning and Control – Functions - Stages in PPC – Gantt – PPC in Mass, Batch, and Job Order Manufacturing, Sequencing and Scheduling (Numerical); Manufacturing Resource Planning-ERP

Unit- 3: Supply Chain, Purchase and Stores Management: Supply Chain Management – Framework, principles, electronic supply chain management. Materials Requirement Planning – Planning Elements and Inputs (Numerical); Purchase Management – Principles, Process and Types of Purchasing Systems; Stores Management – Functions, Location, Layout and Accounting Procedures

Unit- 4: Inventory Management and Work study: Inventory Management – Meaning, Types, Costs and Models – Purchasing Model without and with Shortages, Manufacturing Model without and with Shortages (Numerical), Selective Inventory Controlling Techniques (Numerical); Work study – Method study – Steps and Recording Techniques. Work Measurement (Time study) – Steps, Techniques and Estimation of Standard time (Numerical)

Unit -5: Quality, Maintenance and Project Management: Quality Management – Concepts-TQM, Six sigma, ISO-9000 Standards, quality circles, cost of quality, acceptance sampling, Statistical Quality Control charts – $\bar{X}$ and Range , c chart and p chart (Numerical); Maintenance Management – Functions, Objectives, Types of plant maintenance, Cost balance, Types of failures, machine replacement problems, Project Management – Meaning, Phases / Framework, Roles and Responsibilities of Project manager-PERT-CPM.

Reference Books:

1. Sidhartha S. Padhi. Operations Management – Text and Cases. Star Business Series. 2018
2. R. Panneerselvam, Production & operations management, Prentice Hall India private limited, 2017.
3. Mahadevan B., Operations Management Theory and Practice, Pearson Publication, 3rd Edition, 2015 29 MBA syllabus 2020
4. Aswathappa, K.,ShridharaBhat, K., Production and Operations Management , Himalaya Publishing House, 2014
5. Chunnawals, Production & Operation Management Himalaya, Mumbai
6. Upendra Kachru: Operation Management, Excel Publications.
7. Chary , S.N.Production and Operation Management, New Delhi, Tata McGraw Hill
8. Kanishka Bedi, Production & Operation Management, University Press.

M.B.A. DEGREE EXAMINATIONS, MARCH-2023
Second Semester
Business Administration
PAPER 2.4 (R22) – Production and Operations Management

Time: Three Hours **Maximum marks: 70**

Section –A **5X3=15 M**
Answer Any FIVE of the following

1. a) Define Production Management
   b) Allocation of resources
   c) Classification of plant layout
   d) MRP
   e) Job order
   f) Types of inventory management.
   g) Six sigma
   h) SQC Charts
   i) Time study
   j) Write about economic order quantity.

Section –B **5X8=40 M**
Answer the following questions

2. a) Discuss the recent developments in operations management.
   (OR)
   b) Explain productivity. List the factors that affect the productivity. And how it can be improve?
3. a) What are various factors influencing the location decision? Explain.
   (OR)
   b) What is scheduling? Explain the different scheduling activities with an example.
4. a) Mention some of the advantages and disadvantages of material requirement planning system.
   (OR)
   b) Explain the electronic supply chain management system. State the issues in e-SCM.
5. a) Explain method study. What factors should be kept in mind while method study is carried out.
   (OR).
   b) How inventory control techniques works in real world? List out its importance.
6. a) Explain the features of theory of control charts?
   (OR)
   b) Discuss about TQM management techniques.

Section –C **1X15=15 M**
(Compulsory)

Case Study:

A biscuit manufacturing company buy a lot of 20,000 bags of wheat per annum the cost per bag is Rs 800/- and the ordering cost is Rs 500/- the inventory cost is estimated as 10% of price of the wheat. Determine EOQ

BUS 2.2 (R22)

CONTENTS

LESSON-1

INTRODUCTION TO PRODUCTION AND OPEATIONS MANAGEMENT

Learning Objectives

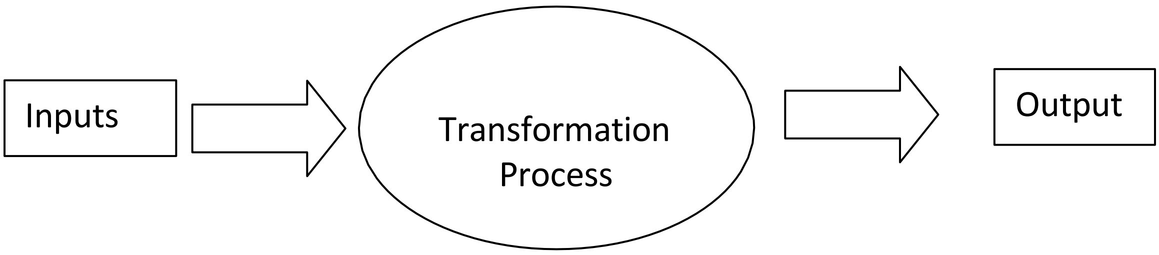
By the end of this lesson, learners will be able to:

1. Know about Importance of Operations management.
2. Functions of operations management.
3. Evolution of operation management.

Structure of the Lesson:

1.1 INTRODUCTION

Operations management‟ is a broad term which includes manufacturing as well as service organizations. Operations management also highlights the increasing importance of the service industry in the overall business environment.



The process in the above diagram in often referred to as the "Conversion Process". There are several different methods of handling the conversion or production process of Job, Bath, Flow and Group.

Added POM incorporates many tasks that are grouped under five main headings:

i) PRODUCT : Marketers in a business must ensure that a business sells products that meet customer needs and wants. The role of PRODUCT in POM therefore concerns areas such as: - Performance -Aesthetics - Quality -Reliability - Quantity -Productioncosts - Delivery dates

ii) PLANT : To make PRODUCT, PLANT of some kind is needed. In determining which PLANT to use, management must consider areas such as: - Future demand - Design and layout of factory, equipment, offices - Productivity and reliability of equipment - Need for (and costs of) maintenance - Heath and safety of equipment - Environmental issues

iii) PROCESSES: There are many different ways of producing a product. Management must choose the best process, or series of processes. They will consider: - Available capacity - Available skills - Type of production - Layout of plant and equipment - Safety - Production costs - Maintenance requirements

iv) PROGRAMMES : The production PROGRAMME concerns the dates and times of the products that are to be produced and supplied to customers. The decisions are influenced by factors such as: - Purchasing patterns (e.g. lead time) - Cash flow - Need for / availability of storage – Transportation.

v) PEOPLE : Production depends on PEOPLE, whose skills, experience and motivation vary.

Key people related decisions will consider the following areas: - Wages and salaries - Safety and training - Work conditions - Leadership and motivation - Unionization - Communication MEANING & DEFINITION: OPERATIONS MANAGEMENT is an area of management concerned with designing and• controlling the process of production and redesigning the business operations in the production of goods or services. It is concerned with managing the process that converts inputs (raw materials, labour, energy) into outputs (goods and/or services). Operations management is concerned with managing all operational function in an organization. Operations is one of the major functions in an organization along with marketing, finance and human resources.

PRODUCTION• Production is a scientific process which involves transformation of raw material (input) into desired product or service (output) by adding economic value.
PRODUCTION MANAGEMENT: Production management means planning, organising, directing and controlling of production¬ activities. Production Management deals with decision-making related to production process. (or) Production management deals with converting raw materials into finished goods or products.¬ It brings together the 6M's i.e. men, money, machines, materials, methods and markets to satisfy the wants of the people.

1.2 NATURE AND IMPORTANCE OF OPERATIONS MANAGEMENT

1) Transformational Process: The production management is concerned with the conversion of raw material.

2) Results into Value Addition: In this at every successive level some value is added to the previous one. For example, sand at sea shore does not and any value but sand used in construction adds to the value.

3) System Itself: Itisacompletestep-wiseprocess.i.e.,aproperwell-definedsequence is followed in production management.

4) Exists for Certain Objective: First there is an objective and to meet that particular objective a complete procedure is followed.

5) Carried-Out in Part of Organization: Its meaning is that production is not alone in the organization rather there are certain other acts also like finance, research and development, etc.

6) Interrelationship among the System: No system can ever work in isolation and depends on others for certain help. So, there exists an interrelationship among different system.

7) Stratum Formulation: A production system consists of various strata of corporate hierarchy in which every stratum has a role to play depending upon the size of the firm. Every stratum enjoys certain benefits as a result of stratum performance.

8) Specialization of Function: As different functions are performed separately, due to this they are repetitively performed by same people and there is specializations of functions.

9) Increase in Entropy: It is a measure of degradation of the matter and energy in the universe to an ultimate stage. To check this degradation process fresh blood must be infused in every production system.

10) Increase in Productivity: As there is specialization in functions so the speed of doing a task increases as a result there is increase in productivity.

1.3 SCOPE OF OPERATIONS MANAGEMENT

A) Long term/Strategic decisions

1. Product design and selection: The product mix is chosen keeping in mind overall mission and objectives of the firm. Design of product is important and value engineering helps to achieve the best effective design.

2. Process selection and planning: Process selection involves taking decisions about technology, machines and equipment. Process planning helps in optimum automation and mechanization,

3. Facilities location: Location should as for as possible cut down on production or distribution cost. The diverse factors should be considered for evaluation of location.

4. Facilities layout and material handling: Layout of plants deals with arrangement of machines and plant facilities. The arrangement should be in such a way that the flow of the production remains smooth. The department is laid out in such a way (that the cost of material handling is minimum).

5. Capacity planning: Capacity refers to a level of output of the conversation process over a period of time. This is planning for short term as well as long-term. Tools that help in this are marginal costing (BEA), linear programming, linear curves, decision tree etc.

B) Operational/Short term Decisions

1. Production planning: It aims at setting goals or targets and allocating the resources viz., men, materials, machines, plant services, among varied production operation so that best possible use can be made in the set goals.

2. Production control: It aims to see that activities are carried on in-line with the predetermined standards and schedules of production. (1) And (2) jointly known as PPC (production planning and control).

3. Inventory Control: It deals with the control of raw materials, work-in-progress, finished products, suppliers, tools etc., and storage of them effectively.

4. Quality control: Various statistical techniques are used for the effective quality control. The success of the company depends on its ability to maintain the quality standards which are prescribe in terms of specification like size, cooler, shape etc. Quality control is maintained by testing the actual production and by ascertaining whether they conform to the set standards.

5. Method Study: With the help of time study and motion study, standard method is devised with elimination of unnecessary time.

6. Maintenance and replacement: This deals with preventive methods to avoid machine break downs, Scheduled and breakdown maintenance, policies regarding repair and replacement decisions.
7. Cost reduction and control: Value engineering, budgetary control, etc. help us to keep our costs optimal. All production decision is subject to control measure, after proper feedback.

1.4 FUNCTIONS OF OPERATIONS MANAGEMENT

1) Production Planning: Production planning deals with the preparation of long-and short-term production programs: It comprises routing, scheduling and preparation of orders. Routing lays down the necessary work operations and their sequence. Scheduling specifies the starting and completion time of various production activities. The authority to proceed with a production program is called work order. These orders set the operations going in various locations.

2) Production Control: After planning, the next responsibility of the production manager is to control the production by taking steps to utilize the various factors of production in an efficient manner so that the goods are produced at the lowest possible cost and according to the requirements and satisfaction of the customers and are supplied to them on the delivery dates in the ordered quantity. This function calls for scheduling the required work.

3) Quality Control: The production manager is also responsible for maintaining a specific quality of the product. Steps should be taken to produce the goods according to the specifications and to minimize the amount of defective work. The defective work should be sorted out and sold separately.
4) Industrial Engineering: Industrial engineering is concerned with the determination of methods and processes of manufacturing activities. It also designs tools jigs fixtures, gaugesandotheraccessoriesrequiresforoperations.Finally,itdetermines standards of performance on the basis of time and motion studies, which lie at the base of incentive schemes.

5) Purchasing: Purchasing is partially a production function. It plays a significant role in arriving at make or buy decisions. Specifications and quality requirements of materials and equipment, .are laid down either by the staff department or production department. Decisions relating to quantity requirement sand frequency of purchases are generally made by the materials department in consultation with the production manager. Decisions relating to supplier, price, delivery date etc., lie in the jurisdiction of purchasing department.

6) Plant Engineering: Plant engineering has the responsibility for maintaining the plant and equipment, and services including light, heat, and power.

7) Manufacturing: Manufacturing is the actual process of conversion of materials into outputs of goods and services. Industrial engineering, plant engineering, production planning and purchasing perform the staff functions of rendering services and advice to manufacturing. They all set stage for the actual manufacturing operations by providing production programs, schedules, routed and work orders; by specifying methods, processes and standards of operations; by taking care of the maintenance of plant and equipment; and by making supplies and raw materials available to the person in-charge of operations.

8) Method Analysis: There may be so many alternatives for manufacturing a product. As because all alternatives do not work equally. Some may be more economical than others. The production manager must study the various alternatives and analyze them in right perspective in order to choose the best one. This activity of choosing best alternative is called methods analysis. Method analysis improves the productivity of the concern and minimizes the cost of production.

9) Inventory Control: Production manager is supposed to have control over the cost of production by reducing the wastage of man and material. So he is to make the best use of material. For this purpose, he is to determine the economic lot size, economic order quantity, reorder level(minimum, maximum and danger level of the stock of material) so that the problems of over and under stock of materials may not arise. This involves the physical and financial control of material. Thus, he is to arrange the procurement of raw materials.

10) Plant Layout and Materials Handling: Plant layout is an arrangement of machines and equipment in such a manner so as to maintain the flow of production uninterruptedly. An efficient plant layout aims at efficient material handling which in turn reduces wastages of man material and helps in reducing the cost of production. The production manager must see the sufficient handling systems and plant layout are designed and developed.

11) Work Measurement: One of the main responsibilities of the production manager is to control and reduce the labour cost per unit. At different levels of production, the labour cost per unit differs. Here work-measurement is necessary. By work-measurement methods we mean the level of performance of worker by a worker. Time and motion studies are work-measurement techniques.

12) Other Functions: Apart from the above functions, the production manger is to perform certain other functions such as engineering economics, cost control, maximizing the labour efficiency, standardization and storage, price analysis, wage incentives to workers, etc.

1.5 EVOLUTION OF OPERATIONS MANAGEMENT

For over two centuries, operations and production management has been recognized as an important factor in a country‘s economic growth. The traditional view of manufacturing management began in eighteenth century when Adam Smith recognized the economic benefits of specialization of labour. He recommended breaking of jobs down into subtasks and recognizes workers to specialized tasks in which they would become highly skilled and efficient.

Production management becomes the acceptable term from 1930s to 1950s. As F.W. Taylor‘s works become more widely known, managers developed techniques that focused on economic efficiency in manufacturing. Workers were studied in great detail to eliminate wasteful efforts and achieve greater efficiency. At the same time, psychologists, socialists and other social scientists began to study people and human behaviour in the working environment. In addition, economists, mathematicians, and computer socialists contributed newer, more sophisticated analytical approaches.

With the 1970s emerge two distinct changes in our views. The most obvious of these, reflected in the new name operations management was a shift in the service and manufacturing sectors of the economy. As service sector became more prominent, the change from „production" to „operations" emphasized the broadening of our field to service organizations. The second, more suitable change was the beginning of an emphasis on synthesis, rather than just analysis, in management practices.

Operations Management (OM) evolved from Adam Smith's division of labour in the 18th century, through Taylor's Scientific Management (early 20th C), Ford's assembly line, Hawthorne's Human Relations, WWII Operations Research (OR) for optimization, and post-war service growth, to modern IT/globalization impacts, emphasizing efficiency, quality (JIT/Lean), systems thinking, and digital integration.

Key Eras & Developments:

1. **Industrial Revolution (18th C):**

- **Focus:** Mechanization, steam power, specialization of labor (Adam Smith).
- Shift from craft to factory, increased output.

2. **Scientific Management (Early 20th C):**

- **Focus:** Efficiency, task standardization, eliminating waste, worker productivity.

3. **Mass Production & Human Relations (1920s-1930s):**

- **Impact:** High-volume, low-cost production.

Hawthorne Studies revealed human/social factors affect productivity.

4. **Operations Research (OR) & Quantitative Methods (1940s-1960s):**

- **Origin:** WWII military optimization (linear programming, queuing theory).
- **Focus:** Mathematical models for inventory, forecasting, capacity planning, optimization.

5. **The Service Revolution & Quality Focus (1960s-1980s):**

- Economies moved to services.
- **Influence:** Japanese quality management (Deming, JIT, Lean Manufacturing) emphasized quality, waste reduction, and flexibility.

6. **Information Technology & Globalization (1990s-Present):**

- **Tools:** MRP II, ERP, EDI, Supply Chain Management (SCM) software.
- **Focus:** Global supply chains, e-commerce, data analytics, agility, sustainability, integration.

7. **Modern Era (21st Century):**

- **Focus:** Digital transformation (AI, IoT, Big Data), resilience, customer-centricity, sustainable operations.

1.6 SUMMARY

Operations management" is a broad term which includes manufacturing as well as service organizations. Operations management also highlights the increasing importance of the service industry in the overall business environment. Evolution of Operations management: For over two centuries, operations and production management has been recognized as an important factor in a country's economic growth. The traditional view of manufacturing management began in eighteenth century when Adam Smith recognized the economic benefits of specialization of labour. He recommended breaking of jobs down into subtasks and recognizes workers to specialized tasks in which they would become highly skilled and efficient.

1.7 KEY WORDS: PRODUCTION MANAGEMENT, OPERATIONS MANAGEMENT, PLANT, PRODUCT , QUALITY.

1.8 SELF-ASSESSMENT QUESTIONS:

1. Define operation processes and explain its key components?
2. Discuss the various stages in the evolution of production and operation management discipline?
3. What are the future trends in production and operation management?

1.9 SUGGESTED READINGS

1. R. Panneerselvam, Production & operations management, Prentice Hall lndia,2017.
2. Mahadevan B., Operations Management Theory and Practice, Pearson Publication, 3rd Edition,
3. Aswathappa, K., Shridhara Bhat, K., Production and Operations Management, Himalaya Publishing House,20l4
4. Kanishka Bedi, Production & Operation Management, University Press.
5. Chunawalla and Patel, Production & Operation Management Himalaya. Mumbai
6. Sidhartha S. Padhi, Operations Management - Text and Cases, Star Business Series, 2018
7. Upendra Kachru: Operation Management, Excel Publications.
8. Chary, S.N. Production and Operation Management, New Delhi, Tata McGraw Hill

Dr. A. Kanaka Durga

LESSON-2
TYPES OF PRODUCTION SYSTEMS

Learning Objectives

By the end of this lesson, learners will be able to:

1. Learn about types of manufacturing process.
2. Understand about Product Design.
3. Know about the process of product design.

STRUCTURE OF THE LESSON

2.1 INTRODUCTION

Manufacturing is the use of machines, tools and labor to make things for use or sale. The term may refer to a range of human activity, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large on a large scale. Such finished goods may be used for manufacturing other, more complex products, such as household appliances or automobiles, or sold to wholesalers, who in turn sell them to retailers, who then sell them to end users –the "consumers".

Manufacturing is characterized by tangible (products), outputs that customers consume overtime, jobs that use less labour and more equipment, little customer contact, no customer participation in the conversion process (in production and sophisticated methods for measuring production activities and resource consumption as product are made.

A manufacturing process is the activity (or a combination of activities) of transforming a given material into a product of different forms and sizesand with or without changing the physical and mechanical properties of the product material. A manufacturing process is always accomplished with the help of a variety of tools, equipment and other devices or mechanical aids at the human effort.

2.2 TYPES OF MANUFACTURING PROCESS

1. Project

Project technology deals with one-of-a-kind products that are tailored to the unique requirements of each customer. A general construction company, with its many kinds and sizes of projects, is an example of project technology. Since the products cannot be standardized, the conversion process must be flexible in its equipment capabilities;
human skills, and procedures. The conversion process features problem solving, teamwork, and coordinated design and production of unique products.

2. Job Production

Job one-off or „make complete are descriptions given to organization whereby the complete task is handled by a single worker or group of workers. The hair dresser, who cuts, washes and perms the customer’s hair, the tailor who makes the entire suit, the construction of a bridge, installation of capital plant in a factory, and ship-building are all examples of tasks which are organized using the job approach.

CHARACTERISTICS OF JOB ORDER PRODUCTION

i) **Small production Runs:** Job order production is characterized by the manufacture of one or few numbers of single product designed and manufactured strictly to customer’s specification.
ii) **Flow of Materials:** The flow of materials and components between different stages of manufacture is highly discontinuous due to imbalance operation wise work content.
iii) **Manufacturing Cycle Time:** Relatively long delays occur at the assembly as well as at the material processing stags due to lack of materials of materials or components, imbalanced work flow, design changes, design errors detected during manufacturing etc.
iv) **Layout of Plant and Equipment:** The machines are arranged according to process layout. Because the operations and their sequence change from product to product.
v) **Skill Required:** Highly skilled and versatile workers are necessary. They are expected to do the work independently and display a great deal of initiative and judgment.
vi) **Quality of Supervision:**Highly competent general engineers are usually engaged as supervisors,practicalmenwiththoroughtraining,capableoftakingindependentchange of each contract are employed to work at site. Close supervision is also necessary.

3. Batch Production

Under this system, the manufacturing is done in batches or groups or lots either on the basis of customer’s order or with a hope of a continuous demand of the product. Under this system, scale production is warranted.

In batch production, machines and equipment are made available for the next batch as soon as the production of first batch is completed. The best example of this type of production system is chemical industry where different medicines are produced in batches.

Characteristics of Batch Production

i) **Short Runs:** Batch production is characterized by short production runs and frequent changes in set ups.
ii) **Investment:** Needs high investment. The production is generally made to stock.
iii) **Planning:** Planning, routing and scheduling changes with fresh batch of orders.
iv) **Skill of labour:** Skilled labour capable of handling variety of jobs is required.
v) **Quality of supervision:** The supervisors need considerable knowledge of specific process. The amount of supervision required in batch production is lower than that of job order production.
vi) **Plant Layout:** Plant and equipment are procured and arranged to obtain flexibility. General purpose machines and handling equipments capable of performing variety of operations with minimum set up times are installed according to process layout.
vii) **Material Handling:** Material handling in batch production is less as compared to job order production.
viii) **Flexibility in Production Schedule:** Disruptions due to machine breakdown or absenteeism do not seriously affect production as another machine can be used or another operator from another machine can be shifted.

Aims of Batch Production

- Concentrate skills
- Obtain high equipment utilization

Suitability

Batch production is applied when either the volume of output increased resulting in come repetitiveness or the market demand is not uniform throughout the fear. In the latter case occasional discontinuity of production occurs as switching to other product becomes necessary.

Advantages:

- It reduces unit production costs in relation to job production by exploiting the benefits of bulk production.
- It grants some flexibility in product design and variations.
- It streamlines the use of the workforce and machinery, enhancing productivity.
- It promotes the uniform quality of each batch.

Disadvantages:

- Setup time between batches can lead to production delays.
- It requires storage space for work-in-progress inventory.
- It is less flexible than job production when it comes to fully customized products.

Examples:

- Baked goods (pastries, loaves, biscuits)
- Drugs and medical pills
- Clothing and textile products
- Journal publications and literature

4. Mass Production

Mass production is the large-scale production of standardized goods or commodities through fully automated processes. It is concerned with efficiency, cost-cutting, and uniformity.

Characteristics:

- Production is continuous, with products moving through an assembly line.
- Minimal customization is required, as products are standardized.
- Specialized machinery and workers are used to enhance productivity.
- Mass production lowers the unit cost of an item due to economies of scale.
- Uniformity of products is ensured through standardized quality checks throughout the process.

Advantages:

- It is the most efficient, as it provides large quantities at a low cost.
- It guarantees standardization and quality of products.
- It also involves minimal labor due to automation, and human error is minimized.
- It contributes to high market demand because it can produce at a faster rate.

Disadvantages:

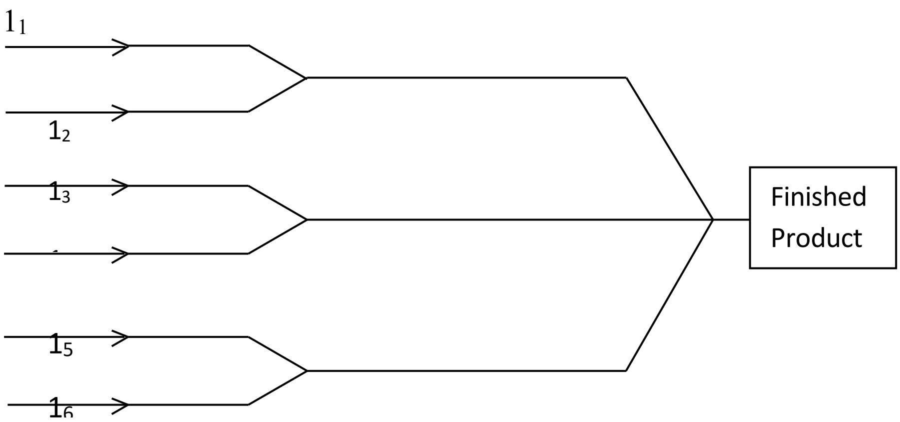
- It involves a large start-up cost in equipment and facilities.
- It lacks flexibility and thus cannot easily change the product designs.
- It may lead to job dissatisfaction, as employees may be required to perform repetitive tasks.

Examples:

- Car production (e.g., Toyota, Ford)
- Manufacturing of Smartphones (e.g., Samsung, Apple)
- Home appliances (e.g., fridge, washing machine, etc.)
- Fast-food chains (e.g., McDonald's, Burger King)

5. Assembly Lines

It was developed in the automobiles industry in U.S.A where two or morecomponentsarecombinedtomanufactureafinishedproduct.Assemblylineisparticularly useful when a limited variety of similar products is to be produced on a mass scale or in fairly large batches on a continuous basis. The design of assembly line involves the proper balancing of technology and other manufacturing facilities so as to develop a rational approach of optimization of results.



6. Continuous or Flow Production

Batch methods are characterized by the irregularity in the way the work is carried outon particular task. Or the increase in the value added to the material involved. Batch becomes flow when the rest/idle/queuing period mentioned earlier is eliminated. Flow has been defined as method of organization such that the task worked on continuously, or alternatively as a system whereby the processing of material is continuous and progressive.

CHARACTERISTICS OF CONTINUOUS OR FLOW PRODUCTION

i) **Flow of Material:** The flow of materials is continuous and there is little or no queuing at any stage of processing.

ii) **Machines and plant Layout**: Special purpose machines are used and plant and assembly stages are laid on the basis of product layout.

iii) **Material Handling**: Material handling is comparatively less firstly because materials move through a short distance between stages and secondlythe material handling activity is mostly mechanized by conveyors and transfer machines.

iv) **Skill of labour**: Relatively low skilled labour is necessary.

v) **Manufacturing Cycle Time:** The manufacturing cycle time is very short. The machine capacities are balanced by line balancing.

vi) **Quality of Supervision:** Supervision is relatively easier as only few instructions are necessary only at the starting of the job; since standard jobs are produced.

vii) **Flexibility in Production Schedules:** Interruptions due to breakdowns and absenteeism seriously affect production as stoppage of one machine in the line usually disturbs the working of other machines. Systematic preventive maintenance is necessary to prevent interruptions in production.

Advantages:

- It is the most efficient with the least downtime.
- It assists in cost reduction of labor through automation.
- It has the ability to make homogeneous and repetitive products in large volumes.
- It is best suited in the industry where goods have to be supplied continuously.

Disadvantages:

- It is very capital-intensive in terms of infrastructure and technology.
- It is also not very flexible, and switching between products is a complex process.
- It requires regular maintenance and supervision to prevent any failures.

Examples:

- Oil refineries
- Power plants
- Manufacture of steel and cement
- Production of fertilizers, paints, etc. (e.g., chemicals)

7. Lean Production

Lean production focuses on minimizing waste and maximizing efficiency while maintaining high-quality standards. It aims to eliminate non-value-adding processes.

Characteristics:

- Emphasizes waste reduction to improve resource efficiency.
- Uses just-in-time (JIT) inventory management to reduce excess stock.
- Ongoing refinement (Kaizen) lies at the heart of this methodology.
- Promotes teamwork across departments to foster innovation and drive collaboration.
- Focuses on delivering value to customers.

Advantages:

- It helps reduce operational costs by eliminating unnecessary steps.
- It improves overall productivity and efficiency.
- It helps enhance product quality through continuous improvement strategies.

Disadvantages:

- It requires that the process be constantly checked and corrected.
- JIT inventory is closely dependent on the efficiencies of suppliers.
- This implementation process may be problematic in certain areas.

Examples:
- Toyota Production System
- Assemblies: consumer electronics.
- Custom-built computers (e.g., Dell-built computers).

9. Flexible Manufacturing System (FMS)

A Flexible Manufacturing System (FMS) is a combination of automation, robotics, and computerized controls that enable the creation of multiple types of products with high adaptability.

Characteristics:
- Seamlessly transitions between varying product lines.
- Minimizes delays during production changeovers.
- High efficiency while still allowing for some customization.

Advantages:
- It is quite flexible to product demands.
- It minimizes inventory expenses because of effective production planning.
- It makes the most of the automated technology, making it more efficient.

Disadvantages:
- It does not necessitate a large start-up capital for technology and equipment.
- It requires a well-trained human resource to operate automated systems.
- Maintenance and troubleshooting of this system can be a complicated process.

Examples:
- Aerospace industry (e.g., Boeing/Airbus)
- Car production (e.g., automated production lines in Tesla)
- Semiconductor manufacturing (e.g., high-tech industry)

2.3 PRODUCT DESIGN

Meaning and Definition of Product

Product is anything that can be offered to a market that might satisfy a want or need. There are two concepts of product – narrow concept and wide concept. In its narrow concept, a product is bundle of physical or chemical properties which has some utility. A product isnot a nonliving object; it is not a mere assemblage of matter-physical and chemical. Utility alone is the function of the product.

A product means an object which satisfies the need of the customer. Thus fan, table, pen, cooler, chair etc. are products. In its wider concept, all the brands, all the colors all the packaging or all the designs of a product is taken to be different products.

Definition of Product Design

Design is the conversion of knowledge and requirement into a form, convenient and suitable for use for manufacture. It is observed that inputs of the organizations resource resulting properly designed product and service known as outputs satisfying the customer‘s desire.

According to C.S. Deverell, —product Design in its broadest sense includes the whole development of the product through all the preliminary stages until actual manufacturing begins.‖

According W. Alderson, —A product is a bundle of utilities consisting of various features and accompanying services‖.

According to Philip Kotler, —A product is a bundle of physical services and symbolic particulars expected to yield satisfactions or benefits the buyer‖.

Typology of Products

Operations management is fundamental to an organization‘s achievement of its mission and competitive goals. It is involved in creating value in the products. Products can be tangible or intangible. Tangible products are called goods, while intangible products include services and contracts‘. These are collectively referred to as products.

1) Goods: Are tangible items that are usually produced in one location and purchased in another. They can be transferred from one place to another and stored for purchase by a consumer at a later time. For example, of goods are products such as cars, washing machines, televisions, packaged foods, etc,

2) Services: Are intangible products that are consumed as they are created. Services now dominate the economies of most industrialized nations. Service organizations include hotels, hospitals, law offices, educational institutions, and public utilities.

Customer contact is a key characteristic of services. A high quality of customer contact is characteristic of a good service organization. This is vital to retain current customers as well as for attracting new ones.

3) Contracts: Are business exchanges in which neither services nor goods are transferred; instead, there is an implicit understanding between the customer and the provider that goods and services will be provided on an as needed basis. With a contract, the customer pays a fee and is then entitled to manufactured goods or services. Many goods and services are now evolving into contracts.

2.4 CONCEPTS INVOLVED IN PRODUCT DESIGN

1) Research and Development: The design of new products is done by the Research and Development (R&D) department of organizations with the help of many other departments. In R&D, fundamental research is the advancement of the state of knowledge in a subject, though it may be to be practically converted into commercial applications.

2) Reverse engineering: Reverse engineering is the process of carefully dismantling an existing product (of a competitor) step by step in order to understand the unique underlying concepts. It helps in designing new products, which are better than those of the competitors. In the field of consumer electronics, Sony Corp. is on the forefront in designing new innovative items such as the walkman, handy cam, digital cameras, etc.

3) Manufacturability: Manufacturability implies designing a product in such a way that it‘s manufacturing/assembling can be done easily. While designing a new product, the manufacturing capabilities (such as existing machines, equipment, skills of workers, etc.) of the organization have to be kept in mind. If the required capabilities by making more investments.

4) Standardization: Standardization refers to less variety in the design of products ,i.e., new products are designed such that there is no major variation from the existing productions.

5) Robust Design: Robust design means designing a product that is operational in varying environmental conditions. For example, if you compare a car with a jeep (a four-wheel drive), the jeep is more robust in design as it can even be used efficiently on hilly areas with poor road conditions. The Japanese Engineer, Genichi Taguchi, emphasized that it is easier. To easier. To create a product with robust design rather making changes in the environment to suit the product.

6) **Concurrent Engineering:** Concurrent engineering is the product design approach in which the design team includes personnel from the marketing department (to specify the customer requirements), engineering department (to look at the feasibility of the design), production department (to suggest if production capability exists for the design), materials department (to give inputs about material lavailability according to design specifications), and finance department (to suggest financial feasibility of the design) in addition to the design department.
7) **Computer-Aided Design:** Computer-aided design(CAD) is a software which helps the designer to make the three-dimensional design of a product on the computer and visualize the design from various angles. In the earlier times, when CAD software were not available, design engineers had to make designs from various angles (say, front, back, side, top, bottom views of the product/ components) on paper charts by using rulers and other equipment, which was tedious and time consuming. The designs made on CAD can be seen at different workstations through intranets simultaneously.
8) **Life Cycle of a Product:** The product lifecycle has five stages spread throughout life of a product. These are incubation, growth, maturity, saturation, and decline. The duration of the life of a product depends upon the type of product. The incubation stage witnesses a low demand of the product owing to the customer not being aware of the new product.

As the awareness increase and new features are added to the masses, leading to the saturation phase and eventually the decline phase.

2.5 OBJECTIVES OF PRODUCT DESIGNING

The objects of designing the product may be summarized as follows:

- The first object of designing is to create attention in product for increasing the sales potentials.
- To enlarge the importance of product from customers‘ point of view.
- To make the product more effective and create more utility in the product for the consumer.
- To produce better quality at the lowest possible price.

2.6 FACTORS DETERMINING THE PRODUCT DESIGN

1. Customer's Requirements and Psychological Effects: The product should be acceptable to the consumer and should satisfy his needs. It should create a good impression on the customer and generate his confidence regarding durability, quality and performance of the product.

2. Facility to Operators: The designer must see that an operator is provided with all possible comforts and facilities in handling the operations involved in the product design.

3. Functionality: The design should be such that the product is functionally sound. It should be able to perform the functions, for which it is made, to the complete satisfaction of the consumer.

4. Material Requirements: The nature and quality of the materials have significant affect on the design of the product. The designer should have up to date information about new materials available to make the desired product

5. Work Methods and Equipment: The work method and equipment required to perform the operations specified in the design are of great significance on the utility and viability of the design. The designer must be aware of innovations for improving the work methods and nature of the equipment.

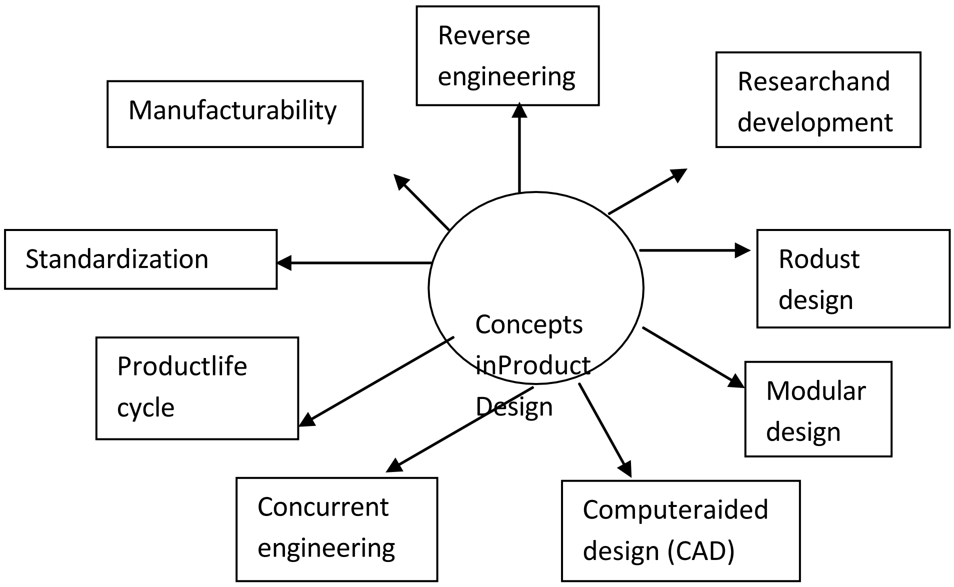


Fig: Concept in Production Design

2.7 TYPES OF DESIGN

1. Functional Design: Functional design involves developing an idea into tough model of the proposed products. This necessitates first making a rough sketch of the proposed products to dive some idea of its shape and of parts necessary to accomplish its purpose. Then, the designer makes drafting room sketches of the individual parts in correct dimensions and then a full sketch of proposed products.

2. Aesthetic Design: Before production on a commercial scale is undertaken, another type of design must be integrated with the functional design and it is aesthetic design or style or fashion design for market acceptability. It is not possible to improve the functionality efficiency, it, however, gives it a more attractive appearance and helps to increase sales.

3. Production Design of Product Design: Generally, the functional design is means a design which may result in affecting the economies without affecting its functional efficiency.

4. Packing Design: Packing design should also be appealing to the consumers depending upon the size and the nature of the product. Different packing materials can be used to suit the consumer‘s needs and to maintain the chemical properties of the product.

The product designer should use as far as possible standard parts or assemblies to reduce the cost of production because standard parts in some cases may be purchased cheaper from outside firms specializing their manufacture. The product designer should also know about the possibility of simplification and diversification of product.

2.8 PROCESS OF PRODUCT DESIGN

Product design is the process of creating a new product to be sold by a business to its customers. A very broad concept, it is essentially the efficient and effective generation and development of ideas through a process that leads to new products. Product design is one of the crucial stages in Operations Management. In designing the product, or the item to be processed in non-manufacturing systems, the product designer specifies materials, tolerances, basic configurations, methods of joining parts and the like, and through these specifications sets the minimum possible production cost.

The two basic steps in designing a product are functional design and production design.
- Functional Design.
- Production Design

Characteristics of a good product design

A good product design should contain the following characteristics:

1. Functionality.
2. Reliability.
3. Productivity.
4. Quality.
5. Standardization.
6. Maintainability.
7. Safety.
8. Cost Effectiveness.

TYPES OF PRODUCT DESIGN

- Aesthetic design
- Functional design
- Production design
- Packing design

ELEMENTS IN PRODUCT DESIGN

- Research and development
- Reverse engineering
- Manufacturability
- Standardisation
- Modular design
- Robust design
- Concurrent engineering
- Computer aided design
- Life cycle of a product

FACTORS AFFECTING PRODUCT DESIGN

- Customers requirements
- Production facilities
- Raw materials to be used
- Cost to price ratio
- Quality policy
- Plant and machineries
- Effect on existing products
- Reputation of the company

The Product Development Process :A process is a sequence of steps that transforms a set of inputs into a set of outputs. Most people are familiar with the idea of physical processes, such as those used to bake a cake or to assemble an automobile. A product development process is the sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product. Many of these steps and activities are intellectual and organizational rather than physical. Some organizations define and follow a precise and detailed development process, while others may not even be able to describe their process. Furthermore, every organization employs a process at least slightly different from that of every other organization. In fact, the same enterprise may follow different processes for each of several different types of development projects.

A well-defined development process is useful for the following reasons:

• Quality assurance: A development process specifies the phases a development project will pass through and the checkpoints along the way. When these phases and check- points are chosen wisely, following the development process is one way of assuring the quality of the resulting product.

• Coordination: A clearly articulated development process acts as a master plan that defines the roles of each of the players on the development team. This plan informs the members of the team when their contributions will be needed and with whom they will need to exchange information and materials.

• Planning: A development process includes milestones corresponding to the completion of each phase. The timing of these milestones anchors the schedule of the overall development project.

• Management: A development process is a benchmark for assessing the performance of an ongoing development effort. By comparing the actual events to the established process, a manager can identify possible problem areas.

• Improvement: The careful documentation and ongoing review of an organization's development process and its results may help to identify opportunities for improvement.

2.9 SUMMARY

Manufacturing is characterized by tangible (products), outputs that customers consume overtime, jobs that use less labour and more equipment, little customer contact, no customer participation in the conversion process (in production and sophisticated methods for measuring production activities and resource consumption as product are made.

A manufacturing process is the activity (or a combination of activities) of transforming a given material into a product of different forms and sizes and with or without changing the physical and mechanical properties of the product material. Different types of production and about Product Design.

2.10 KEY WORDS: MASS PRODUCTION, BATCH, ASSEMBLE LINE, PRODUCT DESIGN.

2.11 SELF-ASSESSMENT QUESTIONS

1. Explain different types of production systems?
2. Write the advantages and disadvantages of Batch production and mass production?
3. Explain about the process of product design?

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LESSON-3
ALLOCATING RESOURCES TO STRATEGIC ALTERNATIVES

OBJECTIVES:

On successful completin of this lesson you will be:

- Understanding how to formulate a real situation into LPP.
- Can formulate diversified situations of scarce allocation of resources.
- Solve LPP problems using graph.
- Understand exceptional cases and their solutions.

STRUCTURE:

3.1 INTRODUCTION

Today business organizations are facing serious problem in optimum allocation of scare or limited resources among diversified and demanding customers across the globe. Accordingly, the functions of Operations management are getting complicated. The operations function is that turns organizations resources into products and services. Products are going to utilize multiple resources in the process of manufacturing. Resources include raw material, machine hours, equipment, man hours and tools. For example production from a factory is limited due to capacity constraints: organizations face working capital constraints and technical constraints.

If it is long time till a decision is to be made then many of these constraints can be avoided by changing resources, i.e., add more capacities and resources, i.e., add more capacities, borrow more funds etc. Another example, media selection of an organization is limited to capacity constraints, organizations facing selection of type of media constraints and buyer constraints. Similarly for individual investments they face the problem of investment decisions. The investment constraint: earning capacity constraint and risk and knowledge about market constraints. Like this many problems will occur for available allocation of manpower, machinery material and money. However, if the available resources cannot be expanded, then optimal utilization of existing resources becomes very important task for the organization.

Linear programming is one of the most popular and widely used techniques to solve such types of problems. A liner programming model provides an efficient method for determining an optimal decision (or an optimal strategy or an optimal plan) chosen from a large number of possible decisions, the optimal decision is one that meets a specified objective of management, subject to various constraints or restrictions.

This lesson is going to discuss the formulation of LPP from a real management environment and apply graphical technique to solve the same. As all of know that the graph has a limitation in the sence that only two variables are used for graph.
However in formulation, let us discuss more number of variables.

3.2 FORMULATION OF LPP:
In the following discussion we present different problem situations by formulating them as LPP.

3.3 EXAMPLE 1: MAXIMISATION PROBLEM

Product mix problems deal with optimum mix of scarce resources in the manufacturing process.

ABC India Ltd. makes two products, Tables and Chairs, which must be processed at **Assembly** and **Finish** departments. The available times at assembly and finish departments are 60 hours and 48 hours respectively per day. Manufacturing of one table requires 4 hours of assembly time and 2 hours of finish time. Manufacturing of one chair requires 2 hours of assembly time and 4 hours of finish time. Net profit generated by selling one table is Rs. 8 and that of chair is Rs.6. Any number of tables and chairs can be sold in the market. Determine the maximum profit that can be obtained from the situation?

Formulation: Let x_1 and x_2 be the number of tables and chairs to be manufactured per day. Objective for the product mix problem is to maximize profit. Profit on a table is Rs. 8 and we want to make x_1 tables. Hence ($8x_1$) is the profit on tables. Similarly, profit on a chair is Rs.6 and number of chairs to be made are x_2 . Hence profit on x_2 chairs will be ($6x_2$). Now the total profit is profit on tables and profit on chairs, which is ($8x_1 + 6x_2$). The Objective function is to Maximise $Z = 8x_1 + 6x_2$,

The two constraints are assembly and finish times.
Assembly time constraint: One table requires 4 hours of assembly time. Hence, x_1 tables require ($4x_1$) hours of Assembly time.

One chair requires 2 hours of assembly time. Hence, x_2 chairs require ($2x_2$) hours of Assembly time. Total assembly time is 60 hours and we cannot use more than 60 hours.
Assembly time constraint: $4x_1 + 2x_2 \leq 60$ because maximum available assembly time is 60 hours.
Similarly we can formulate the Finish time constraint. **Finish time constraint**: $2x_1 + 4x_2 \leq 48$ because maximum available assembly time is 48 hours.

Non negativity constraint is $x_1 \geq 0$; $x_2 \geq 0$ because tables and chairs to be produced cannot be negative.

Now the LPP formulation for product mix problem in Example 1 is:

Maximise $Z = 8x_1 + 6x_2$	
Subject to the constraints:	$4x_1 + 2x_2 \leq 60$;
	$2x_1 + 4x_2 \leq 48$ and
Non Negativity:	$x_1 \geq 0$; $x_2 \geq 0$

3.4 EXAMPLE 2: MINIMIZATION PROBLEM

XYZ Company has two floor mills A and B to produce high, medium and low-quality floor. This company has entered into a contract for supplying floor to a firm every day equal to 12, 8 and 24 quintals of high, medium and low-quality floors. The cost of operating mill A and mill B respectively are Rs. 1000 and Rs. 800 per day. The production capacity of the mill A per day is 6 quintals of high, 2 quintals of medium and 4 quintals of low-quality, while that of mill B is 2 quintals of high, 2 quintals of medium and 12 quintals of low-quality floor. Formulate this as a LPP to determine the optimum number of days to run the mills A and B?

Formulation: The given information can be presented as below:

Floor Quality	Mill A	Mill B	Minimum quantity of supply required
High	6	2	12
Medium	2	2	8
Low	4	12	24
Cost of operation (Rs.)	1000	800	

Let x_1 and x_2 be the number of day the Mills A and B to be operated.

Minimise $Z = 1000x_1 + 800x_2$
Subject to: $6x_1 + 2x_2 \geq 12$
$2x_1 + 2x_2 \geq 8$
$4x_1 + 12x_2 \geq 24$
Non Negativity: $x_1 \geq 0$; $x_2 \geq 0$

3.5 EXAMPLE 3: MEDIA MIX PROBLEM

Campaign in three different media – TV, Radio and Magazines. The purpose of Ad. Program is to reach as many potential customers as possible. Results of a market survey are as follows:

Item	Television(TV)			
	Day Time	Prime Time	Radio	Magazine
Cost of an Ad. Unit(Rs.)	40,000	75,000	30,000	15,000
Number of potential customers reached per unit	4,00,000	9,00,000	5,00,000	2,00,000
Number of women customers reached per unit	3,00,000	4,00,000	2,00,000	1,00,000

The company does not want to spend more than Rs. 8,00,000 on advertising. It further wants that a) at least 2 million exposures take place among women; b) advertising on TV be limited to Rs. 5,00,000;c) at least 3 advertising units be bought on day time TV and 2 units during prime time; and d) the number of advertising units on radio and magazine should each be between 5 and 10. Formulate this as a LPP and solve.

Formulation:

Maximise $Z = 400\,x_1 + 900\,x_2 + 500\,x_3 + 200\,x_4$

Subject to $40\,x_1 + 75\,x_2 + 30\,x_3 + 15\,x_4 \leq 800$

$30\,x_1 + 40\,x_2 + 20\,x_3 + 10\,x_4 \geq 200$

$40\,x_1 + 75\,x_2 \leq 50$

And $x_1 \geq 3$; $x_2 \geq 2$; $5 \leq x_3 \leq 10$; $5 \leq x_4 \leq 10$

3.6 EXAMPLE 4: PRODUCT MIX PROBLEM – A BY-PRODUCT CASE

Two products A and B are made involving two chemical operations for each. Each of product A requires 2 hours on operation 1 and 3 hours on operation 2. Each of product B requires 3 hours on operation 1 and 4 hours on operation 2. Available time for operation 1 is 16 hours and for operation 2 is 24 hours.

The production of product B also results in a by-product C at no extra cost. Though some of this by product can be sold at a profit, the remainder has to be destroyed. Product A sells at a profit of Rs. 4 per unit, while Product B sells at a profit of Rs.10 per unit. By- product C can be sold at a profit of Rs. 3 per unit, but if it cannot be sold, the destruction cost is Rs. 2 per unit. Fore casts show that upto 5 units of C can be sold. The company gets 2 units of C for every unit of B produced. The problem is to determine the production quantity of A and B keeping C in mind, so as to make the largest profit.

Formulation:

Maximise $Z = 4\,x_1 + 10\,x_2 + 3\,x_3 - 2\,x_4$

Subject to: $-2\,x_2 + x_3 + x_4 = 0$

$x_3 \leq 5$

$2\,x_1 + 3\,x_2 \leq 16$

$3\,x_1 + 4\,x_2 \leq 24$

$x_1 \geq 0$; $x_2 \geq 0$; $x_3 \geq 0$; $x_4 \geq 0$

3.7 EXAMPLE 5: DIET PROBLEM

Diet problems deal with optimum amount of spending in connection with a buying activity. This helps in optimum spending on buying materials. Three Nutrient components, namely, Thiamin, Phosphorous and Iron are found in two foods A and B. The amount of availability of each nutrient in the foods A and B in milligrams per ounce (i.e., mg/oz) are given below:

Nutrient	Food A	Food B
Thiamin	0.15	0.10
Phosphorous	0.75	1.70
Iron	1.30	1.10

The cost of food A is Rs.2 per oz and that of food B is Rs.1.70 per oz. As per the guidelines of dietician the minimum daily requirements of nutrients are 1.00 mg of thiamin, 7.50 mg of phosphorous and 10.00mg of iron must be consumed. Formulate the problem as a linear programming problem. (Minimisation problem)

Formulation:

Minimise $Z = 2\ x_1 + 1.70\ x_2$

Subject to $0.15\ x_1 + 0.10\ x_2 \geq 1.00$

$0.75\ x_1 + 1.70\ x_2 \geq 7.50$

$1.30\ x_1 + 1.10\ x_2 \geq 10.00$

$x_1 \geq 0\ ;\ x_2 \geq 0$

3.8 EXAMPLE 6: FERTILIZER USE PROBLEM

An Agriculture Research Institute has suggested to a farmer to spread out at least 4800 Kgs of Phosphate fertiliser and no less than 7200 Kgs of Nitrogen fertiliser to rise productivity of crops in his fields. There are two sources of obtaining these ingredients, namely, mixture A and mixture B. Both of these are available in bags weighing 100 Kgs each and costs Rs.400 and Rs. 240 respectively. Mixture A contains Phosphate and Nitrogen equivalent to 20Kgs. and 80 Kgs. respectively while mixture B contains these ingredients equivalent to 50 Kgs. each. Formulate this as a LPP.

Formulation:

The given information can be presented as below:

Fertiliser	Mixture-A	Mixture-B	Minimum quantity required
Phosphate	20	50	4800
Nitrogen	80	50	7200
Cost per bag in Rs.	400	240	

Let x_1 and x_2 be the number of units of Mixture-A and Mixture-B to be purchased by the farmer.

Minimise $Z = 400\ x_1 + 240\ x_2$
$20\ x_1 + 50\ x_2 \geq 4800$
$80\ x_1 + 50\ x_2 \geq 7200$
$x_1 \geq 0;\ x_2 \geq 0$

3.9 SOLUTION TO LPP BY GRAPH:

The following is the problem of product mix presented in example 1.

A) Graphical Solution to Example 1

Maximise $Z = 8\ x_1 + 6\ x_2$
Subject to the constraints: $4\ x_1 + 2\ x_2 \leq 60$;
$2x_1 + 4x_2 \leq 48$ and
Non Negativity: $x_1 \geq 0;\ x_2 \geq 0$

Solution:

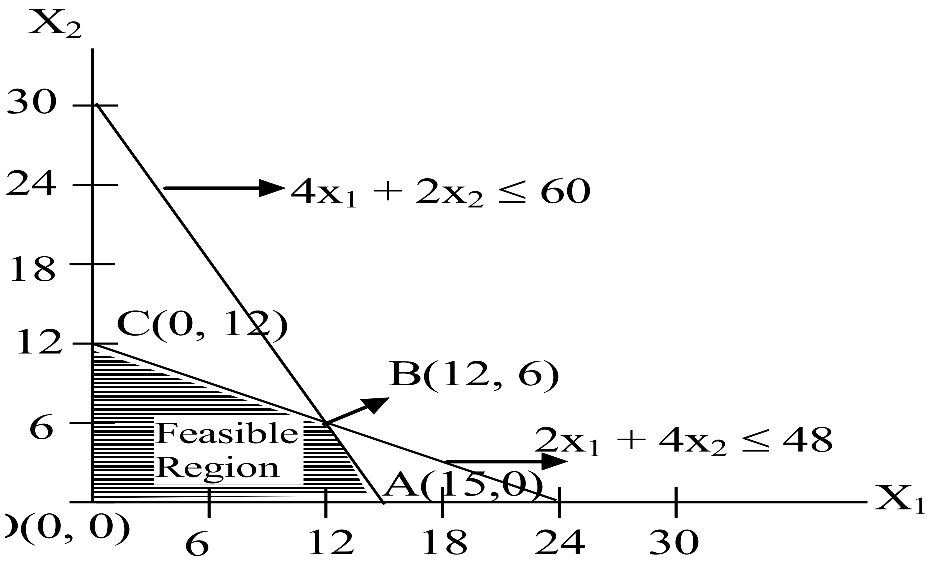
Assembly Constraint: Assume $4x_1 + 2x_2 = 60$; Put $x_1 = 0$ in $4x_1 + 2x_2 = 60$ to determine $x_2 = 30$. This gives the coordinates as (0, 30). This will be a point on Y axis.
Assume $4x_1 + 2x_2 = 60$; Put $x_2 = 0$ in $4\ x_1 + 2\ x_2 = 60$ to determine $x_1 = 15$
This gives the coordinates as (15, 0). This will be a point on X axis.
This gives the coordinates as (0, 30) and (15,0). Draw a line on graph as shown below.
Similarly,

Finish Constraint: Assume $2x_1 + 4x_2 = 48$; Put $x_1 = 0$ in $2x_1 + 4x_2 = 48$ to determine $x_2 = 12$. This gives the coordinates as (0,12).
Assume $2\ x_1 + 4\ x_2 = 48$; Put $x_2 = 0$ in $2\ x_1 + 4x_2 = 48$ to determine $x_1 = 24$. This gives the coordinates as (24,0). This gives the coordinates as (0, 12) and (24,0). Draw a line on graph as shown below. Write the equation on the line for clarity.

Now let us look at the original constraints and determine the common area on graph to mark as shaded part of the graph. This area is called as feasible region. This is bounded by lines. Identify the corner points as: O(0,0), A(15,0), C (0,12). Get the corner point B by uniquely solving two simultaneous linear equations. The Corner point B(12,6).

Evaluate Objective function at the corner points.
Z at O(0, 0) is Z = 8 (0) + 6 (0) = 0
Z at A(15, 0) is Z = 8 (15) + 6 (0) = 120
Z at B(12, 6) is Z = 8 (12) + 6 (6) = 132
Z at C(0, 12) is Z = 8 (0) + 6 (12) = 72 Of all the Z values maximum is at the corner point B(12,6) with maximum profit as 132 units. In other words Number of tables to be manufactured as 12 and number of chairs to be manufactured as 6.

Fig. 3.1: Maximisation



B) Graphical Solution to Example 2

The problem formulated in example 2 is solved below by using graph.

Minimise $Z = 1000\, x_1 + 800\, x_2$

Subject to: $6\, x_1 + 2\, x_2 \geq 12$

$2\, x_1 + 2\, x_2 \geq 8$

$4\, x_1 + 12\, x_2 \geq 24$

Non Negativity: $x_1 \geq 0$; $x_2 \geq 0$

We now graph the constraint inequalities as follows:

The first inequality will have the solution above the line $6X_1 + 2X_2 = 12$.

Its points of intersection are (0,6) and (2,0) on the X_1 and X_2 axes respectively. The second inequality will have solution above the line $2X_1 + 2X_2 = 8$,

whose points of intersection are (0,4) and (4,0) on the X_1 and X_2 axes respectively.

The third inequality will be satisfied above the line $4\, X_1 + 12\, X_2 = 24$, whose points of intersection are (0,2) and (6,0).

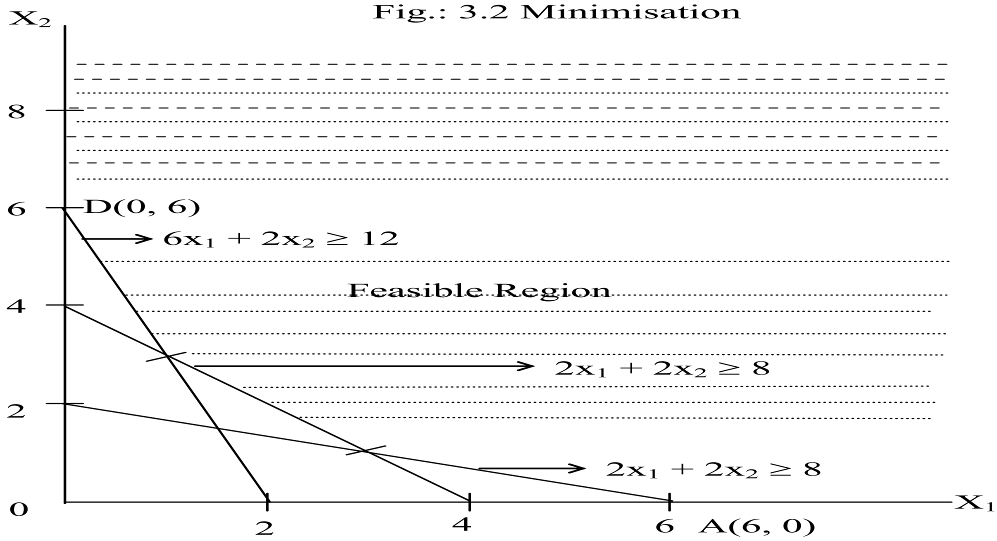
We note that the solution can not be negative, i.e., below X_1 axis or left of X_2 axis. In order to get the solution, we have to check the points of intersections on X_2 and X_1 axes which do not violate the constraints. For example, in the graph K is a point of intersection but it lies below $2\, X_1 + 2X_2 = 8$ and, thus, it violates the second inequality condition. The only points of intersection in our graph that are possible feasible solutions are: A, B, C and D.The area shaded is called the region of feasible solutions. Every line on the graph taken alone is a lower boundary for the feasible solutions satisfying the inequality it represents as an equation. Again any point in the shaded region is feasible, but not necessarily optimal, unless, in our example, it represents the lowest cost, i.e., the company pays least when it operates using the combination of days for the respective mills as represented by the point. The solution must lie in the bounded plain whose lower extreme points are A, B, C and D.

The extreme points of the feasible regions are A(6,0), B(3,1), C(1,3) and D(0,6).
The objective function values at these points are:

Z at A = 1000(6) + 800(0) = Rs.6000/-
Z at B = 1000(3) + 800(1) = Rs.3800/-
Z at C = 1000(1) + 800(3) = Rs.3400/-
Z at D = 1000(0) + 800(6) = Rs.4800/-

The least value of Z is occurring at C(1,3) with Z = Rs.3400.
The optimum number of days the mills M and N should work are 1 and 3 days respectively per week.

Fig.: 3.2 Minimisation



Let us present some more solutions for LPP by graph.

C) Example 7: Additional example

Maximize: $Z = 50\ X_1 + 60\ X_2$

$2\ X_1 + 3\ X_2 \leq 1500$

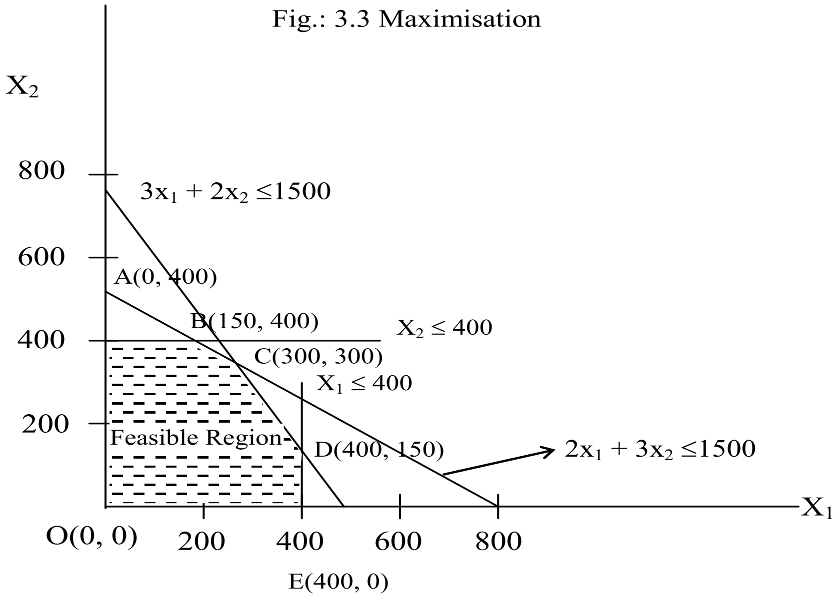
$3\ X_1 + 2\ X_2 \leq 1500$

$X_1 \leq 400$

$X_2 \leq 400$

and $X_1 \geq 0, X_2 \geq 0$

Fig.: 3.3 Maximisation



Find the Optimum solution from the corner points of the feasible region marked in the graph by your self.

D) Example 8: Infeasible Solution:

Maximize $Z = 20 X_1 + 30 X_2$

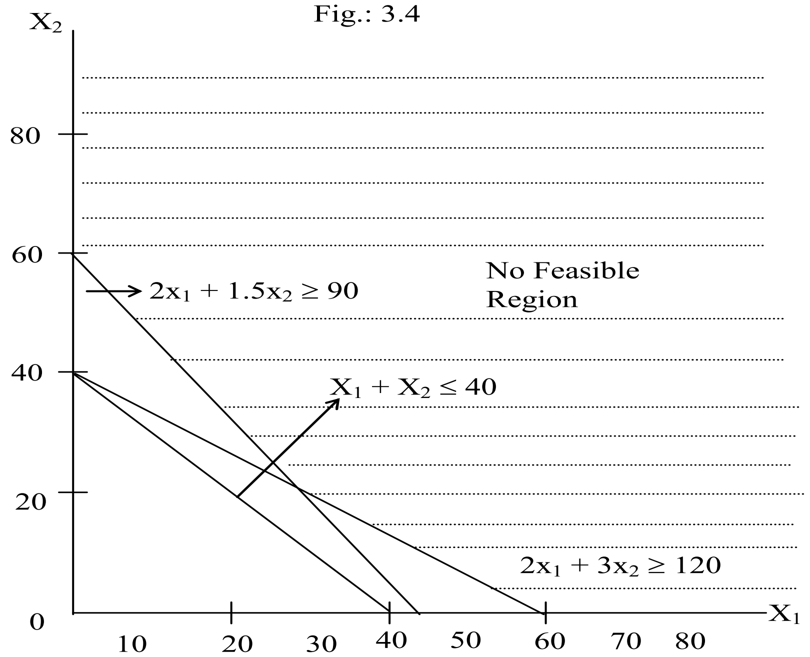
$2 X_1 + 3 X_2 > 120$

$X_1 + X_2 > 40$

$2 X_1 + 1.5 X_2 > 90$

and $X_1, X_2 > 0$

Fig.: 3.4



From the graph it can be observed that no common area that can satisfy all the constraints. Hence the problem is infeasible. In real life this type of problems can be due to mismatch between the resources. By adding resources the problem can be made feasible and can have an optimal solution.

E) Example: Multiple Optimal Solutions

Maximize: $Z = 4 X_1 + 3 X_2$

$4 X_1 + 3 X_2 < 24$

$X_1 < 4.5$

$X_2 < 6$

and $X_1, X_2 > 0$

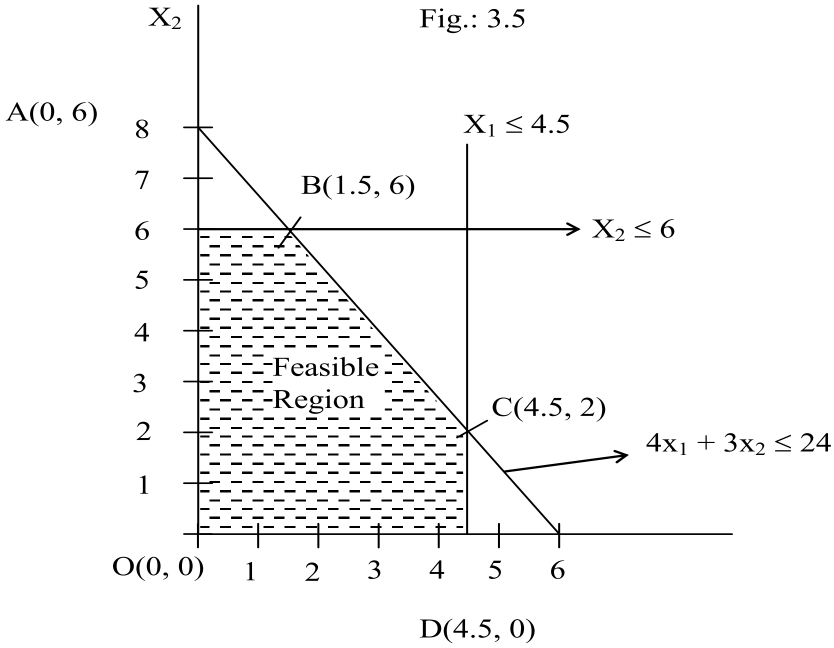


Fig.: 3.5

3.10 SUMMARY

Optimum use of scarce and natural resources is a very important requirement in order to preserve the resources for future. In this direction LPP is a way in which optimum use of scarce resources in order to maximize profit or minimize cost is possible. This lesson has discussed in detail about formulating and solving the real situation faced by industry in using the resources. Product mix, diet, by product problems, fertilizer application problems are discussed. Some examples to explain about exceptional cases are presented.

3.11 KEY WORDS

Linear Programming is a technique to optimize a linear objective function subject to linear constraints

Product Mix is problem associated with mixing of different products in manufacturing which use same resources.

Diet proble is to plan to minimize the cost in buying products for a balanced diet requirements.

Media mix problem is associated with mixing different media in the process of advertising . one can have different objectives.

Fertilizer use problem can be a plan of use of fertilizer in least expenditure.

Optimization is achieving maximum/minimum value of some effectiveness criterion

3.12 SELF ASSESSMENT EXERCISES

1) The Handy–Dandy company wishes to schedule the production of a kitchen appliance which requires resources of labor measured in hours per unit and material measured in Kilograms per unit. The company is considering three different models. The production engineering department has furnished the following data.

	Model - A	Model – B	Model - C
Labor	7	3	6
Material	4	4	5
Profit(Rs. /unit)	4	2	3

The supply of raw material is restricted to 200 Kgs. Per day. The daily availability of labor is 150 hours. Formulate a LPP to determine the daily production of various models in order to maximise the total profit.

2) A factory makes cricket bats and hockey sticks. A cricket bat takes 1.5 hrs of machine time and 2 hrs of craftsman's time, while a hockey stick takes 2.5 hrs of machine time and 1.5 hrs of craftsman's time. In a day the factory has up to 80 hrs of machine time's availability and 70 hrs of craftsman's time. The profits respectively on bat and stick are Rs. 50 and Rs.35. What is the maximum profit and the corresponding combination of bats and sticks?

3) A fruit squash manufacturing company manufactures three types of squashes. The basic formulae apart from water are :5 litre lemonade: 2 dz. lemons, 2kg. of sugar, 2 oz. citric acid 5 litre grapefruits: 1.5 kg. grapes, 1.5 kg. of sugar, 1.5 oz. citric acid 5 litre orangeade: 1.5 dz. oranges, 1.5 kg. of sugar, 1.0 oz. citric acid
The squash sells at lemonade: Rs.37.50 per 5 litre. Grapefruits: Rs.40.00 per 5 litre and orangeade: Rs.42.50 per 5 litre. In the last week of the season they have in stock 2,500 dozen lemons, 2000 kg. Grapefruits,750 dozen oranges,5000 kg of sugar and 3000 ozs. of citric acid. What should be their manufacturing quantities in the week to maximise the turnover?

4) The manager of dairy corporation is trying to determine the blend of two types of feed. Both contain various percentages of four essential ingredients. What is the least cost blend? Use graph and solve.

Ingredients	% per Kg. Of feed		Minimum Requirement(in Kg.)
	Feed 1	Feed 2	
1	40	20	400
2	10	30	300
3	20	2.5	100
4	1	10	60
Cost(Rs./Kg.)	500	350	

3.13 SUGGESTED READINGS

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Prof. B. Krishna Reddy

LESSON-4

CAPACITY PLANNING – FRAMEWORK AND TYPES

Learning Objectives:

By the end of this lesson, learners will be able to:

1. Capacity planning definition and measuring capacity.
2. Different types of capacities.
3. Capacity planning framework.

STRUCTURE OF THE LESSON:

4. 1 CAPACITY PLANNING–CONCEPT

Capacity planning refers to determining what kind of labor and equipment capacities are required and when they are required. Capacity is usually planned on the basis of labor or machine hours available within the plant. Thus, capacity planning is planning for quantity or scale of output. There are four major considerations in capacity planning:

- Level of demand
- Production
- Availability of fund
- Management Policy

4.2 DEFINING AND MEASURING CAPACITY

Capacity often refers to an upper limit on the rate of output. In selecting a measure of capacity, it is important to choose one that does not require updating. For example, rupee amounts are often a poor measure of capacity (e.g., capacity of Rs 30 crore a year) because price changes necessitate updating of that measure. Where only one product or service is involved, the capacity of the productive unit may be expressed in terms of that item. However, when multiple products or services are involved, as is often the case, using a simple measure of capacity based on units of output can be misleading. An appliance manufacturer may produce both refrigerators and freezers. If the output rates for these two products are different, it would not make sense to simply state capacity in units without reference to either refrigerators or freezers. The preferred alternative in such cases is to use a measure of capacity that refers to availability of inputs.

Thus,

- a hospital has a certain number of beds,
- a factory has a certain number of machine hours available,
- a bus has a certain number of seats.

Measures of capacity

Business	Inputs	Outputs
Auto manufacturing	Labor hours, machine hours	Number of cars per shift
Steel mill	Furnace size	Tons of steel per day
Oil refinery	Refinery size	Gallons of fuel per day
Farming	Number of acres, number of cows	Bushels of grain per acre per year, gallons of milk per day
Restaurant	Number of tables, seating capacity	Number of meals served per day
Theater	Number of seats	Number of tickets sold per performance
Retail sales	Square feet of floor space	Revenue generated per day

Goal of Capacity Planning:

The goal of capacity planning of an organization is to achieve a match between long-term capabilities and the long-term demand. Overcapacity causes high operating costs, while under capacity causes strained resources and possible loss of customers.

The basic questions in capacity handling are:

- What kind of capacity is needed?
- How much is needed? (Forecasts are key inputs)
- When is it needed? (Frequency)

The question of what kind of capacity is needed depends on the products and services that management intends to produce or provide.

Forecasts are key inputs used to answer the question of how much is needed.

The factors that influence this frequency are the stability of demand, the rate of technological change in equipment and product design, and competitive factors.

4.3 TYPES OF CAPACITY

1. Licensed capacity - denotes the capacity licensed by the Government authorities concerned.

2. Potential capacity - The decision on potential capacity is taken mostly by a senior most executive of the organization.

3. Immediate capacity - is that which can be made available within the current budget period. Immediate capacity is subject to certain constrains like plant equipment size, availability of equipment, availability of manpower, financial policy, sub-contracting policy, the technical demands of the tasks, and the number of different tasks being undertaken. For example, the capacity of a restaurant is limited by the size of the dining area or the number of tables.

4. Design or Installed capacity - It is the maximum output that can be achieved in a given time period form a particular plant. It is a theoretical capacity as it does not take into consideration power breakdown, pool planning, non-availability of materials, labor absenteeism, etc. This capacity is reliable only if certain conditions are satisfied. They are:

- There are no interruptions of any kind.
- There is 100% utilization of capacity.
- Men and machines work in ideal conditions.
- Quality of inputs according to specification

In real life situation, it is difficult to fulfill these conditions. Therefore, installed capacity only sets the maximum limit and also serves to judge the actual utilization of plant capacity. Hence it is also known as maximum capacity.

5. Effective or Practical or Operating capacity: Effective capacity can be influenced by technical abilities in the pre-operations stages, organizational skills in the planning stages, purchasing skills, sub-contracting skills, maintenance policies and abilities, efficiency of workforce, multiple shift operation, etc. No plant can work up to the maximum or theoretical capacity due to plant efficiency factor and scrap factor. A portion of the available hours cannot be worked due to scheduling delays, machine breakdown, preventive maintenance, etc. This results in the efficiency of plant being less than what is rated.

6. Actual or Utilized capacity: This is the actual output achieved during a particular time period.

Ex: If installed capacity is 100,000 tons and the actual production is 80,000 tons, we say that capacity utilization is 80% or the plant worked at 80% of the capacity.

7. Normal Capacity or Rated capacity: It is the capacity estimated by a qualified authority as to the amount of production that should be usually secured Actual capacity is usually expressed as a percentage of the rated capacity.

8. Excess capacity: Generally, plant and equipment are indivisible in nature. Plant and equipment are long term facilities and constitute the major part of production cost. It is not possible to adjust fully and immediately the size of the plant and machinery to suit day to day changes in sales and production. Therefore, excess (unutilized) capacity may occur frequently.

Efficiency and Utilization: Design capacity is the maximum rate of output achieved under ideal conditions. Effective capacity is usually less than design capacity owing to the need for periodic maintenance of equipment, lunch breaks, coffee breaks, problems in scheduling and balancing operations, and similar circumstances.

- Efficiency is the ratio of actual output to effective capacity.
- Utilization is the ratio of actual output to design capacity.

*Both measures are expressed as percentages.

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}}$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}}$$

It is common for managers to focus exclusively on efficiency, but in many instances, this emphasis can be misleading. This happens when effective capacity is low compared with design capacity. In those cases, high efficiency would seem to indicate effective use of resources when it does not. Because effective capacity acts as a lid on actual output, the real key to improving capacity utilization is to increase effective capacity by correcting quality problems, maintaining equipment in good operating condition, fully training employees, and fully utilizing bottleneck equipment. Hence, increasing utilization depends on being able to increase effective capacity, and this requires knowledge of what is constraining effective capacity.

Efficiency/Utilization Example – Compute the efficiency and the utilization of the vehicle repair department:

$$\text{Design capacity} = 50 \text{ trucks per day}$$
$$\text{Effective capacity} = 40 \text{ trucks per day}$$
$$\text{Actual output} = 36 \text{ trucks per day}$$

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} = \frac{36 \text{ trucks per day}}{40 \text{ trucks per day}} = 90\%$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} = \frac{36 \text{ trucks per day}}{50 \text{ trucks per day}} = 72\%$$

4.4 FACTORS DETERMINING EFFECTIVE CAPACITY:

Increasing utilization depends on being able to increase effective capacity, and this requires knowledge of what factors affect effective capacity. The main factors relate to facilities, products or services, human considerations, operational factors, the supply chain, and external factors.

Facilities:

1. The design of facilities, including size and provision for expansion.
2. Location factors, such as transportation costs, labour, energy sources.
3. Layout of the work area often determines how smoothly work can be performed.
4. Environment factors such as heating, lighting, and ventilation also play a significant role in effective planning.

Product/Service factors

- When products are similar, the ability of the system to produce those items is generally much greater than with products that differ.
- Thus, a restaurant that offers a limited menu can usually prepare and serve meals at a faster rate than a restaurant with an extensive menu.
- Generally speaking, the more uniform the output, the more opportunities there are for standardization of methods and materials, which leads to greater capacity.

Process factors:

- If quality of output does not meet standards, the rate of output will be slowed by the need for inspection and rework activities.
- Hence process improvements that increase quality should be a part of effective capacity.

- **Human factors**
  - Training, skill, and experience required to perform a job have an impact on the potential and actual output.
  - Employee motivation has a very basic relationship to effective capacity.
- **Operational factors**
  - Inventory stocking, late deliveries, acceptability of purchased materials, quality inspection can have an impact on effective capacity.
  - Inventory shortages of even one component of an assembled item can cause a temporary halt to assembly operations until new components become available.
  - Insufficient capacity in one area can affect overall capacity.

Supply chain factors

- Supply chain factors must be taken into account in capacity planning is substantial capacity changes are involved.
- Key questions include – what impact will the changes have on suppliers, warehousing, transportation and distributors?

External factors

- Defined quality and performance standards can restrict management's options for increasing and using capacity.
- Union contract limits the number of hours and type of work an employee may do.

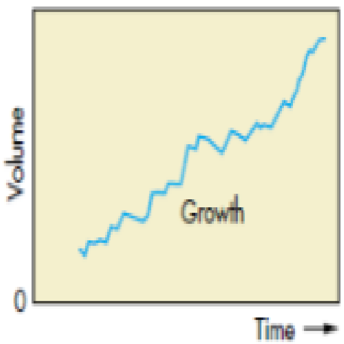
4.5 PROCEDURE FOR CAPACITY PLANNING/ CAPACITY PLANNING FRAMEWORK

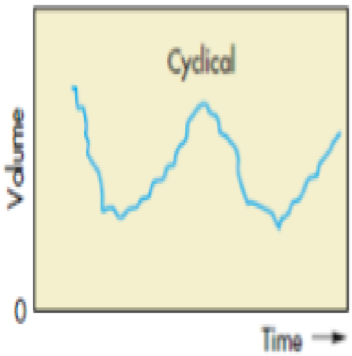
- **Assessment of Existing Capacity:** Capacity of a unit can be measured in terms of output or inputs. Output measure is appropriate in case of manufacturing concerns. e.g. ,automobile plant (number of cars), iron and steel plant (tons of steel), cannery (tons of food), etc. Service concerns like hospitals (number of beds), theatres (number of seats), etc., can measure capacity in terms of inputs.
- **Forecasting Future Capacity Needs:** Short term capacity requirements can be estimated by forecasting product demand at different stages of the product life cycle. It is more difficult to anticipate long-term capacity requirements due to uncertainties of market and technology. Capacity forecast helps to determine the gap between the existing capacity and estimated capacity so that necessary adjustments may be made.

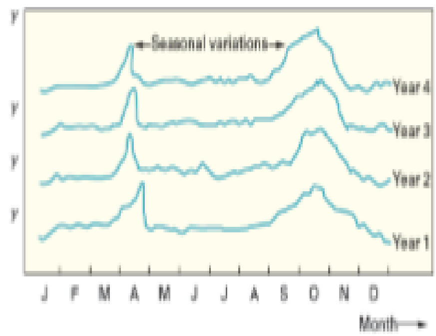
- **Identifying Alternative ways of Modifying Capacity:** In case where the existing capacity is inadequate to meet the forecast demand capacity, the expansion is required to meet the shortage. Additional shifts may be employed to expand the capacity. Expansion will provide economies of scale and help in meeting the forecast demand. But it involves additional investment and danger of fall in forecast demand in future. When the existing capacity exceeds forecast capacity, there is a need for reduction of excess capacity. Developing new products, selling of existing facilities, layout of workers or getting work from other firms are the methods of overcoming it.
- **Evaluation of Alternatives:** Various alternatives for capacity expansion or reduction are evaluated from economic, technical and other viewpoints. Reactions of employees and local community should also be considered. Cost-Benefit analysis, Decision theory and Queuing theory are the main techniques of evaluating alternatives.
- **Choice of Suitable Course of Action:** After performing the cost-benefit analysis of various alternatives to expand or reduce the capacity, the most appropriate alternative is selected.

4.6 FORECASTING CAPACITY REQUIREMENTS

Capacity planning decisions involve both long-term and short-term considerations. Long-term considerations relate to overall level of capacity, such as facility size; Short-term considerations relate to how well the capacity is used to meet the demand.
Long term capacity is for the long run of the organization when initial plant is setup. We determine long-term capacity needs by forecasting demand over a time horizon and then converting those forecasts into capacity requirements. For this, the organization looks into trend and cyclical forecasts.







- When **trends** are identified, the fundamental issues are

(1) how long the trend might persist, because few things last forever, and
(2) the slope of the trend.

- If **cycles** are identified, interest focuses on

(1) the approximate length of the cycles, and
(2) the amplitude of the cycles (i.e., deviation from average).

- Short term capacity is how we deal with the current demand. For this the organization looks into **seasonal and random** forecasts. These deviations are particularly important because they can place a severe strain on a system's ability to satisfy demand at some times and yet result in idle capacity at other times.

4.7 DEVELOPING CAPACITY ALTERNATIVES

Things organization can do to enhance capacity management:

Design flexibility into systems

- Have provision for future expansion in the original design can be obtained at a small price compared to what it would cost to remodel an existing structure.
- Example, if future expansion of a restaurant seems likely, water lines, power hookups, and waste disposal lines can be put in place initially.
- Obtaining adjacent land.
- Flexible design involve layout of equipment, location, equipment selection, production planning.

Take stage of life cycle into account

Capacity requirements are often closely linked to the stage of life cycle that a product or service is in.

- At the introduction phase, it is difficult to determine how the market reacts, therefore, organizations should be cautious while making large or inflexible capacity investments (a cautious approach).
- In the growth phase, the organization's share grows, which will need increase in capacity, investment and complexity.
- In the maturity phase, organizations tend to have a stable market share making full use of capacity and profitability.
- In the decline phase an organization is faced with underutilization of capacity. During this phase organizations may decide to sell excess capacity, introduce new products, or transfer capacity to another location that has lower labour costs.

Take a "big picture" approach to capacity changes

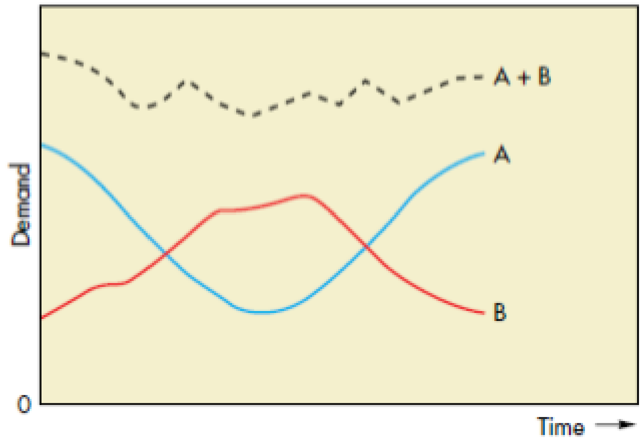
When developing capacity alternatives, it is important to consider how parts of the system interrelate. For example, when making a decision to increase the number of rooms in a hotel, one should also take into account probable increased demands for parking, entertainment and food, and housekeeping. This is a "big picture" approach. The risk of not taking big-picture approach is that the system will be unbalanced – possible bottleneck situation. A bottleneck operation is an operation whose capacity is lower than other capacities of other operations in the sequence. As a result the capacity of this operation limits the system capacity. Organizations should work on eliminating bottleneck situation.

Prepare to deal with capacity "chunks"

Capacity increases are often acquired in fairly large chunks rather than smooth increments, making it difficult to achieve a match between desired capacity and feasible capacity.
For instance,
Desired capacity – 55 units/hr
Machine capacity – 40 units/hr
Another machine would increase the excess capacity by 25 units/hr.

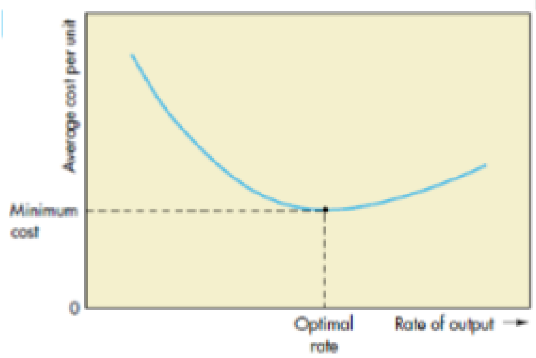
Attempt to smooth out capacity requirements

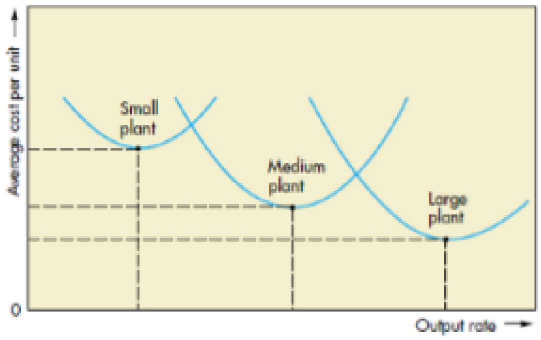
Unevenness in capacity requirements can create certain problems. At certain times the system will tend to be overloaded, while at other times it will tend to be under loaded, which tends to alternate between underutilization and over utilization of the system. One possible approach to this problem is to identify products or services that have complementary demand patterns, that is, patterns that tend to offset each other. For instance, demand for air-conditioner is greater in the summer, and demand for heating equipment is greater winter. These products involve the use of the same resources but at different times, so that overall capacity requirements remain stable.



Identify the optimal operating level.

Production units typically have an ideal or optimal level of operation in terms of unit cost of output. At the ideal level, cost per unit is the lowest for that production unit; larger or smaller rates of output will result in a higher unit cost. Organization tends to manage their operations so that fall into this range.





The optimum level of operation is a function of plant size as shown in pic. Choose a strategy if expansion is involved

- Consider whether incremental expansion or single step is more appropriate.
- Lead or follow competitors.

Evaluating Alternatives

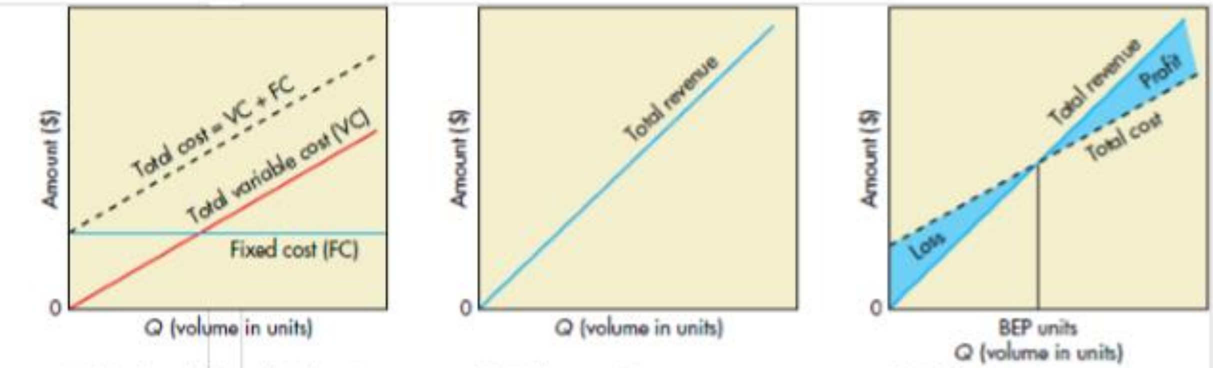
An organization needs to examine alternatives for future capacity from a number of different perspectives.

Most obvious are economic considerations:

- Will an alternative be economically feasible?
- How much will it cost?
- How soon can we have it?
- What will operating and maintenance costs be?
- What will its useful life be?
- Will it be compatible with present personnel and present operations?

Cost-Volume Analysis-

By using this technique we can compute the break-even point (BEP). Break-even point (BEP): The volume of output at which total cost and total revenue are equal. Use of the technique requires identification of all costs related to the production of a given product Fixed costs tend to remain constant regardless of volume of output. Examples - rental costs, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs. Variable costs vary directly with volume of output.



A. Fixed, variable, and total costs. B. Total revenue increases C. Profit = TR – TC.

Concept of indifference – The quantity at which a decision maker would be indifferent between two alternatives.

4.8 IMPORTANCE OF CAPACITY DECISIONS

Capacity decisions are among the most fundamental of all the design decisions that managers must make.

1. Impacts ability to meet future demands: Having capacity to satisfy demand can allow a company to take advantage of tremendous opportunities.
2. Affects operating costs: Ideally, when capacity and demand match, it tends to minimize operating costs. In practice, this is not always achieved because actual demand either differs from expected demand or tends to vary.
3. Major determinant of initial costs: The greater the capacity of a productive unit, the greater its cost. Hence while planning capacity future trend of product to be kept in mind.
4. Involves long-term commitment: Once they are implemented, it may be difficult or impossible to modify those decisions without incurring major costs.
5. Affects competitiveness: If a firm has excess capacity, or can quickly add capacity, that fact may serve as a barrier to entry by other firms.
6. Affects ease of management: Having appropriate capacity makes management easier than when capacity is mismatched.
7. Globalization adds complexity: Far-off supply chains and distant markets add to the uncertainty about capacity needs.
8. Impacts long range planning: Some facility might take years to be functional at which it must be able to match the actual demand.

4.9 SUMMARY

Capacity planning refers to determining what kind of labor and equipment capacities are required and when they are required. Capacity is usually planned on the basis of labor or machine hours available within the plant. Thus, capacity planning is planning for quantity or scale of output.

4.10 KEY WORDS: CAPACITY PLANNING, EFFECTIVE CAPACITY, CAPACITY DECISIONS.

4.11 SELF-ASSESSMENT QUESTIONS

1. Define Capacity planning and what are the factors that determine effective capacity?
2. Explain about different types of capacities?
3. Write about importance of capacity decisions and explain about its framework?

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LESSON-5
LOCATION PLANNING – LOCATION DECISIONS, FACTORS, PLANNING METHODS

Learning Objectives

By the end of this lesson, learners will be able to:

1. Know how to choose a location for business.
2. Identity the factors influencing Facility location .
3. Learn about the Methods of Location Decisions.

STRUCTURE OF THE LESSON:

5.1 INTRODUCTION

5.2 FACTORS INFLUENCING FACILITY LOCATION DECISIONS.

5.3 STEPS IN THE FACILITY LOCATION STUDY.

5.4 METHODS OF LOCATION DECISIONS - SUBJECTIVE, QUALITATIVE AND SEMI-QUANTITATIVE TECHNIQUES.

5.5 RECENT TRENDS IN FACILITY LOCATION.

5.6 SUMMARY.

5.7 KEY TERMS.

5.8 SELF-ASSESSMENT QUESTIONS.

5.9 SUGGESTED READINGS.

5.1 INTRODUCTION

A plant is a place where men, materials, machines, equipment etc., are brought together for manufacturing the product. Plant location decisions are crucial because they commit organizations to long lasting financial, employment, a distribution patterns. As such they deserve the careful financial attention, personnel, marketing and other managers as well as that of the operations manager who manages all the facilities.

Plant location is not a static decision that can be made and forgotten. Plant layout/facility layout choices follow the location decisions. They influence the type of equipment and level of technology employed the flow of work and the design of jobs, inventory levels and other operating characteristics of the firm. Layout can be changed more easily than locations. However, they represent more of a continuing concern. In addition, they fall more directly within the responsibility of operations manager. Because they deal with physical arrangement of productive facilities.

- Plant location refers to the choice of region and the selection of a particular site for setting up a business or factory.
- An ideal location is one where the cost of the product is kept to minimum, with a large market share, the least risk and the maximum social gain.
- It is the place of maximum net advantage or which gives lowest unit cost of production and distribution.

Plant location studies are conducted in three phases.

- Regional factors,
- Community factors and
- Site factors

5.2 FACTORS INFLUENCING FACILITY LOCATION DECISIONS

1. Proximity to Customers:
A key factor, especially in service-oriented industries. Being closer to customers can reduce transportation costs, improve delivery times, and increase customer satisfaction.
2. Labour Costs and Availability:
Access to skilled labour and the cost of labour can have a significant impact on the decision. Low-cost labour might attract companies to certain regions, but the availability of skilled workers should also be considered.
3. Transportation Costs:
Transportation costs are often a key factor in determining the location of manufacturing or distribution centers. A central location can help minimize the cost of raw materials and goods transportation.
4. Proximity to Suppliers:
Being close to key suppliers can help reduce material costs and ensure faster production processes.
5. Real Estate and Infrastructure:
The cost and availability of real estate for building a facility, and the quality of infrastructure (roads, utilities, etc.) are crucial.
6. Government Regulations and Incentives:
Tax incentives, zoning laws, labor laws, and environmental regulations may vary by location. Governments often offer incentives to attract businesses to certain regions.
7. Market Conditions:
Economic conditions and the size and growth potential of the market in the location must be considered. A growing market might make a location more attractive even if costs are higher.
8. Environmental Impact:
Environmental regulations and the potential environmental impact of a facility can influence location decisions, especially with stricter regulations on emissions and waste disposal.
9. Quality of Life:
Factors such as healthcare, education, housing, and general living conditions can affect employee satisfaction and retention.
10. Risk Factors:
Natural disaster risks (earthquakes, floods, hurricanes) or political instability can make some locations less attractive.

Significance of Location Planning
Efficient location planning offers several benefits to supply chain management:

- **Cost Reduction:** Strategic location decisions can minimize transportation costs, labor costs, and operational expenses, leading to overall cost savings.
- **Improved Customer Service:** Proximity to target markets allows for quicker deliveries and enhanced customer service, contributing to customer satisfaction and loyalty.
- **Enhanced Supply Chain Resilience**: Evaluating risk factors during location planning helps build resilience against potential disruptions.
- **Competitive Advantage**: Optimally located facilities can give a business a competitive edge by reducing lead times and improving market access.

Steps in Location Planning:
Successful location planning involves a systematic approach, typically consisting of the following steps:

1. Define Objectives:
Clearly articulate the objectives of the location planning process. Common objectives include cost minimization, improving customer service, or market expansion.

2. Gather Data:
Collect relevant data about the supply chain, including customer locations, supplier locations, transportation costs, and market demand.

3. **Identify Candidate Locations**:
Create a list of potential locations based on the defined objectives and available data. Consider factors such as proximity to suppliers, target markets, and transportation infrastructure.

4. Quantitative Analysis:
Utilize quantitative methods and tools to evaluate candidate locations. These may include cost models, network optimization software, or geographic information systems (GIS).

5. Cost Analysis:
Calculate the total costs associated with each candidate location, including transportation costs, labor costs, facility construction costs, and operational expenses.

6. Market Analysis:
Assess the proximity of each location to target markets and customers. Consider factors like market size, growth potential, and competitive dynamics.

7. Risk Assessment:
Evaluate potential risks associated with each location, such as natural disasters, political stability, and regulatory constraints.

8. Qualitative Factors:
Consider qualitative factors that may not be easily quantifiable, such as workforce availability, community support, and environmental impact.

9. Weighted Scoring:
Assign weights to the different factors based on their importance to the objectives. Calculate a weighted score for each candidate location to facilitate decision-making.

10. **Select Optimal Location:**
Choose the location that best aligns with the defined objectives and has the highest weighted score.

11. Implementation:
Once the optimal location is selected, proceed with the implementation phase, which may involve securing real estate, building facilities, and establishing operational processes.

12. Continuous Monitoring:
Regularly monitor and evaluate the performance of the selected location to ensure it continues to meet supply chain objectives. Adjust as needed based on changing circumstances.

Single vs. Multi-Facility Location Decisions

Single Facility Location:

- Generally simpler and focuses on finding the best location based on demand distribution.
- Techniques like the Centre of Gravity method or Break-even analysis are used.
- Suitable for smaller operations or when the company only requires one production or distribution facility.
- **Multi-Facility Location:**
- More complex as it involves choosing locations for multiple facilities and assigning
- customers to these facilities.
- Techniques like K-median or Integer programming are common.
- Often used by larger organizations or when dealing with geographically dispersed customer bases.

Choosing the right facility location is critical to operational efficiency. For a single facility, techniques like the Center of Gravity and Break-even analysis are commonly used. For multi facility scenarios, more advanced methods like K-median and Integer programming are applicable. The key is to consider various factors such as customer proximity, transportation costs, labour availability, and government regulations.

5.3 STEPS IN THE FACILITY LOCATION STUDY

Location studies are usually made in two phases namely, (i) the general territory selection phase, and (ii) the exact site/community selection phase amongst those available in the general locale.

Overlap of considerations of factors in the two stages of facility location

.	**Location Factors**	**Phase 1 General Territory Selection**	**Phase II Particular Selection of Site and Community**
1	Market	□	
2	Raw Materials	□	
3	Power	□	□
4	Transportation	□	□
5	Climate and Fuel	□	
6	Labour and Wages	□	□
7	Laws and Taxation	□	□

8 Community Services and Attitude		□
9 Water and Waste		□
10 Ecology and Pollution		□
11 Capital Availability	□	□
12 Vulnerability to enemy attack	□	□

A Typical team studying location possibilities for a large project might involve economists, accountants, geographers, town planners, lawyers, marketingexperts, politicians, executives, industrialengineers, defense analysts and ecologists etc. It is indeed an inter-disciplinary team that should be set up for undertaking location studies.

5.4 METHODS OF LOCATION DECISIONS - SUBJECTIVE, QUALITATIVE AND SEMI- QUANTITATIVE TECHNIQUES

Factor Rating Method

The Factor Rating Method is a decision-making tool used to evaluate and compare potential locations for a facility based on a set of factors that are important for the business. It involves assigning a weight to each factor (reflecting its importance), rating each potential location on those factors, and then calculating a score for each location. The location with the highest score is typically chosen.

The factor rating method is a structured approach to location selection that involves identifying key factors, assigning weights based on their importance, scoring potential locations, and calculating weighted scores to determine the most suitable option.

Steps in the Factor Rating Method:

1. Identify Factors:
Select a set of factors that are important for the location decision (e.g., transportation costs, labor availability, proximity to customers, etc.).
2. Assign Weights to Each Factor:
Assign a weight to each factor based on its relative importance to the business. The weights should sum to 1 or 100%.
3. Rate Each Location:
Rate each location on each factor on a scale, often from 1 to 10, where a higher score indicates a better performance on that factor.
4. Multiply Scores by Weights:
Multiply the rating for each location by the weight of each factor to calculate the weighted score for each factor.
5. Sum the Weighted Scores:
Add the weighted scores for each location to get a total score for each location.
6. Compare Locations:
The location with the highest total score is considered the best location based on the weighted criteria.

Example:

Let's say we are choosing between three locations (A, B, and C) based on three factors: transportation costs, labour availability, and proximity to customers. Here's a simplified example:

Factor	Weight	Location A	Location B	Location C
Transportation Costs	0.40	8	6	7
Labor Availability	0.30	7	9	6
Proximity to Customers	0.30	6	8	9

Now, calculate the weighted scores:

- Location A: (8 × 0.40) + (7 × 0.30) + (6 × 0.30) = 3.2 + 2.1 + 1.8 = 7.1
- Location B: (6 × 0.40) + (9 × 0.30) + (8 × 0.30) = 2.4 + 2.7 + 2.4 = 7.5
- Location C: (7 × 0.40) + (6 × 0.30) + (9 × 0.30) = 2.8 + 1.8 + 2.7 = 7.3

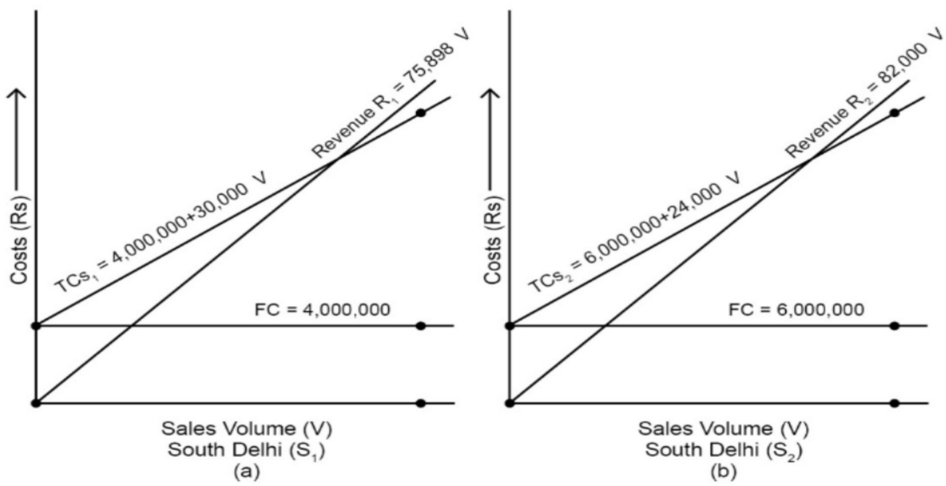
Based on the scores, Location B would be the best choice because it has the highest score (7.5).

Locational Break-Even Analysis

Sometimes, it is useful to draw location break-even charts which could aid in deciding which location would be optimal. The location of a Tractor factory in a South Delhi site will result in certain annual fixed costs, variable costs and revenue. The figures would be different for a South Bombay site. The fixed costs, variable costs and price per unit for both sites are given below:

Cost Data

Location Site	Fixed Costs	Variable Costs per unit	Price per Unit
South Delhi (S_1)	40,00,000	30,000	75,898
South Bombay(S_2)	60,00,000	24,000	82,000



Let us assume that the expected sales volume as estimated by a market research team is 95. The data of Table is depicted pictorially in Figure I showing the location break- even charts. Now the break-even point is defined to be the point or volume where the total costs equal total revenue. Thus for each site S1 and S2, the break-even point can be determined by using a simple formula (which could be easily derived) as follows:

$$\text{Break-even Volume (BE)} \frac{\textit{Fixed Costs}}{(\textit{Revenue per Unit} - \textit{Variable Cost perUnit})}$$

At the South Delhi Location S_1

$$BE = \frac{40,00,000}{75,898-30,000} = 87.1497 = 88 \text{ tractors}$$

and at the South Bombay location S_2

$$BE = \frac{60,00,000}{82,000-24,000} = 103.448 = 104 \text{ tractors}$$

Let us see what would be the profit or loss for the two sites at the expected volume of 95 Units. The calculations are shown:

Cost Comparisons

South Delhi (S_1)			South Bombay(S_2)		
Cost			Cost		
	Fixed	40,00,000		Fixed	60,00,000
	Variable	28,50,000		Variable	22,80,000
	68,50,000			82,80,000	
Revenue			Revenue		
	75,898 × 95 =72,10,310			82,000 × 95 =77,90,000	
Profit	= (72,10,310-68,50,000		Loss	=(77,90,000-82,80,000)	
	= 1,80,155			= 4,90,000	

Now what do we find? The South Delhi (S1) site is preferable, even though the revenues are lower, since the Company will lose money by locating the plant in south Bombay (S2).

SOME QUANTITATIVE MODELS FOR FACILITY LOCATION

Various types of quantitative models (or operations research models) have been used to help determine the best facilities location. Let us describe a few models that are simple to understand and powerful enough to give some good answers that could aid you in taking a location decision.

Median Model

Let us discuss the simple median model which is based on the assumption that the mode of interaction or the path of movement/transportation of load is done on a rectangular/rectilinear pattern. The movement is similar to the movement of ‘rooks’ on a chess board. Thus all

movements are made horizontally along and east-west and/or vertically in a north-south direction.
Diagonal moves are not considered.

Dr= Rectilinear Distance Between a new facility P(X,Y) and an anciliary existing facility A(ai,bi)

$$= |X - a_i| + |Y - b_i|$$

$$\text{(TC)Total Transportation Cost} = \sum_{i=1}^{m} L_i \times D_i \times \text{Cost/unit distance/unit load}$$

Where Li is the number of loads to be moved between the new facility to be located and the ancillary existing ith Facility (say raw material sources ormarketdistributionoutletpoints),Diistherectilineardistancebetween anew facility and ith existing facility and m is the number of ancillary existing facilities.
Thus as a location analyst, we essentially want to determine the least transportation cost location solution. The simple median model can help answer this question by using these three steps.

i) Identify the median value of the total number of loads moved.
ii) Find the X-Coordinate value of the existing facility that ends (or receives) the median load and
iii)Find the Y-coordinate value of the existing facility that ends (or receives) the median load.

The X and Y values found in steps (ii) and (iii) define the desired optimal (best) location of the new facility.

The Gravity Model

The technique determines the low cost 'Centre of Gravity' location of a new facility with respect to the fixed ancillary existing facilities like source suppliers (S1S2 etc.) and distribution points (D1, D2, etc.) for which each type of product consumed or sold is known. The only difference between the Median model and the Gravity model is that the mode of interaction between the single new facility and the existing facilities. In this case we assume that all goods move in straight line joining the ancillary facilities and the new facilities. This is so-called 'Euclidean' mode of interaction and is in fact the shortest distance between the two reference points. The diagonal movements are allowed here.

Thus De = Euclidean Distance = [(X- ai)2+(Y- bi)2]1/2
TCe(Total transportation cost)(Euclidean case)

$$= \sum_{i=1}^{m} \text{Li}[/X - ai/^2 + /Y - bi/^2]^{1/2} \times \text{ cost / unit distance / unit load}$$

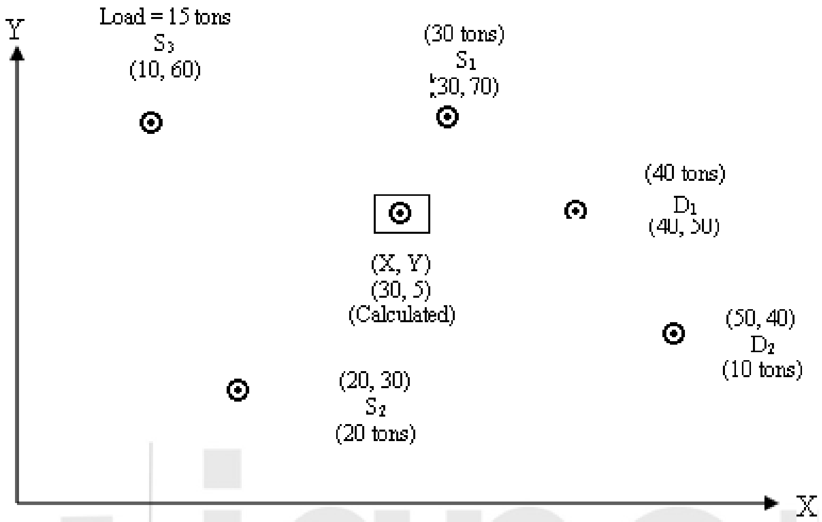
The value of X and Y can be calculated as follows

$$\text{x} = \frac{\sum_{i=1}^{m} L_1(a_i)}{\sum_{i=1}^{m} L_i} \text{ and y} = \frac{\sum_{i=1}^{m} L_i(b_i)}{\sum_{i=1}^{m} L_i}$$

The application of median model and gravity model will be illustrated in the following Example.

Example: A new processing point is to be located which will be receiving certain raw materials from three supply sources S1, S2 and S3 and will be sending its finished products to two distribution points D1 and D2. The coordinate locations of the sources and distribution points and loads are:

shown in below Fig. Find out the best location of the new processing point by using both median model and gravity model and also find out the total cost of transportation for the above two models if the rate is rupees 2 per unit distance per ton of load.



Solution-Median Model:

Total load moved = 30 + 20 + 15 +10 +40 = 115 tons
The median number of loads is the value that has half an equal number of loads above and below it which is equal to tons.

Next put the X-coordinate of existing facilities in Ascending Oder, these are:

S_3	S_2	S_1	D_1	D_2
(10, 60)	(20,30)	(30,70)	(40,50)	(50,40)
(15t)	(20t)	(30t)	(40t)	(10t)

Loads 1t to 15t are shipped from S3 at x3 = 10 Loads 16t to 35t are shipped from S2 at x2 = 20 Loads 36t to 65t are shipped from S1 at x1 = 30
Since the median load 58t falls in the interval 36t to 65t, therefore X = 30 (X- coordinate of the new facility).

Again put the Y-coordinates of existing facilities in Ascending order, these are:

S_2	D_2	D_1	S_3	S_1
(20, 30)	(50,40)	(40,50)	(10,60)	(30,70)
(20t)	(10t)	(40t)	(15t)	(30t)

Loads 1t to 20t are shipped from S2 at y2 = 30
Loads 21t to 30t are shipped to D2 at y2 = 40
Loads 31t to 70t are shipped to D1 at y1 = 50

Sincemedianload58tfallsintheinterval31tto70t,thereforeY=50(Y- coordinate for the new facility)

TransportationcostfromS_1tonew facility

$$= 30\{|X - x_1| + |Y - y_1|\} \times 2 = 30\{|30 - 30| + |50 - 70|\} \times 2 = 30 \times 20 \times 2 = Rs.1200$$

Transportation cost from S_2 to new facility = Rs. 1200

Transportation cost from S_3 to new facility = Rs. 900

Transportation cost from new facility to D_1 = Rs. 800

Transportation cost from new facility to D_2 = Rs. 600

Total cost = Rs. 4700

The median model is very simple to operate but it could suffer from the following disadvantages

(a) It assumes that only one single new facility is to be located.
(b) Every point in the (x, y) plane has been assumed to be an eligible point for the location of the new facility. (There may be some restriction or constraints at some point in the x-y plane)
(c) The median model is valid when the movement is based on a rectilinear mode only.

Gravity Model

$$X = \frac{x_1 \times \text{Load}_1 + x_2\text{Load}_2 + x_3\text{Load}_3 + \cdots}{\text{Load}_1 + \text{Load}_2 + \text{Load}_3 + \cdots}$$

$$= \frac{10 \times 15 + 20 \times 20 + 30 \times 30 + 40 \times 40 + 50 \times 10}{15 + 20 + 30 + 40 + 10}$$

$$= \frac{3550}{115} = 30.87$$

$$Y = \frac{y_1 \times \text{Load}_1 + y_2 \times \text{Load}_2 + y_3 \times \text{Load}_3 + \cdots}{\text{Load}_1 + \text{Load}_2 + \text{Load}_3 + \cdots}$$

$$= \frac{60 \times 15 + 30 \times 20 + 70 \times 30 + 50 \times 40 + 40 \times 10}{15 + 20 + 30 + 40 + 10}$$

$$= \frac{6000}{115} = 52.17$$

$$PQ = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

$$\text{Transportation cost} = \Sigma\text{load}\left\{\sqrt{(X-x_i)^2+(Y-y_i)^2}\right\} \times \text{ Rs. } 2/\text{ unit dist / ton}$$

$$= \Big[30\sqrt{(30.87-30)^2+(52.17-70)^2} + 20\sqrt{(30.87-20)^2+(52.17-30)^2}$$

$$+15\sqrt{(30.87-10)^2+(52.17-60)^2} + 40\sqrt{(30.87-40)^2+(52.17-50)^2}$$

$$+10\sqrt{(30.87-50)^2+(52.17-40)^2}\Big] \times 2$$

$$= [30 \times 17.85 + 20 \times 24.69 + 15 \times 22.29 + 40 \times 9.38 + 10 \times 22.67] \times 2$$
$$= (535.50 + 493.80 + 334.35 + 375.20 + 226.70) \times 2 = 1965.55 \times 2$$

$$= \text{Rs. } 3931.10 < \text{ Rs. } 4700 \text{ of median model.}$$

It will be seen that for the same data of the problem, gravity model provides less transportation cost compared to median model. You would have noticed that we have only discussed the location problems dealing with just a single new facility and also what is termed as a **minimum** objective of minimizing the sum weighted appropriate distances. There could be cases when the location as determined above turn out to be non-feasible, because of existence of certain restrictions or limitations. Methods are available for drawing iso-cost contour lines which aid the decision maker to take subsequent appropriate decisions. Some times a minimax objective might be more suited in which case the location analyst attempts to minimize the maximum weighted appropriate distances. Such a criterion would be applicable in emergency like facility location problems of fire stations, hospitals etc. Minimum objective situations are appropriate for locating factories and warehouses etc.

You would have observed that facilities location decision is based on a set of factors some of which are tangible/objective whereas some others are intangible/ subjective in nature. Objective Factors are those that can be evaluated in inventory terms such as labour, raw materials, utilities and taxes etc. Subjective Factors are characterized by a qualitative type of measurement. For example the nature of community support may be evaluated but its monetary equivalent cannot be established. Similarly research climate, recreation and entertainment, housing and community attitude etc. are also subjective factors. **Brown and Gibson** have proposed a composite location measure to aid the decision makers.

Composite Location Measure Model – 2 (Brown Gibson Model)

Let us now discuss Brown Gibson Model which provides a composite location measure of the objective and subjective factors. We illustrate the procedure with the help of an example with some steps.

Step – 1
First of all identify the factors that deserve to be included in the study and determine which of these must be absolutely satisfied, e.g, there is no point in choosing a site having scarcity of water whereas the plant requires an abundant water supply. Rest of the steps will be explained in the solution to the Example

Example (Brown Gibson Model) We have the following data for the three possible sites 1,2 and 3 with annual cost(in thousand of Rs) for each in respect of labour , marketing ,utilities and taxes:

Annual costs in thousands of rupees

Site (i)	Labour	Marketing	Utilities	Taxes	Total Ci
1	248	181	74	16	519
2	211	202	82	8	503
3	230	165	90	21	506

The subjective factors for the sites include housing, recreation and competition. We deal with the subjective intangible factors with the help of a forced pair-wise comparison rating method. The procedure is applied to rank the importance of the factors Ik (Ik is the Property weight – weight of a subjective factor k relative to all subjective factors, (0 < 1k < 1) first and is then applied to each site to rate how well the site satisfies the factors Sik (Sik is the site weight – weight of the site i relative to all potential sites for subjective factors k, 0 <Sik< 1. These two ratings are combined to obtain the subjective factor (SFi) ranking for each site as SFi = ∑(Ik.Sik). The factor comparison is shown in pairs. If one factor is preferred over the other , the one preferred is given 1(one) point whereas the other factor is given 0(zero) point. If one is indifferent between the two factors, 1(one) point each can be assigned as seen in decision 3 while comparing factor B and C in the given tables.
You are required to make selection for the most preferred site.

Let us derive an objective factor (OFi) for the ith location site by multiplying that site's rupees cost (Ci) by the sum of reciprocal of all the costs $\sum\left(\frac{1}{C_1}\right)$ and take the inverse of the product $OF_i = [C_i \times \sum(1/C_i)]^{-1}$

We have $\sum(1/C_i) = 1/519 + 1/503 + 1/506 = 0.005891$
$OF_1 = (519 \times 0.005891)^{-1} = 0.3271$
$OF_2 = (503 \times 0.005891)^{-1} = 0.3374$
$OF_3 = (506 \times 0.005891)^{-1} = 0.3355$
Now we shall deal with the subjective factors I_k and S_{ik}

(Determination of I_k)

Factor	Comparison Decision			Sum of preferences	Factors Rating(I_k)
	1	2	3		
A:Housing	1	1	-	2	2/4=0.50
B:Recreation	0	-	1	1	1/4 =0.25
C:Competition	-	0	1	1	1/4 =0.25
				Total=4	Total=1.0

Factor A-Housing

Site	Decision			Total	S_{Ak}
	1	2	3		
1	1	0	-	1	1/3=0.33
2	0	-	0	1	0
3	-	1	1	2	2/3=0.67

Factor B-Recreation

Site	Decision			Total	S_{Bk}
	1	2	3		
1	0	0	-	0	0
2	1	-	1	2	0.67
3	-	1	0	1	0.33

Factor C-Competition

Site	Decision			Total	S_{Ck}
	1	2	3		
1	1	0	-	1	0.25
2	1	-	0	1	0.25
3	-	1	1	2	0.50

Summary of subjective factors

Site	Site Rating			Importance
	1	2	3	
A	0.33	0	0.67	0.50
B	0	0.67	0.33	0.25
C	0.25	0.25	0.50	0.25

We can now calculate the subjective factor value SFi for each site as follows:

$$SF_1 = (0.50) \times (0.33) + (0.25) \times (0) + (0.25) \times (0.25) = 0.2275$$
$$SF_2 = (0.50) \times 0 + (0.25) \times (0.67) + (0.25) \times (0.25) = 0.2300$$
$$SF_3 = (0.50) \times (0.67) + (0.25) \times (0.33) + (0.25) \times (0.50) = 0.5425$$

Now depending upon the parties concerned, would depend the objective factor decision weight (X) which is given to the objective versus subjective factors. Objective factors being more important than subjective ones, we give a 2/3 weightage to objective and only 1/3 weightage to subjective factors i.e. X=0.67.

The value of X may be variated according to the situation of objective & subjective factors such as availability of raw materials, labour, utilities and extent of taxes levied and environmental condition, research climate, housing facilities and community attitude etc.

The composite location measures(LM_i)=(X)(OF_i)+(1–X)(SF_i)

LM1 = 0.67 × 0.3271 + 0.33 × 0.2275 = 0.29433

LM2 = 0.67 × 0.3374 + 0.33 × 0.2300 = 0.30203

LM3 = 0.67 × 0.3355 + 0.33 × 0.5425 = 0.4038 (max)

Obtaining the maximum score of 0.4038, site 3 is the obvious preferred site.

Brown Gibson modified model

The following table shows the various subjective factors of the six possible sites along with their annual costs in thousands of rupees. You are required to determine the most preferred site amongst the six sites mentioned below.

Site	Objective factor cost(OFi) in thousand Rs	Availability of Transportation	Availability of labour	Managerial control	Support of community
1	3.0	Good	Good	Fair	High
2	5.5	Excellent	Fair	Good	Very high
3	4.1	Good	Good	Excellent	Good
4	3.5	Low	Very Good	Good	Low
5	3.9	Good	Fair	Very Good	High
6	3.2	Very Good	Excellent	Very Good	Very High

Solution: The objective facto r measure for site i,OFi in terms of the objective function costs is defined as follows:

$$OFi = \frac{\text{Maximum OF} - OF_i}{\text{Maximum OF} - \text{Minimum OF}}$$

For example forsite3we haveOF3=(5.5 –4.1)/(5.5-3.0)=0.56

SimilarlyOF1 = 1.00,OF2=0.00,OF4= 0.80,OF5=0.64 andOF6=0.92

The subjective factor measure $SF_i=\sum(Ik.Sik)$ where Ik is the property weight – weight of subjective factors k relative to all subjective factors, Sik is the site weight – weight of the site i relative to all sites for subjective factor k.

Assumptions – As per the opinion of the manager in charge of the project and also by group consensus, the percentage contribution of the subjective factors and also the rating scale of these factors have been finalized as below:

Contribution	%		Rating scale
Availability of transportation	= 20 %	Very high/Excellent	= 1.00
Availability of labour	=30%	High/Very Good	= 0.75
Managerial control	= 30%	Good	= 0.50
Support of community	= 20%	Fair	= 0.25
		Low	= 0.00

Objective Factors Decision Weight(X) is taken to be equal to 0.67

Calculation of Subjective Factor Measure

Site	Availability of transportation (0.20)	Availability of labour (0.30)	Managerial control (0.30)	Support of community (0.20)	Subjective factor measure
1	0.50	0.50	0.25	0.75	0.340*
2	1.00	0.25	0.50	1.00	0.625
3	0.50	0.50	1.00	0.50	0.650

4	0.00	0.75	0.50	0.00	0.375
5	0.50	0.25	0.75	0.75	0.550
6	0.75	1.00	0.75	1.00	0.875

*0.2× 0.50 +0.3 × 0.50+0.3 × 0.25 + 0.2×0.75= 0.340

Location Measure for six sites (X=0.67taken)

Site	**jective factor measure**	**Subjective factor measure(FromTable15)**	**Location measure**
1	1.00	0.340	0.782**
2	0.00	0.625	0.206
3	0.56	0.650	0.590
4	0.80	0.375	0.660
5	0.64	0.550	0.611
6	0.92	0.875	**0.905(Max)**

**0.67 × 1.00 + 0.33 × 0.340 = 0.782

Site 6 produces the largest overall location measure and hence this Site 6 is the preferred choice.
Note: The decision for the choice of scale and relative importance of the subjective factors is commonly based on managerial judgement that requires a careful analysis of the trade-off between cost and combined effect of the dictating factors.

Bridgeman's Dimensional Analysis : The comparison and selection of a site is very easy in case all the costs were tangible and quantifiable and the least cost site would have been the obvious choice. In most cases, however, there are many intangible costs which may be better expressed in relative terms rather than absolute terms. For example, educational facilities for children or lack of it at a site is difficult to quantify in absolute term but relative merits/demerits of two alternative sites can be compared more easily. One site may be said to have a facility twice as good as the other site. Since both tangible and intangible costs need to be considered for the selection of a site, a procedure of comparing relative merit of alternative sites requires to be worked out and Bridgeman's Dimensional Analysis is the answer.

It consists in computing the relative merits (or cost ratios) for each of the cost items giving every ratio an appropriate weightage by means of the power (index) raising and then multiplying these weighted ratio together to come up with a comprehensive figure. This figure gives the relative merit of the two alternate sites. Thus if X11, X12, X13. are the different costs associated with site M and X21, X22,X23.. are the different costs associated with site N and w1,w2,w3 are the weightages given to these items, then the relative merit of site M and site N is given by:

$$R_{MN} = \left(\frac{X_{11}}{X_{12}}\right)^{w_1} \times \left(\frac{X_{21}}{X_{22}}\right)^{w_2} \times \left(\frac{X_{31}}{X_{32}}\right)^{w_3}$$

If RMN> 1 then site N is superior
If RMN <1 then site M is superior

The examples that follow would make understanding quite clear.

A five point scale for dimensional analysis is developed for Reasearch Climate, Labour Supply, Community Attitude and Community Services. The scores range from 1 to 5 from the best to the worst conditions. The scores could be determined by the manager in-charge of the project and by the group consensus. The decision is commonly based on managerial judgement that requires a careful analysis of the trade-off between the cost and the combined effect of the subjective and the objective factors.

Example: The following dimensional analysis is given for selecting the best site out of the two with their tangible and intangible factors. Select the preferred one by Bridgeman's Analysis.

Factor	**Site**		**Weight**
	M	N	
Labour	Rs. 1,50,000	Rs. 1,00,000	1
Power	Rs. 40,00,000	Rs.25,00,000	1
Educational facilities	2	6	2
Communityattitude	2	4	2

Solution: Relative cost of site M to site N is

$$R_{MN} = \left(\frac{1{,}50{,}000}{1{,}00{,}000}\right)^1 \times \left(\frac{40{,}00{,}000}{25{,}00{,}000}\right)^1 \times \left(\frac{2}{6}\right)^2 \times \left(\frac{2}{4}\right)^2$$

=0.066<1.00 so site M is preferred.

Although the tangible costs for site M are higher than those for site N, the effect of the intangibles is seen to be overwhelming. In practice such things do happen. There are many reasons other than quantifiable costs which go into the choice making between alternate sites. However when such choice is important from the national or social point of view, then choice of the intangibles and weightages attached to them assumes a critical importance.

Example: The intangible and tangible figures for the three sites S1, S2 and S3 are given below in a tabular form. Make out your calculations by Bridgeman's Dimensional Analysis to select the best site out of the three.

Factors	**Sites**			**Weight**
	S_1	S_2	S_3	
Building cost and Equipment cost(Rs.)	25,00,000	15,00,000	20,00,000	4
Taxes per year (Rs)	2,50,000	1,00,000	1,80,000	4
Power cost per year Rs.	1,00,000	1,50,000	1,20,000	4
Community attitude	2	4	3	1
Labour Supply	4	6	5	3
Research Climate	5	30	20	2

$$R_{12} = \left(\frac{25}{15}\right)^4 \times \left(\frac{25}{10}\right)^4 \times \left(\frac{10}{15}\right)^4 \times \left(\frac{2}{4}\right)^1 \times \left(\frac{4}{6}\right)^3 \times \left(\frac{5}{30}\right)^2 = 0.045 < 1 \text{ hence site 1 is better than 2}$$

$$R_{13} = \left(\frac{25}{20}\right)^4 \times \left(\frac{25}{18}\right)^4 \times \left(\frac{10}{12}\right)^4 \times \left(\frac{2}{3}\right)^1 \times \left(\frac{4}{5}\right)^3 \times \left(\frac{5}{20}\right)^2 = 0.092 < 1 \text{ hence site 1 is better than 3}$$

$$R_{23} = \left(\frac{15}{20}\right)^4 \times \left(\frac{10}{18}\right)^4 \times \left(\frac{15}{12}\right)^4 \times \left(\frac{4}{3}\right)^1 \times \left(\frac{6}{5}\right)^3 \times \left(\frac{3}{2}\right)^2 = 0.378 < 1 \text{ hence site 2 is better than 3}$$

From the above analysis, we conclude that the over all choice is site 1.

5.5 RECENT TRENDS IN FACILITY LOCATION

The following most important trends have come to fore recently with regards to plant location.

1) To locate the plant away from cities.
2) Development of industrial estates.
3) Competition among states to develop industries.
4) Trends towards decentralization.
5) Pollution control
6) Location of industries leading to balanced regional development
7) Growth of multinational firms thereby transcending the geographical area of the country.

5.6 SUMMARY

Plant location is not a static decision that can be made and forgotten. Plant layout/facility layout choices follow the location decisions. They influence the type of equipment and level of technology employed the flow of work and the design of jobs, inventory levels and other operating characteristics of the firm. Layout can be changed more easily than locations. However, they represent more of a continuing concern. In addition, they fall more directly within the responsibility of operations manager. Quantitative models of facility location.

5.7 KEY WORDS: PLANT LOCATION, COST REDUCTION, MARKET ANALYSIS.

5.8 SELF-ASSESSMENT QUESTIONS

1. Discuss about Multi Facility location problem with appropriate illustrations to solve the same.
2. What are the factors influencing plant location?
3. Explain the procedure developed in solving the single facility location problem with appropriate illustrations.
4. Every entrepreneur is faced with the problem of deciding the best site for location of his plant or factory. Comment.
5. A company planning to manufacture tennis racquets has to decide on the location of the plant. Three locations are being considered viz. Mysore, Bangalore and Hosur. The fixed costs at the three locations are estimated to be Rs.30 lakhs, 50 lakhs and 25 lakhs per annum respectively. The variable cost are Rs.300, Rs.200 and Rs.350 per unit respectively. The expected sales price of the tennis racquet is Rs.700 per unit. Find out (i) the range of annual production /sales volume for which each location is the most suitable and (ii) which one of the three is the best location at a production / sales volume of 18000 units.
6. Explain the Brown and Gibson Method of facilities' location with an example. Also discuss multi plant location analysis.

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LESSON-6
LAYOUT PLANNING – PLANNING AND PRINCIPLES OF LAYOUT, CLASSIFICATION OF PLANT LAYOUT

LEARNING OBJECTIVES

By the end of this lesson, learners will be able to:

1. Know about plant layout concept and its objectives.
2. Learn about principles of plant layout.
3. Know about plant layout planning procedure and its different types.

Structure of the Lesson:

6.1 PLANT LAYOUT - CONCEPT

After deciding the proper site for locating an industrial unit, next important point to be considered by an entrepreneur is to decide about the appropriate layout for the plant. Plant layout is primarily concerned with the internal set up of an enterprise in a proper manner. The concept of plant layout is not static but dynamic one. It is on account of continuous manufacturing and technological improvements taking place necessitating quick and immediate changes in production processes and designs. A new layout may be necessary because of technological changes in the products as well as simple change in processes, machines, methods and materials".

"Plant layout is the arrangement of machines, work areas and service areas within a factory".

- George R. Terry.

"Plant layout involves the development of physical relationship among building, equipment and production operations, which will enable the manufacturing process to be carried on efficiently". - Morris E. Hurley.

6.2 OBJECTIVES OF PLANT LAYOUT

The primary objective of plant layout is to maximize production at minimum cost. The layout should be designed in such a way that it is flexible to change according to new processes and production techniques. The layout should be able to satisfy the needs of all those who are associated with the production system such as workers, supervisors, managers etc., to fulfill the above goals, the plant layout should be designed with the following objectives:

- Minimizing handling of materials.
- Maintaining flexibility of operations.
- Ensuring optimum utilization of men, materials, equipment and available space.
- Achieving good workflow and avoiding accumulation of work.
- Minimizing delays and bottlenecks in the production system.
- Ensuring safety of workmen by minimizing and eliminating the chances of accidents.
- Providing for effective supervision and production control.
- Minimizing work-in-process inventory.
- Providing sufficient and conveniently located service centres.
- Flexibility in design to adapt to the changing future requirements.

6.3 Principles of Plant Layout:

While designing the plant layout, the following principles must be kept in view:

- **Principle of minimum movement:** Materials and labour should be moved over minimum distances; saving cost and time of transportation and material handling.
- **Principle of space utilization:** All available cubic space should be effectively utilized – both horizontally and vertically.
- **Principle of flexibility:** Layout should be flexible enough to be adaptable to changes required by expansion or technological development.
- **Principle of interdependence:** Interdependent operations and processes should be located in close proximity to each other; to minimize product travel.
- **Principle of overall integration:** All the plant facilities and services should be fully integrated into a single operating unit; to minimize cost of production.
- **Principle of safety:** There should be in-built provision in the design of layout, to provide for comfort and safety of workers.
- **Principle of smooth flow:** The layout should be so designed as to reduce work bottlenecks and facilitate uninterrupted flow of work throughout the plant.
- **Principle of economy:** The layout should aim at effecting economy in terms of investment in fixed assets.
- **Principle of supervision:** A good layout should facilitate effective supervision over workers.
- **Principle of satisfaction:** A good layout should boost up employee morale, by providing them with maximum work satisfaction.

6.4 FACTORS AFFECTING PLANT LAYOUT:

The major factors which influence the nature of layout of plant in any type of production system are as follows:

Human Factor

It is the most important factor of production system. It arranges, coordinates and integrates physical infrastructure, machines, equipment and materials for effective conversion. Human factor is most critical as well as highly flexible element of production system which may decide about the facilities and their arrangements.

Nature of Material to be Used

Material takes three aspects during manufacturing. The incoming material is in raw form and has own shape and size. During process its form is changed and waste produced. The material in process has to move from machine to machine. The final product has a different form. The plant layout will have to be based on ease of handling and safety at each stage.

Machine—Their Types and Sizes

Machines, their types and sizes dictate the types of plant layout. Machines are required for processing of materials, testing and inspection. Some equipment are needed for repairs. All the machines are identified and then placed as per the requirement.

The first three factors, viz. human, material and machines are basics of physical facility.

Movement of Men and Material

It is related to movement of men, machines and materials, besides information flow for the purpose of effective communication within the industries and outside. This factor of plant layout is generally concerned with different types of movement in production system.

Building Layout

It is another important factor in the process of plant layout design as well as in the installation. Basically, plant building is a shell which houses the basic facility and other supporting services. It includes every factor inside as well as outside which is related to plant building design and building utility distribution system.

Service Factor

Several activities are carried out in a plant which indirectly contribute to production. Many of them require specialized equipment and machines which have to be moved on shop floor. These activities include:

(i) Maintenance of plant.
(ii) Quality control.
(iii) Inspection of product.
(iv) Control of wastage.
(v) Scheduling.
(vi) Material handling.
(vii) Dispatching.
(viii) Fire protection.
(ix) Facilities for employees.

6.5 PLANT LAYOUT PLANNING PROCEDURE:

Plant layout exercise requires a systematic approach. The procedure requires the following steps:

Step 1 - Information Collection

The following data are to be collected:

(i) Volume and rate of production.
(ii) Production specifications and bill of materials.
(iii) Process sheets indicating tools, equipments and methods.

(iv) Flow process charts.
(v) Standard time to complete the operation.

Step 2 - Analysis and Coordination
The information collected is used to decide the following:
(i) The work force size and type.
(ii) Number of work stations required.
(iii) Types of equipment required.
(iv) Storage and other space requirement

Step 3 - Choice of Machinery and Equipment
The machinery and equipment needed for the production service is to be decided on the basis of following:
(i) Number of components to be produced.
(ii) Capacity of each equipment.
(iii) Time in which a particular work order is completed.

Step 4 - Selection of Material Handing System
The selection is based on the following factors.
(i) Material/products to be moved.
(ii) Container in which it will be moved.
(iii) Length of movement
(iv) Speed of movement.

Step 5 - Sketching the Plant on the Plot
Sketching the plant on the plot, building out line, roads, storage and service areas, etc. are marked on the available plot. It must be kept in mind that the orientation of plant should utilize maximum natural head, light and other weather conditions.

Step 6 - General Flow Pattern
The next step is laying out the details of shop areas as follows:
(i) Machinery may be laid as per production process requirements, and plant building be constructed around the same.
(ii) Flow pattern of materials should be such that the distance involved is least between the store and shipping department through the production centers. There should be minimum backtracking and bottleneck.
(iii) Flow pattern may be analyzed using operation process charts or flow process charts.

Step 7 - Individual Work Stations Design
Each work station is laid for achieving optimum performance of operations, material and space utilization and safety and comfort of employees.

Step 8 - Assembly of the Individual Work Station Layout
The total assembly is made in accordance with the general flow pattern and the building facilities.

Step 9 - Storage Space Required
Storage space can be calculated by knowing volume of each stored item, number of items to be kept in stores and the time for each item to be kept in store.

Step 10 - Preparation of Flow Diagrams for Work Stations
After making flow diagrams the work stations are allocated to their respective areas of the plan.

Step 11 - Planning and Locating Service Areas
Service areas such as offices, toilets, wash rooms, rest and lunch room, cafeteria, dispensaries, power generation area, parking areas etc. are planned and located appropriately.

Step 12 - Making Master Layout
Master layout is prepared using templets and models.

Step 13 - Checking Final Layout
The final layout is checked for the safe and economical material handling, adequate production and production control, plant building and its surroundings, service areas, employees safety and comfort, etc.

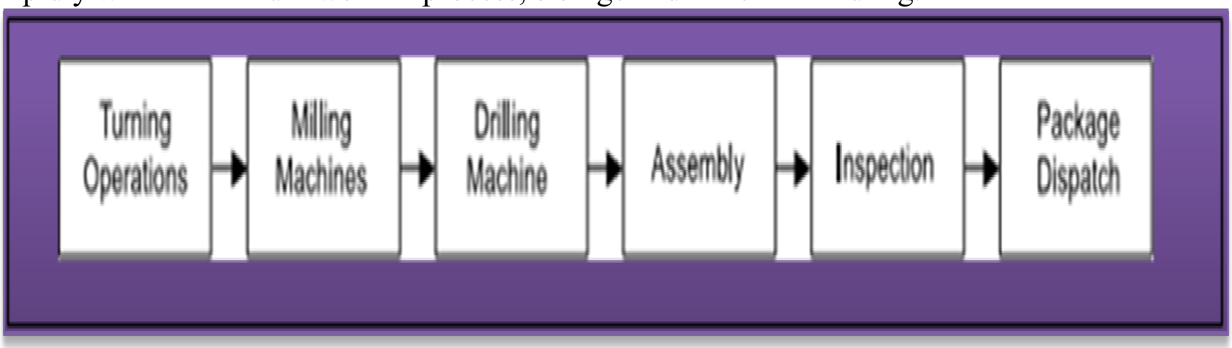
Step 14 - Approval of Layout
The finally checked layout has to be got officially approved from the concerned authorities.

6.6 TYPES OF PLANT LAYOUT:
Layouts can be classified into the following five categories:

- Product layout
- Process layout
- Combination layout
- Fixed position layout
- Service Facility layout

Product Layout (or Line Layout):

In this type of layout, all the machines are arranged in the sequence, as required to produce a specific product. It is called line layout because machines are arrange in a straight line. The raw materials are fed at one end and taken out as finished product to the other end. The raw material is supplied at one end of the line and goes from one operation to the next quite rapidly with a minimum work in process, storage and material handling.



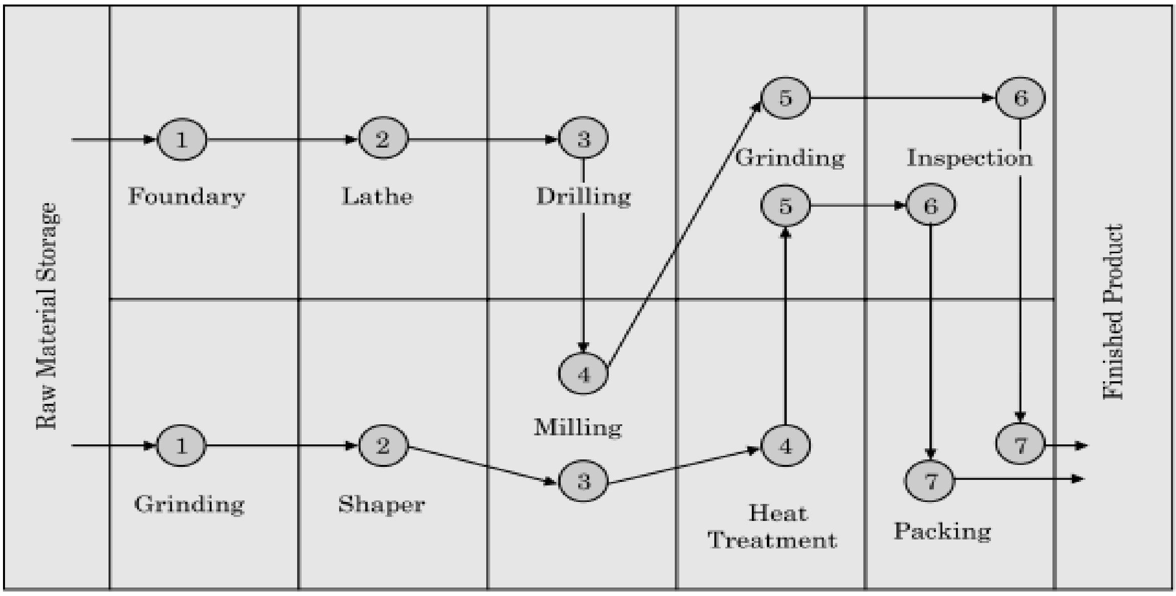
Advantages offered by Product Layout:
(i) Lowers total material handling cost.
(ii) There is less work in processes.

(iii) Better utilization of men and machines,
(iv) Less floor area is occupied by material in transit and for temporary storages.
(v) Greater simplicity of production control.
(vi) Total production time is also minimized.

Limitations of Product Layout:

(i) No flexibility which is generally required is obtained in this layout.
(ii) The manufacturing cost increases with a fall in volume of production.

Processor Functional Layout:



The process layout is particularly useful where low volume of production is needed. If the products are not standardized, the process layout is lower desirable, because it has creator process flexibility than other. In this type of layout, the machines and not arranged according to the sequence of operations but are arranged according to the nature or type of the operations. This layout is commonly suitable for non repetitive jobs.

Same type of operation facilities are grouped together such as lathes will be placed at one place; all the drill machines are at another place and so on. Therefore, the process carried out in that area is according to the machine available in that area.

Advantages of Process Layout:

(i) There will be less duplication of machines. Thus, total investment in equipment purchase will be reduced.
(ii) It offers better and more efficient supervision through specialization at various levels.
(iii)There is a greater flexibility in equipment and man power thus load distribution is easily controlled.
(iv)Better utilization of equipment available is possible.
(v) Breakdown of equipment can be easily handled by transferring work to another machine/work station.
(vi)There will be better control of complicated or precision processes, especially where

much inspection is required.

Limitations of Process Layout:

(i) There are long material flow lines and hence the expensive handling is required.
(ii) Total production cycle time is more owing to long distances and waiting at various points.
(iii) Since more work is in queue and waiting for further operation hence bottle necks occur.
(iv) Generally, more floor area is required.
(v) Since work does not flow through definite lines, counting and scheduling is more tedious.
(vi) Specialization creates monotony and there will be difficult for the laid workers to find job in other industries.

Comparison of product and process layout:

Factors	Product Plant layout	Process Plant layout
Nature	Sequence of facilities	Similar group of machineries together
Machines utilization	Not to full capacity	Better utilization
Product	Standardized	diversified
Processing time	Less	More
Material handling	Less	More
Inventory	Highwip	Low wip
Break down	Can't tolerate	Can tolerate
Flexibility	Low	High
Floor space	Requires less	Requires more
Investment	High	Low

Fixed Position Layout:

This type of layout is the least important for today's manufacturing industries. In this type of layout the major component remain in a fixed location, other materials, parts, tools, machinery, man power and other supporting equipment's are brought to this location.

The major component or body of the product remain in a fixed position because it is too heavyor too big and as such it is economical and convenient to bring the necessarytools and equipment's to work place along with the man power. This type of layout is used in the manufacture of boilers, hydraulic and steam turbines and ships etc.

Advantages of Fixed Position Layout:

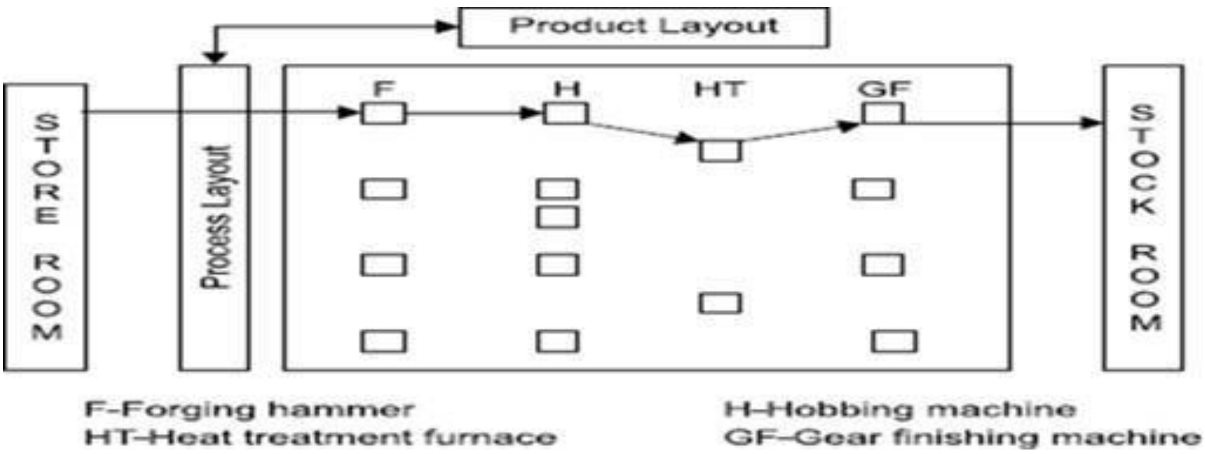
(i) Material movement is reduced.
(ii) Capital investment is minimized.
(iii) The task is usually done by gang of operators, hence continuity of operations is ensured.
(iv) Production centers are independent of each other. Hence, effective planning and loading can be made. Thus total production cost will be reduced.
(v) It offers greater flexibility and allows change in product design, product mix and production volume.

Limitations of Fixed Position Layout:

(i) Highly skilled man power is required.
(ii) Movementofmachinesequipment'stoproductioncentremaybetimeconsuming.
(iii) Complicatedfixturesmayberequiredforpositioningofjobsandtools.Thismayincrease the cost of production.

Combination Type of Layout:

Now a day in pure state any one form of layouts discussed above is rarely found. Therefore, generally the layouts used in industries are the compromise of the above mentioned layouts. Everylayouthasgotcertainadvantagesandlimitations.Therefore,industrieswouldtolike use any type of layout as such. Flexibility is a very important factory, so layout should be such which can be molded according to the requirements of industry, without much investment. If the good features of all types of layouts are connected, a compromise solution can be obtained which will be more economical and flexible.



In practice, plants are rarely laid out either in product or process layout form. Generally a combination of the two basic layouts is employed; to derive the advantages of both systemsof layout. For example, refrigerator manufacturing uses a combination layout.

Advantages:

- Component standardization rationalization.
- Effective machine operation and productivity.
- Customer service.
- It can decrease the paper work and overall production time.
- Work-in-progress and work movement.

Service Facility Layout:

Services facility layouts should provide for easy entrance to these facilities Large, well organized and well-designed walk ways to and from parking areas are some of the requirements of service requirements. Fundamental difference between service facility and manufacturing facility layouts is that many service facilities exist together customers and services. Examples; Hospitals – processing of physical materials and production efficiency Banks - customer receiving and servicing function.

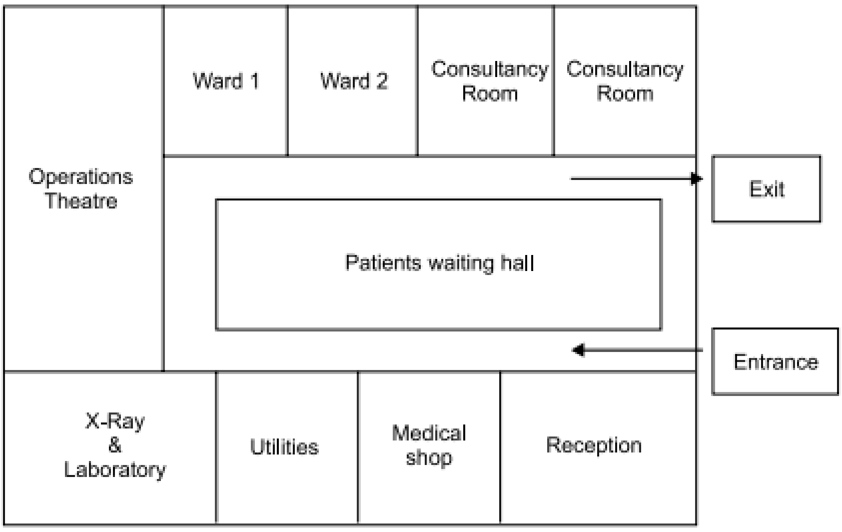


Fig: Service Layout of a Hospital

Group Layout (or Cellular Layout)

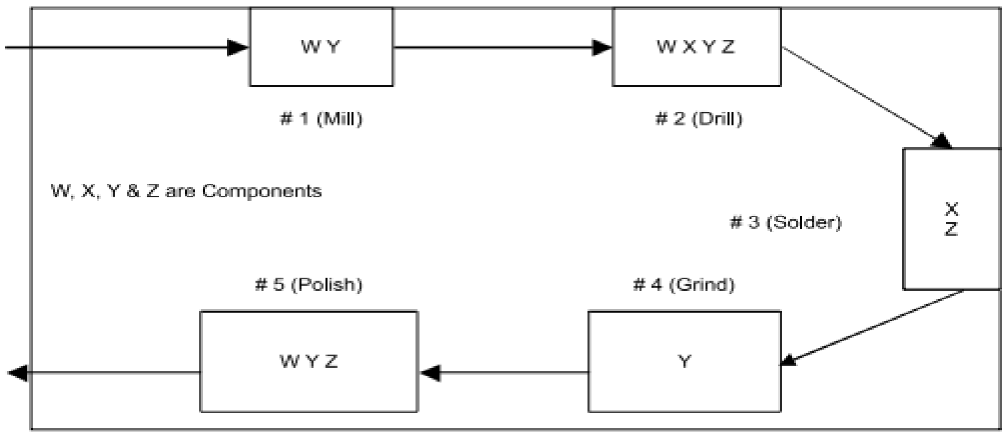
There is a trend now to bring an element of flexibility into manufacturing system as regards to variation in batch sizes and sequence of operations. A grouping of equipment for performing a sequence of operations on family of similar components or products has become all the important. Group technology (GT) is the analysis and comparisons of items to group them into families with similar characteristics. GT can be used to develop a hybrid between pure process layout and pure flow line (product) layout. This technique is very useful for companies that produce variety of parts in small batches to enable them to take advantage and economics of flow line layout.

The application of group technology involves two basic steps:

(i) first step is to determine component families or groups.
(ii) The second step in applying group technology is to arrange the plants equipment used to process a particular family of components.

This represents small plants within the plants.
The group technology reduces production planning time for jobs. It reduces the set-up time. Thus group layout is a combination of the product layout and process layout. It combines the advantages of both layout systems. If there are m-machines and n- components, in a group layout (Group-Technology Layout), the m-machines and n-components will be divided into distinct number of machine-component cells (group) such that all the components assigned to a cell are almost processed within that cell itself. Here, the objective is to minimize the inter cell movements.

The basic aim of a group technology layout is to identify families of components that require similar of satisfying all the requirements of the machines are grouped into cells. Each cell is capable of satisfying all the requirements of the component family assigned to it. The layout design process considers mostly a single objective while designing layouts. In process layout, the objective is to minimize the total cost of materials handling. Because of the nature of the layout, the cost of equipments will be the minimum in this type of layout. In product layout, the cost of materials handling will be at the absolute minimum. But the cost of equipments would not be at the minimum if the equipments are not fully utilized. In-group technology layout, the objective is to minimize the sum of the cost of transportation and the cost of equipments. So, this is called as multi-objective layout.



Advantages of Group Technology Layout

Group Technology layout can increase—

1. Component standardization and rationalization.
2. Reliability of estimates.
3. Effective machine operation and productivity.
4. Customer service.

It can decrease the—

1. Paper work and overall production time.
2. Work-in-progress and work movement.
3. Overall cost.

Limitations of Group Technology Layout

This type of layout may not be feasible for all situations. If the product mix is completely dissimilar, then we may not have meaningful cell formation.

6.7 SUMMAY

layout is primarily concerned with the internal set up of an enterprise in a proper manner. The concept of plant layout is not static but dynamic one. It is on account of continuous manufacturing and technological improvements taking place necessitating quick and immediate changes in production processes and designs.

6.8 Key Words: Plant Layout, Line layout, Combined layout, Fixed position Layout.

6.9 Self-Assessment Questions:

1. Explain process layout? State its advantages and disadvantages in brief.
2. Distinguish between product layout and process layout.
3. Explain the suitability of fixed position layout.
4. From the point of view of plant layout, name the three categories of classifying small business or unit.
5. Discuss about the various types of layouts with appropriate illustrations, its merits and demerits.

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LESSON-7
PRODUCTION PLANNING AND CONTROL

OBJECTIVES:

After Studying this unit, the learner will be able to:

- Understand in detail about production planning and control, its functions and related concepts.
- Comprehend and understand various types of production systems and to study how they operate. To appreciate their adoption in present day manufacturing.
- Understand and appreciate the modern manufacturing techniques like modular production, cellular production and group technology.
- Understand and apply the concepts of LOB and Line Balancing in batch and assembly line production.

STRUCTURE

7.1 INTRODUCTION

A production planning and control system is about planning and controlling of all facets of manufacturing, along with materials planning and control, scheduling machines and people, and coordinating suppliers and customers. Organisations utilize resources like employees, materials and production capacity etc., to manufacture products required by the present and potential customers. An effective production planning and control system is essential to the success of any organisation. Different types of production systems like project, batch, job shop, mass etc have their own type of production planning. Production planning is developing a plan for future. A production plan is developed by organizations for a specific period of time involving decisions related to product mix, resource allocation considering labour hours, materials, supply and demand, scheduling etc. While, production control is the activity of controlling and monitoring production or operational activities being performed in organizations. The functions of a production, planning and control system in an organization is as follows:

i. **Planning Phase**: Planning phase has two elements namely, prior planning and active planning. Prior planning can further be divided as forecasting, order writing and product design. While, active planning can further be divided as process planning and routing, material control, tool control, loading and scheduling of operations.
ii. **Action Phase**: In the action phase the actual work is started and plans are implemented. The function being performed at this stage is dispatching.
iii. **Control Phase**: This phase has two components namely, progress reporting and corrective action. Data processing is done in progress reporting stage while expediting and re-planning are carried out in control phase.

7.2 PRODUCTION PLANNING AND CONTROL

In a nut shell production planning and control has the following functions, namely, i) Estimating, ii) Routing, iii) Scheduling, iv) Loading v) Dispatching and vi) Expediting/ Progressing.

7.2.1 Estimating:

Deciding quantity of output to be produced, cost involved on the basis of sales forecast. Manpower, machinery, material requirements to meet the anticipated targets of production is determined. Bill of material is prepared listing items required for manufacturing the desired output.

Bill of Materials (BOM) is a document describing the details of an item's product build up, including all component items, their build up sequence, the quantity needed for each and the **work centers that perform the buildup sequence. The BOM identifies how each end product is** manufactured, specifying all sub-component items, their sequence and their quantity in each finished unit. This information is obtained from product design documents, work-flow analysis and other standard manufacturing and industrial engineering documentation. The primary information to the MRP from the BOM is the product structure.

7.2.2 Routing:

Sequence of operations to be performed in the production process is routing. Methods and techniques are decided in routing. Routing determines what work will be done on a product/part as well as where and how it will be done. Routing specifies the operations to be performed, their sequence and the proper types of machines, equipment and personnel required. Objectives of routing is to select the best and the cheapest method of work. Routing depends upon the nature of machines, efficiency of employees, availability of physical facilities and the type of manufacturing process.

In continuous process industry, route is standardized and fixed. In job order shop, each lot must be separately routed. Route is a path over which materials will travel in the course of their conversion into finished product. Separate route sheets may be prepared for the main product, sub-assemblies and each individual part.

Route sheet: written specification of the sequence of operations. Lays down the precise route through the plant that the given product will flow.
Route sheet contains: i) operations required and their desired sequence, ii) machine or equipment to be used for each operation and iii) estimated setup time and/runtime per piece. Route sheets are very useful in guiding operation for each part. Route sheets are used for calculation of schedule times for each production order and for recording progress through production. The processing steps or stages needed to create a product or do a job.

7.2.3 Scheduling:

It is the time phase of loading and determines when and in what sequence the work will be carried out. It fixes the starting as well as the finishing time for the job. Objectives of scheduling is to issue coordinated schedules to the plant so that the product is manufactured by the delivery date planned by the delivery date planned by the sales department. Lack of information concerning existing workload, lead-time, manufacturing time is the main obstacle in good scheduling. Scheduling ranks the job in order of its priority and provide for its release to the plant at the proper time and in the correct sequence.

Master schedule is one, which represents the overall production program for the plant for a given time period. It shows weekly/monthly breakup of production. Indicates the dates of completion of various jobs. It is prepared on the basis of sales forecast, route sheet, loading chart and delivery schedules promised.

7.2.4 Loading:

It is the cumulative amount of work currently assigned to a work center for future processing. Assigning or allocation of new jobs among the work centers, thus establishing load to be taken by each and every work center or department is known as loading. Machine loading is the assignment of specific jobs to specific machines keeping in views the properties and machine utilization. Allocation pf available work to the machines in a methodical way helps to complete each operation by the specified date.

7.2.5 Dispatching

It is the transition from planning to action phase. In this phase the employee is ordered to physically start the actual work. In dispatching, orders are issued in terms of their priority and work is assigned to operations. It determines by whom the work shall be done. It involves giving the necessary authority to start the work as per schedule. Work orders and authorizations are issued to the production department to perform work according to planned sequence using prescribed tools and pre-determined schedules. Dispatching department issues requisitions for materials and tools on the production order and checks to see that materials, parts and tools are available in time.

Dispatch section of ppc is responsible for:

- Collecting and issuing to supervisors the drawings, specifications, material lists, job tickets, route cards, requisitions etc.
- Ensuring that materials, parts, tools and other aids are made available to the manufacturing departments at right time.
- Obtaining inspection schedules and issuing them to the inspection dept.

- Informing the progress section that production is commencing.
- Releasing work orders for the start of manufacturing operations.
- At the end of manufacture, ensuring that all the drawings, layouts and tools are returned to their appropriate places.
- Dispatching may be centralized/decentralized.

7.2.6 Expediting/Progressing

It is the tracking of a job's progress and taking required special action to move the job through the facility on time. Progressing is ensuring that the work is carried out as planned and delivery dates are met obj. of progressing is to control variations or deviations from the programmed level. It ensures that production is proceeding according to plans. Continuous follow up procedure is created to monitor progress of work and to check / expedite the work centers falling behind schedules.

Progress chasers or expeditors are employed for this purpose. Their duties are:

a) To determine the causes of deviations from the program.
b) To assist in removing the problems causing the deviations
c) To maintain liaison with other departments supplying materials and components.
d) To authorize and sign requisitions.
e) To prepare a list of materials and components which are in short supply.

Progressing consists of:
Watching progress of work and reporting actual facts and conditions and deviations, if any.

- Physical control of work in progress through frequent checking.
- Expediting corrective action in case of deviations so that bottlenecks are removed at the earliest possible moment.
- Documents used in production control:
- Work order
- Material requisition
- Control sheet
- Internal delivery note
- Progress note/ move note
- Machine load chart
- Gantt chart/schedule
- Control graph
- Job ticket
- Control boards

i) **Work Order/ Marketing order**: Issued to authorize the plant to commence production contains information such as code no., description of the product, quantity, job no., material required, list of operations and process through which the product is routed together with the allowed time of theses. Work order is often called route card/route sheet because it lays out the sequence of operations or route taken by the product.
ii) **Material Requisition**: A document used to draw materials from the stores. An order to the store-keeper to issue the materials.
iii) **Control sheet:** Prepared for each batch of work. Control note proceeds through each process with the batch of work. Provides a record for scrap produced by each operation as

well as the good work forwarded for the next operation. It may be used as an internal delivery note at the final stage when the finished parts are kept into stores.

iv) **Internal delivery note**: a separate note is issued to deliver finished products, components, and even excess material into stores. It is a function opposite to that of the requisition. Known as "return to stores note".

v) **Progress note move note:** prepared after completion of each operation. State the no. of rejects and the no. Of good items forwarded.

vi) **Machine Load Chart**: Display the available capacity of a machine/workstation contains over load/under load of the machine or workstation's details.

vii) **Gantt milestone chart**

- A chart depicting work to be done
- Denotes interrelationships between & among all phases of work
- Shows coordination required between various phases of the projects
- One can easily show how long it will take to accomplish a specified project using Gantt chart

Gantt Chart shows:

- Interrelationships between milestones within the same task
- Does not tell the Relationships between milestones in different tasks

This is a serious limitation of Gantt Chart

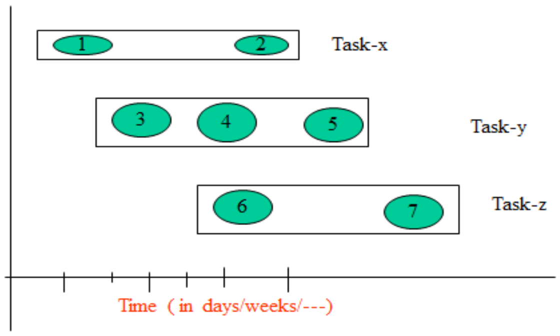
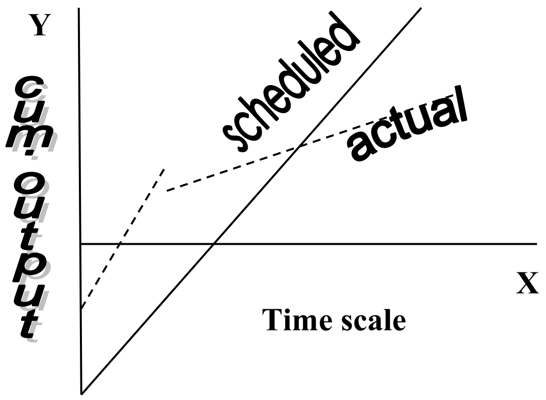


Fig.-1: Gantt Chart

viii) **Control Graph: Visual picture of schedule output and actual output.**



Job Ticket: Authorize the performance of individual operations of marketing process.

Control Boards: A device used to ensure that the production facilities are put into operation progressively at the speed and rate provided in the schedule. Commonly used in flow production can be used for batch/line production also. Various types like pictorial, hook, index visible, tape and peg boards etc. are used.

7.3 SUMMARY

Organisations utilize resources namely, men, machines, materials, money and methods to manufacture products required by the present and potential customers. Manufacturers follow different types of production systems to manufacture based on the type of product being produced. The various systems are, continuous, intermittent and project type of production systems. To bring in flexibility in manufacturing the manufacturers are implementing modern methods like modular production and group technology.Batch production system is discussed in detail. Assembly line production along with line balancing across work stations is explained. Concepts of aggregate planning and LOB are also covered as part of understanding the planning and control of manufacturing process.

7.4 KEY WORDS

Scheduling: it is the time phase of loading and determines when and in what sequence the work will be carried out. It fixes the starting as well as the finishing time for the job.
Group Technology: It is popularly known as GT. It is a manufacturing approach in which similar parts (similarities in terms of geometry, manufacturing process and manufacturing functions etc) are identified and grouped together to be manufactured in one location using a limited number of machines or processes.
Line Balancing: It aims at grouping the work stations, facilities and workers in an efficient pattern in order to obtain an optimum or most promising balance of the capacities and flow of the production on assembly processes.
LOB Technique: Line Of Balance (LOB) is a management control process for collecting, measuring and presenting facts relating to time, cost and accomplishment - all measured against a specific plan.
Aggregate planning: It can be defined as the process of planning the quantity and timing of output over the intermediate range of three to eighteen months by adjusting the production rate, employment, inventory and other controllable variables.

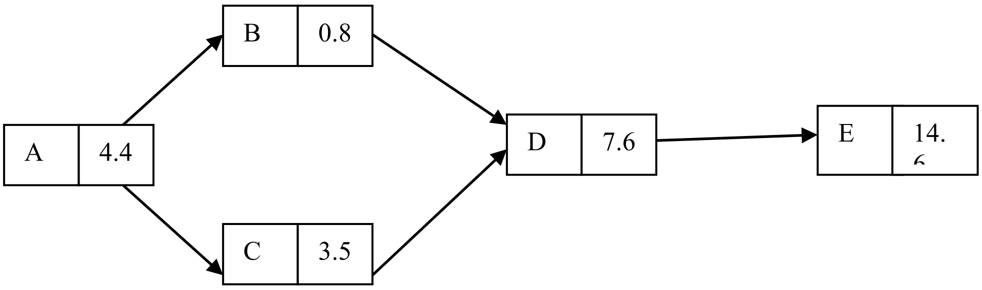
7.5 MODEL EXAMINATION QUESTIONS

A) Short answer questions

1. Holding Cost
2. Economic Lot Size
3. Production Lot Size
4. Economic Order Quantity
5. Aggregate Planning
6. LOB technique

B) Long answer questions

1. Explain various production processes or methods with suitable examples.
2. Describe the differences between Job shop production system and batch production system.
3. Describe various methods of line balancing along with its advantages and disadvantages.
4. Explain the advantages of modular production and group technology to a modern day manufacturer.
5. Discuss the various functions of production, planning and control.
6. A furniture manufacturing activity requires the times shown Fig 7.4 to perform five tasks in an assembly line. Operations are to be scheduled for producing six units per hour and eachemployee can contribute 48 minutes per hour of productive work. Calculate a) the cycle time in minutes per unit? b) the theoretical minimum number of personnel? c) Combine the tasks into the most efficient grouping of work stations – using the longest time rule. What is the resulting balance efficiency?



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LESSON-8
SEQUENCING AND SCHEDULING

Learning Objectives

By the end of this lesson, learners will be able to:

1. Understand about Sequencing and Scheduling.
2. Know about different types of scheduling.
3. Learn about scheduling Techniques and Tools.

STRUCTURE OF THE LESSON:

8.1 INTRODUCTION:

Scheduling process involves the decision making regarding the allocation of available capacity or resources. Thus, the process can be called as time-phased plans or schedule of activities. There are several objectives viz., high efficiency, low inventories and good customer services, which can be achieved via scheduling process. OR

The process of converting a general or outline plan for a project into a time-based graphic presentation given information on available resources and time constraints.

Scheduling is defined as the allocation of resources over time to perform a collection of tasks'. This rather general definition of the term does convey two different meanings that are important in understanding the purpose.

First, scheduling is a decision-making function: it is the process of determining a schedule. In this sense, much of what we learn about scheduling can apply to other kinds of decision making and therefore has general practical value.

Second, scheduling is a body of theory: it is a collection of principles, models, techniques, and logical conclusions that provide insight into the scheduling function. The vital elements in scheduling models are resources and tasks. The set of tasks available for scheduling does not change over time, the system is called static', in contrast to cases in which new tasks arise over time, where the system is called dynamic.

8.2 SEQUENCING AND SCHEDULING:

Scheduling is the allocation of resources over time to perform a collection of tasks and it is a decision making function. The practical problem of allocating resources over time to perform a collection of tasks arises in a variety of situations. In most cases, however, scheduling does not become a concern until some fundamental planning problems are resolved, and it must be recognized that scheduling decisions are of secondary importance to a broader set of managerial decisions.

Scheduling in Operations Management:

In operation management, scheduling has been put to use so that resources can be utilized in a more efficient way to deliver their tasks as scheduled. Various techniques of scheduling have emerged, which one is meant to use in case one's operational need is key to productivity and effectiveness in different situations.

Job Scheduling

Job scheduling is the assignment of activities to specific resources such that the given time interval is utilized effectively to accomplish each job. This is especially most significant in manufacturing environments because jobs might differ greatly in terms of complexity and resource needs. Thus, by prioritizing jobs according to deadlines and source availability, the company can minimize production delays and optimize workflow, leading to increased throughput and lower operational costs due to effective job scheduling.

Project Scheduling

It gives an overview of the pattern of interrelated tasks in a project so that project objectives can be achieved economically. The use of Gantt charts and Critical Path Method illustrates dependencies and timelines, helping the project manager spot when bottlenecks could appear. This kind of scheduling allows efficient allocation of scarce resources while having clear schedules among teams, which is more important for better collaboration and keeping stakeholders aware of progress.

Employee Scheduling

Employee scheduling will organize work shifts and hours for personnel in ensuring optimal coverage, labor laws, and individual preferences are met. This kind of scheduling is always a need in retail, healthcare, and hospitality. With appropriate schedules, employees will be encouraged, and turnover also decreases. Proper employee scheduling will, therefore, enhance customer service, ensuring that the right number of people are on duty at the point of high demand.

Production Scheduling

Production scheduling refers to when and how the production activities would be scheduled in terms of time and sequence in order to fulfill a demand in an effective manner so that resources are used optimally, not delayed in production, and maximum output is achieved. Mostly, it requires the utilization of advanced software applications for data analysis and informed scheduling decisions. When the production schedules align with the market demand, then waste might be prevented while profitability will improve.

Capacity Scheduling

This is mainly done by using capacity scheduling where one identifies the best allocation of available resources such as machinery and labor in order to meet production goals without overloading the system. In not having bottlenecks while going through production, this approach is essential in being efficient. This calls for creating schedules with a balancing act between workload and capacity which considers the demand forecasts as well as resource availability. This in turn triggers smooth operations and better responses to shifting market conditions.

8.3 TYPES OF SCHEDULE

There can be various ways to represent the scheduling related information;
some of them are given as :

(a) Gantt charts
(b) Milestone chart
(c) Progress chart
(d) Networks
(e) Earned values
(f) Line of balance

Sequencing and scheduling are essential components of operations management that organize tasks and allocate resources to optimize efficiency, minimize costs, and meet customer deadlines.

Sequencing vs. Scheduling

While closely related, they have distinct functions:

Aspect	**Sequencing**	**Scheduling**
Definition	Determining the **order** in which jobs or tasks will be performed.	Allocating **resources** over **time** andassigning start/completion times for those tasks.
Focus	The processing order of jobs based on specific rules or criteria.	Timing, capacity, resource allocation, and overall timelines.

Example	Deciding which of five waiting jobs to run first on a single machine.	Using a Gantt chart to plan the start and end dates for all phases of a construction project.

Key Objectives

The primary objectives of effective sequencing and scheduling include:

- Meeting customer due dates and minimizing tardiness.
- Maximizing the utilization of resources (machines, labor, etc.).
- Minimizing work-in-process (WIP) inventory and average flow time.
- Reducing setup times and overall production costs.
- Minimizing make span (the total time to complete all jobs in a set).

8.4 Common Sequencing Rules (Priority Rules)

When multiple jobs are waiting at a workstation, priority rules (or dispatching rules) are used to determine which job to process next.

- **First-Come, First-Served (FCFS):** Jobs are processed in the order they arrive. This is simple to implement but may not be efficient for other metrics.
- **Shortest Processing Time (SPT):** The job with the shortest processing time is processed first. This rule typically minimizes average flow time and work-in-process inventory.
- **Earliest Due Date (EDD):** The job with the earliest due date is processed first. This rule minimizes the maximum job tardiness.
- **Least Slack Time (LST):** Jobs with the least amount of "slack" (time remaining until the due date minus the processing time remaining) are processed first to avoid delays.
- **Critical Ratio (CR):** This rule calculates a ratio of time remaining until the due date to the total shop time remaining. Jobs with the lowest critical ratio are prioritized.

8.5 Scheduling Techniques and Tools

Managers use various tools and techniques depending on the production system (e.g., job shop, batch, mass production).

- **Gantt Charts:** Visual tools used to display schedules, track progress against timelines, and monitor resource load.
- **Forward Scheduling:** Planning tasks from the current date to determine the earliest possible completion date.
- **Backward Scheduling:** Planning backward from a required due date to determine the latest possible start date.
- **Finite Loading:** Assigning jobs to resources while considering their actual available capacity, preventing overloads.
- **Johnson's Rule:** A specific algorithm used to minimize the makespan when scheduling a set of jobs through two consecutive work centers or machines.

- **Critical Path Method (CPM) and PERT:** Network analysis techniques used in project scheduling to identify the sequence of activities that determines the project's shortest possible duration.

GANTT CHART:

It is a technique used to describe the progression of a project in the form of specialized chart. Initially Gantt chart was built to track the application of ship-building projects.
Role of Gantt Chart in Project Planning :

For larger projects, a work breakdown structure would be developed to identify the tasks before constructing a Gantt chart. For smaller projects, the Gantt chart itself may be used to identify the tasks. The strength of the Gantt chart is its ability to display the status of each activity at a glance. While often generated using project management software, it is easy to construct using a spreadsheet, and often appears in simple ASCII formatting in e-mails among managers. For sequencing and critical path analysis, network models such as CPM or PERT are more powerful for dealing with dependencies and project completion time. Even when network models are used, the Gantt chart often is used as a reporting tool.

Gantt charts are named after Henry Gantt, who developed these charts in the early 1900s. A Gantt chart is a visual representation of a schedule overtime.

Two kinds of Gantt charts are load chart and the progress chart.
Load Chart The load chart shows the planned work load and idle times for a group of machines or individual employees, or for a department.

Progress Chart The progress chart monitors job progress by showing the relationship between planned performance and actual performance.
Types of Operations Scheduling are as follows:

Forward operations scheduling –

- Classified on the basis of the time.
- All the activities are scheduled from the date of the planned order release.
- First task of the job is scheduled.
- Its subsequent task is scheduled on the scheduled completion of the first task.
- Like this, accordingly all the tasks of the job are scheduled.

Backward operations scheduling –

- Also classified on the basis of the time.
- Activities are scheduled from the date or the planned receipt date.
- The last activity is scheduled first.
- Time of the start of the last task is considered as the time for the start of the previous activity.

Johnson's Rule

Johnson's Rules a technique that can be used to minimize the completion time for a group of jobs that are to be processed on two machines or at two successive work centers.

Objectives of Johnson's Rule

The Objectives of Johnson's Rule are:

To minimize the processing time for sequencing a group of jobs through two work centers.
To minimize the total idle times on the machines.
To minimize the flow time from the beginning of the first job until the finish of the last job

Conditions for Johnson's Rule

In order for the technique to be used, several conditions must be satisfied:

Job time(including setup and processing) must be known and constant for each job at each work center.
Job times must be independent of the job sequence.
All jobs must follow the same two-setup work sequence.
Job priorities cannot be used.

PROBLEMS

Problem 1: Single Machine Scheduling (Shortest Processing Time Rule)
Objective: Minimize the average flow time for jobs processed on a single machine.

Job	Processing Time (days)	Due Date (days hence)
A	4	5
B	7	10
C	3	6
D	1	4

Solution using the Shortest Processing Time (SPT) Rule:
1. Sort jobs in ascending order of their processing time. The order is D (1 day), C (3 days), A (4 days), B (7 days).

1. **Calculate Flow Time:** The flow time for a job is its completion time.

- Job D completes at time 1. Flow time = 1.
- Job C starts at time 1, completes at 1 + 3 = 4. Flow time = 4.
- Job A starts at time 4, completes at 4 + 4 = 8. Flow time = 8.
- Job B starts at time 8, completes at 8 + 7 = 15. Flow time = 15.

Job Sequence	Processing Time (P)	Flow Time (CT)	Due Date (D)
D	1	1	4
C	3	4	6
A	4	8	5
B	7	15	10

Solution: The average flow time is the sum of flow times divided by the number of jobs:
$(1 + 4 + 8 + 15)/4 = 28/4 =** 7\text{days} **$
(1+4+8+15)/4=28/4=**7 days**

Problem 2: Single Machine Scheduling (Earliest Due Date Rule)
Objective: Minimize job tardiness (lateness) for the same set of jobs as Problem 1, using the Earliest Due Date (EDD) rule.

Job	Processing Time (days)	Due Date (days hence)
A	4	5
B	7	10
C	3	6
D	1	4

Solution using the Earliest Due Date (EDD) Rule:

1. **Sort jobs** in ascending order of their due date. The order is D (due 4), A (due 5), C (due 6), B (due 10).
2. **Calculate Tardiness:** Tardiness is the amount of time a job is completed after its due date (0 if completed on time or early).

Job Sequence	Processing Time (P)	Due Date (D)	Completion Time (CT)	Tardiness (CT - D)
D	1	4	1	0
A	4	5	1 + 4 = 5	0
C	3	6	5 + 3 = 8	2
B	7	10	8 + 7 = 15	5

Solution: The total tardiness is
$0 + 0 + 2 + 5 =** 7\text{days} **$
0+0+2+5=**7 days**
Note that different rules optimize different measures of effectiveness.

Problem 3: Two-Machine Sequencing (Johnson's Rule)
Objective: Minimize the total elapsed time (makespan) for five jobs processed on two machines (Machine 1 then Machine 2).

Job	Machine 1 Time (hrs)	Machine 2 Time (hrs)
1	5	2
2	1	6
3	9	7
4	3	8
5	10	4

Solution using Johnson's Rule:

1. **Find the shortest processing time** across both machines for all jobs. The minimum time is 1 hour for Job 2 on Machine 1.
2. **Schedule the job:** If the minimum time is on Machine 1, schedule the job as early as possible (at the beginning). The sequence starts with [2, ?, ?, ?, ?]. Eliminate Job 2.
3. **Repeat:** The next minimum time among remaining jobs is 2 hours for Job 1 on Machine 2. If the minimum time is on Machine 2, schedule the job as late as possible (at the end). The sequence is [2, ?, ?, ?, 1]. Eliminate Job 1.
4. **Continue:** Next minimum is 3 hours for Job 4 on Machine 1. Schedule at the beginning of the remaining sequence: [2, 4, ?, ?, 1]. Eliminate Job 4.
5. **Continue:** Next minimum is 4 hours for Job 5 on Machine 2. Schedule at the end of the remaining sequence: [2, 4, ?, 5, 1]. Eliminate Job 5.
6. **Final Job:** Only Job 3 remains, place it in the middle: [2, 4, 3, 5, 1].
   Optimal Sequence: 2 - 4 - 3 - 5 - 1

Solution (Total Elapsed Time/Makespan Calculation):

Job	Machine 1 In	Machine 1 Out	Machine 2 In	Machine 2 Out
2	0	1	1	1 + 6 = 7
4	1	1 + 3 = 4	7 (waits for M1)	7 + 8 = 15
3	4	4 + 9 = 13	15 (waits for M1)	15 + 7 = 22
5	13	13 + 10 = 23	23 (waits for M1)	23 + 4 = 27
1	23	23 + 5 = 28	28 (waits for M1)	28 + 2 = 30

The total elapsed time (makespan) is **30 hours**.

Problem 4: Single Machine Scheduling (First-Come, First-Served Rule)
Objective: Schedule jobs based on their arrival order (FCFS) to calculate average flow time and compare with other methods.

Job	Arrival Order	Processing Time (days)	Due Date (days hence)
A	1	4	5
B	2	7	10
C	3	3	6
D	4	1	4

Solution using the First-Come, First-Served (FCFS) Rule:

1. **Process jobs** in their order of arrival (A, B, C, D).
2. **Calculate Flow Time:**

Job Sequence	Processing Time (P)	Flow Time (CT)
A	4	4
B	7	4 + 7 = 11
C	3	11 + 3 = 14
D	1	14 + 1 = 15

Result: The average flow time is

$$(4 + 11 + 14 + 15)/4 = 44/4 =** 11\text{days} **$$

(4+11+14+15)/4=44/4=**11 days**

. (Note: This is higher than the 7 days achieved by the SPT rule in Problem 1, which is expected as SPT minimizes this metric).

8.6 SUMMARY

Scheduling process involves the decision making regarding the allocation of available capacity or resources. Thus, the process can be called as time-phased plans or schedule of activities. There are several objectives viz., high efficiency, low inventories and good customer services, which can be achieved via scheduling process. Scheduling Techniques and tools.

8.7 KEY WORDS: SCHEDULING, SEQUENCING, GANTT CHART.

8.8 SELF-ASSESSMENT QUESTIONS:

1. Give the differences between Sequencing and Scheduling?
2. Explain about different types of Scheduling?
3. What are the steps involved in John's Rule?

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LESSON-9
MANUFACTURING RESOURCE PLANNING AND ERP

Lesson Objectives:

Upon completion of this lesson, students will be able to:

- Understand Manufacturing Resource Planning (MRP II) and differentiate it from Material Requirements Planning (MRP I).
- Identify the key functional components and integrated modules within an MRP II system.
- Analyze the benefits associated with implementing MRP II system
- Evaluate suitability of MRP II over other systems
- Understand the evolution of ERP
- Learn the role of Enterprise Resource Planning (ERP) as a strategic business management tool.
- Identify and Analyze the core functional modules of a modern ERP system
- Evaluate the strategic benefits and challengesof ERP implementation.
- Learn common strategies for successful ERP deployment.

STRUCTURE OF THE LESSON

9.1 INTRODUCTION

Prior to 1960s businesses generally relied on traditional ways of managing inventories to ensure smooth functioning of the organizations.ERP system has evolved from the Material Planning System of 1980's. Later in 1980s, Manufacturing Resource Planning (MRP II) was developed by integrating other important functions.

With the success of MRP II, a complete integration of all functions was developed and named it as Enterprise Resource Planning (ERP) followed by Extended ERP which integrates the vendors and Clients. It was further improved by real-time applications and named it as ERP II. The various phases of development of resource planning system in relation to time and evolution of concept of ERP are mentioned in the graph.

Figure 9.1 Stages of ERP Evolution

Table 9.1 ERP systems represent the third major evolution in enterprise software

System	Focus	Scope	Key Differentiator
MRP (1960s/70s)	Materials	Production only	Calculates raw material needs.
MRP II (1980s)	Manufacturing Resources	Manufacturing + Finance	Integrated capacity planning and financial link.
ERP (1990s - Present)	Enterprise Resources	Entire Organization	**Cross-functional integration** across all business units (HR, CRM, SCM, etc.).

Nowadays, the organizations can't survive without computerisation with advanced technologies. Data collection from internal and external transactions and gathering information from various external sources will help the enterprises to make right decisions in crucial times. The details of each phase mentioned in figure 9.1 and table 9.1 are given below.

9.2 MATERIAL REQUIREMENT PLANNING (MRP)

Material Requirements Planning (MRP) emerged in the mid-1970s as a fundamental concept in production management and control, marking the first stage in the evolution of Enterprise Resource Planning (ERP). Industries such as automobile manufacturing, which involve thousands of parts and complex assembly operations, struggled with excessively large inventories. The need to reduce these inventory levels led to the development of early MRP systems that focused on planned order releases.

By ensuring proper time-phasing and accurate planning of sub-assemblies, MRP systems addressed the intricate relationships defined by the Bill of Materials (BOM). In a typical automobile plant, where hundreds or thousands of parts must be coordinated, MRP brought order to the otherwise chaotic process of material planning. Leveraging computer processing power, databases for lead times and order quantities, and BOM explosion algorithms, MRP transformed discrete manufacturing operations.

Initially, MRP replaced statistical inventory control techniques. Over time, rescheduling capabilities were added, increasing industry acceptance. At the operational level, capacity checks were introduced, resulting in **closed-loop MRP**, which could show the impact of material plans on available capacity.

However, a key limitation remained: MRP did not fully account for manufacturing capacities, leaving uncertainty about whether requirements could be met. This shortcoming led to the development of **Manufacturing Resource Planning (MRP-II)**, an integrated system that extended beyond manufacturing to encompass financial and marketing functions.

MRP-II linked business functions to production planning, enabling organizations to create feasible plans by augmenting material requirements planning with capacity planning and scheduling. This integration laid the foundation for modern ERP systems, which unify diverse business processes into a single, coherent framework.

9.3 Manufacturing Resource Planning (MRP II)

Manufacturing Resource Planning (MRP II) is a comprehensive method for the effective planning of all resources within a manufacturing company. Unlike traditional Material Requirements Planning (MRP), which focused primarily on material availability, MRP II evaluates production feasibility from a broader resource perspective. It incorporates production facilities, machine capacities, and precedence sequences, ensuring that schedules are not only material-driven but also operationally achievable.

The enhanced functionality of MRP II allows the system to operate in a closed loop:

1. Feasibility Check – Assessing whether a production schedule can be met given existing constraints.
2. Resource Adjustment – Modifying resource loading, where possible, to align with production requirements.
3. Material Planning – Executing traditional MRP functions to plan and manage material needs.

Ideally, MRP II addresses both operational planning (in physical units) and financial planning, while offering simulation capabilities to explore "what-if" scenarios. It represents an extension of closed-loop MRP, moving beyond materials to encompass the full spectrum of manufacturing resources.

Importantly, MRP II is not merely a software solution. Its success depends on effective management practices, skilled personnel, accurate databases, and adequate computing resources. At its core, MRP II is a total company management concept, designed to integrate human and organizational resources for greater productivity and efficiency.

9.3.1 KEY FUNCTIONS AND FEATURES OF MRP II

Almost every MRP II system is modular in construction. Characteristic basic modules in an MRP II system are:

- Master production schedule (MPS)
- Bill of materials (BOM) (technical data)
- Production resources data (manufacturing technical data)
- Inventories and orders (inventory control)
- Purchasing management
- Material requirements planning (MRP)
- Shop floor control (SFC)
- Capacity planning or capacity requirements planning (CRP)
- Cost reporting / management (cost control)

together with auxiliary systems such as:

- Business planning
- Lot traceability
- Contract management
- Tool management
- Engineering change control
- Sales analysis and forecasting
- Finite capacity scheduling (FCS)

And related systems such as:

- General ledger
- Accounts payable (purchase ledger)
- Accounts receivable (sales ledger)
- Sales order management
- Distribution resource planning (DRP)
- Project management
- Computer-aided design/computer-aided manufacturing (CAD/CAM)

The MRP II system integrates these modules together so that they use common data and freely exchange information, in a model of how a manufacturing enterprise should and can operate. The MRP II approach is therefore very different from the "point solution" approach, where individual systems are deployed to help a company plan, control or manage a specific activity. MRP II is by definition fully integrated or at least fully interfaced.

9.3.2 MRP II SYSTEMS CAN PROVIDE THE FOLLOWING BENEFITS:

- Better control of inventories
- Improved scheduling
- Productive relationships with suppliers

For design / engineering:

- Improved design control
- Better quality and quality control

For financial and costing:

- Reduced working capital for inventory Improved cash flow through quicker deliveries
- Accurate inventory records

9.4 ENTERPRISE RESOURCE PLANNING (ERP)

Enterprise resource planning (ERP) has evolved as a strategic tool, an outcome of over four decades. This is because of continuous improvements done to the then available techniques to manage business more efficiently and also with developments and inventions in information technology field.

9.4.1 BEGINNING OF ERP

Enterprise Resource Planning (ERP) is an acronym that stands for the integrated management of core business processes through software and technology. ERP systems gained phenomenal interest from the corporate sector during the period 1995–2000, with the ERP market estimated to exceed USD 80 billion by the year 2000. Analysts widely agree that today's global business environment—characterized by mass customization of products and services, individualized customer needs, and 24×7 delivery timelines—would have been impossible without such enterprise software.

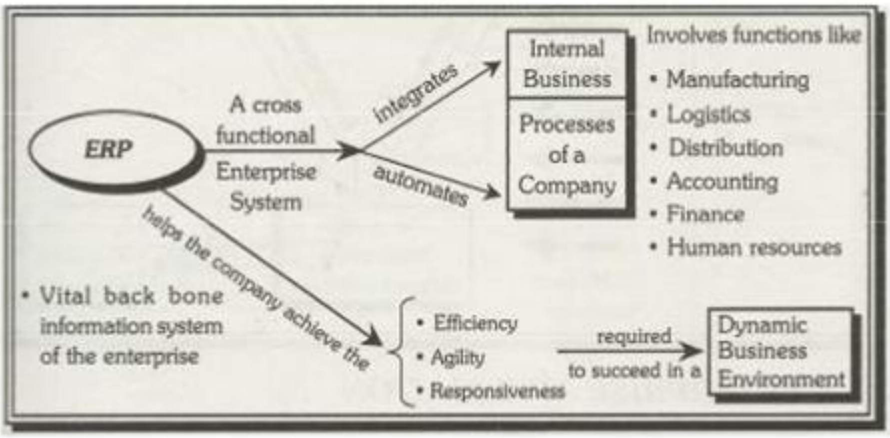
ERP represents one of the most complex and demanding applications in the corporate environment, encompassing diverse domains such as Supply Chain Management (SCM), Customer Relationship Management (CRM), manufacturing, service sectors, and marketing research.

The rise of ERP was driven by the need for integration across all functions of management:

- Activity-based costing required linking manufacturing with accounting.
- Mass customization demanded integration of marketing and manufacturing.
- Flexible manufacturing and workforce empowerment necessitated integration of production with Human Resource Development (HRD).

In essence, the 1990s marked a turning point where enterprises sought complete functional integration. ERP systems emerged as comprehensive information platforms, designed to meet the decision-making and operational needs of organizations by spanning all management functions within a unified framework.

Fig 9.2 Meaning of ERP



Source: *Murthy CVS, Enterprise Resource Planning, Mumbai: Himalaya Publishing House, 2006, Pg.3.*

9.4.2 DEFINITION OF ERP

Kumar et al. (2000) define enterprise resource planning (ERP) systems as "configurable information systems packages that integrate information and information-based processes within and across functional areas in an organization".

Nah et al. (2001) defines ERP as "An enterprise resource planning (ERP) system is typically defined as a packaged business software system that facilitates a corporation to manage the efficient and effective use of resources (materials, human resources, finance, etc.) by providing a total integrated solution for the organization's information- processing requests, through a process-oriented view consistent across the company."

9.4.3 ERP SOFTWARE PACKAGE

ERP is a package software solution that addresses the enterprise needs of an organization by tightly integrating the various functions of an organization using a process view of the organization.

A. ERP software is ready-made generic software; it is not custom-made for a specific firm. ERP software understands the needs of any organization within a specific industry segment. Many of the processes implemented in an ERP software are core processes such as order processing, order fulfillment, shipping, invoicing, production planning, BOM (Bill of Material), purchase order, general ledger, etc., that are common to all industry segments.
B. ERP does not merely address the needs of a single function such as Finance, Marketing, Production or HR; rather it addresses the entire needs of an enterprise that cuts across these functions to meaningfully execute any of the core processes.
C. ERP integrates the functional modules tightly. It is not merely the import and export of data across the functional modules. The integration ensures that the logic of a process that cuts across the function is captured genuinely. This in turn implies that data once entered in any of the functional modules (whichever of the module owns the data) is made available to every other module that needs this data. This leads to significant improvements by way of improved consistency and integrity of data.

D. ERP uses the process view of the organization in the place of function view, which dominated the enterprise software before the advent of ERP. PLAYERS-: JD EDWARDS, ORACLE, SAP

9.4.4 Core Functional Modules and Integration

Modern ERP systems are modular, allowing companies to implement the functions relevant to their operations. The primary modules include:

A. Financial Management (The Core)

- **General Ledger (GL):** The central hub for all financial data.
- **Accounts Payable (AP) & Accounts Receivable (AR):** Manages all company debts and outstanding customer invoices.
- **Asset Accounting:** Tracks fixed assets (machinery, property) for depreciation and regulatory compliance.

B. Supply Chain Management (SCM)

- **Procurement:** Automation of purchasing, vendor management, and requisitioning.
- **Inventory Management:** Real-time tracking of stock levels, warehouse operations, and location.
- **Logistics/Warehouse Management:** Optimizes storage, movement, and shipping of goods.

C. Manufacturing and Production

- **Master Production Scheduling (MPS) & MRP:** Planning production schedules and material requirements.
- **Capacity Planning (CRP):** Balancing required work against available machinery and labor.
- **Quality Management:** Tracking and reporting non-conformance and quality checks.

D. Human Capital Management (HCM)

- **Payroll & Benefits:** Administration of employee compensation and benefits.
- **Talent Management:** Recruiting, performance management, and career development.
- **Time and Attendance:** Tracking employee work hours.

E. Customer Relationship Management (CRM)

- **Sales & Marketing:** Managing leads, quotes, orders, and sales performance.
- **Service Management:** Handling customer inquiries, support tickets, and field service operations.

9.4.5 STRATEGIC BENEFITS OF ERP

Implementing an Enterprise Resource Planning (ERP) system offers benefits like improved efficiency, real-time reporting and better data accuracy by integrating business processes and centralizing data. This leads to higher productivity, enhanced collaboration, and more informed decision-making through a single source of truth. ERP systems also provide scalability, improved data security, and support for regulatory compliance.

Core operational benefits

- **Increased efficiency and productivity:** ERP systems automate routine tasks and streamline processes, reducing manual data entry and minimizing errors.
- **Real-time visibility and reporting:** Centralized data provides a single source of truth, enabling real-time reporting and faster, more accurate business insights.
- **Better collaboration:** Integrating departments into a single system allows different teams to share information and work together more effectively, breaking down information silos

Strategic and financial benefits

- **Improved decision-making:** Access to real-time data and powerful analytics tools empowers managers to make more informed strategic decisions.
- **Cost savings:** Efficiency improvements, reduced manual labor, and better inventory management (by preventing overstocking) can lead to significant cost reductions.
- **Enhanced scalability:** ERP systems can grow with a business, allowing for the addition of new modules and functionalities as the company expands.
- **Stronger data security and compliance:** ERP systems include built-in security controls, role-based access, and audit trails to improve data protection and help ensure compliance with regulations.

9.4.6 Implementation Strategies and Challenges

9.4.6.1 Key Challenges:

- **Cost and ROI:** ERP systems are extremely expensive, requiring careful ROI justification.
- **Business Process Reengineering (BPR):** ERP is not just software; it requires companies to adapt *their* processes to the system's logic, often leading to organizational resistance.
- **Data Migration:** Moving legacy data into the new system is complex and fraught with risks of data loss or corruption.
- **Customization Risk:** Excessive customization can negate the benefits of standardized processes and complicate future system upgrades.

9.4.6.2 Implementation Strategies:

ERP implementation strategies involve choosing a method to transition to a new system, such as the Big Bang (all at once), Phased Rollout (one module at a time), or Parallel Adoption (running both systems concurrently). Key factors for success across all strategies include defining clear objectives, assembling the right project team, comprehensive planning, thorough data cleaning, and extensive user training.

- **Big Bang:**
  All modules are implemented and go live at the same time. This approach is best for quick deployment but carries higher risk.
- **Phased Rollout:**
  The system is implemented in stages, such as one module at a time, one department at a time, or one geographic region at a time. This allows for easier management and troubleshooting but takes longer.

- **Parallel Adoption:**

The old and new systems are run simultaneously for a period. This is a lower-risk strategy as it provides a backup, but it is expensive and labor-intensive, requiring double the data entry.

9.5 FACTORS INFLUENCING MANUFACTURERS TO CHOOSE MRP II OR ERP

Manufacturers should select MRP II over ERP when operations remain focused on core production needs without requiring enterprise-wide integration. MRP II proves ideal for small to medium-sized businesses prioritizing manufacturing efficiency over complex cross-departmental coordination.

Scenario	**Choose MRP II**	**Choose ERP Instead**
Company Size	Small-medium (under 100 employees, single plant)	Large/multi-site enterprises
Budget	Limited	Higher
Complexity	Simple production lines, stable demand	Diverse products, global supply chains
Timeline	Quick deployment (2-6 months)	Lengthy (6-24 months)
Focus Areas	Inventory, capacity planning, shop floor control	Finance, HR, CRM integration

9.5.1 Specific Situations Favoring MRP II

Cost-Sensitive Startups: New manufacturers avoid ERP's high upfront costs and lengthy ROI periods. MRP II delivers immediate inventory optimization and production scheduling benefits.
Single-Function Focus: Job shops or contract manufacturers needing precise material requirements planning (MRP), bills of materials (BOM), and master production schedules without finance/HR modules.
Stable Operations: Companies with predictable demand and minimal supply chain complexity benefit from MRP II's closed-loop manufacturing control rather than ERP's broader scope.
Rapid Implementation Needs: Firms facing urgent production bottlenecks require MRP II's faster setup over ERP's comprehensive change management.
MRP II suits manufacturers where production remains the primary challenge, serving as a scalable stepping stone before ERP expansion

9.5.2 Extended ERP (E-ERP)

The evolution of Enterprise Resource Planning (ERP) systems led to the emergence of Extended ERP (E-ERP), also known as web-enabled ERP. With globalization driving interconnected markets and the rapid development of internet technologies in the late 1990s and early 2000s, organizations increasingly felt the need for web-based IT solutions.

E-ERP integrates the power of the Internet and the World Wide Web (WWW) into traditional ERP frameworks, enabling enterprises to extend their operations beyond internal boundaries. This advancement allows organizations to seamlessly connect suppliers, customers, and business partners, thereby facilitating real-time collaboration across the value chain.

9.5.2.1 Features of E-ERP include:

- Web-based accessibility for employees and stakeholders across geographies.
- Integration with external systems, such as e-commerce platforms and supplier networks.
- Enhanced communication through portals, intranets, and extranets.
- Support for global operations, aligning with the demands of distributed enterprises.

9.5.3 Enterprise Resource Planning II (ERP-II)

Building on the foundation of E-ERP, ERP-II represents the next advanced stage in enterprise systems. ERP-II strengthens the original ERP package by incorporating a broader set of capabilities that extend beyond manufacturing and finance.

9.5.3.1 ERP-II integrates functions such as:

- Customer Relationship Management (CRM) – managing customer interactions and enhancing satisfaction.
- Knowledge Management (KM) – capturing, storing, and leveraging organizational knowledge.
- Workflow Management – streamlining processes and improving efficiency.
- Human Resource Management (HRM) – empowering workforce planning and employee engagement.

As a web-friendly application, ERP-II addresses the challenges of enterprises with multiple office locations, enabling distributed teams to collaborate effectively. It transforms ERP from a system focused on internal efficiency into a platform for enterprise-wide collaboration and external connectivity, aligning organizations with the demands of modern digital business ecosystems.

9.6 SUMMARY

Material Requirements Planning (MRP) is Originated in the 1970s as the first stage in ERP evolution. Its focus is on planning order releases to reduce large inventories in industries like automobile manufacturing. Manufacturing Resource Planning (MRP-II) was developed to overcome MRP's limitations. It makes a road to for effective planning of all manufacturing resources. It includes capacity planning, machine utilization, and precedence sequences. It operates in a closed loop and check feasibility of production schedules and integrates financial planning, marketing, HR, and workflow management.

ERP is an integrated suite of software applications that a company uses to manage and coordinate all the core aspects of its business operations, including finance, human resources, manufacturing, supply chain, services, procurement, and more.

The fundamental characteristic of an ERP system is the **single, shared database**. This means all functional areas—from sales taking an order to the factory producing it to finance billing the customer—operate using the same data, ensuring **data integrity** and providing **real-time visibility** across the enterprise.

9.7 KEY WORDS

MRP: MRP is a computer-based inventory management system, used to determine what materials are needed, how much is needed, and when they are needed for production.
MRPII: MRP II is an extension of MRP that integrates material planning with other manufacturing resources such as labor, machines, and finance.
ERP: ERP is an integrated software system that manages all business processes across an organization using a single database.
Capacity Planning: Capacity Planning is the process of determining the production capacity needed to meet changing demand.
MPS-Master Production Schedule: The Master Production Schedule specifies what products are to be produced, in what quantities, and at what time
BoM-Bill of materials: A Bill of Materials is a complete list of all components, parts, and raw materials required to manufacture a product.
SCM- Supply Chain management: SCM involves the management of the flow of materials, information, and finances from suppliers to customers.
CRM – Customer Relationship Management: CRM is a strategy and software system used to manage a company's interactions with customers.
Big Bang: Big Bang is an ERP implementation method where all modules are implemented simultaneously across the organization

9.8 SELF-ASSESSMENT QUESTIONS (SAQS)

1. Discuss the evolution of Enterprise resource planning systems.
2. Explain the logic of selecting MRPII over ERP
3. Discuss the modules developed under ERP.
4. Explain the benefits of implementing ERP in medium to large scale organisations.
5. A manufacturing firm is considering a $50 million investment in a new ERP system. The CEO questions the need for the HR and CRM modules, arguing that the existing standalone systems work fine. Justify the inclusion of the HR and CRM modules from a strategic **cross-functional integration** perspective.
6. Discuss the trade-off between the **Big Bang** and **Phased Rollout** implementation strategies. If you were advising a large, globally dispersed company, which approach would you generally recommend and why?

9.8.1 Multiple Choice Questions

1. The defining characteristic of an ERP system, which provides data integrity and real-time visibility, is:

a) Its high cost and complexity.
b) Its exclusive focus on manufacturing processes.
c) The use of cloud infrastructure.
d) **The use of a single, integrated database and shared data model.**

2. A company decides to implement its ERP system one functional module at a time (e.g., starting with Financials, then moving to HR). This is an example of which implementation strategy?

a) Blue-Ocean Strategy
b) Phased Rollout
c) Big Bang Strategy
d) Process Optimization

3. In the context of ERP, the term "GIGO" (Garbage In, Garbage Out) most critically applies to which stage of implementation or operation?

a) Hardware Procurement
b) Training of End-Users
c) Master Data Accuracy and Migration
d) System Customization

9.9 SUGGESTED READINGS

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LESSON-10
SUPPLY CHAIN MANAGEMENT

OBJECTIVES OF THE LESSON:

After completing this lesson, students should be able to:

1. Define Supply Chain Management (SCM) and explain its strategic importance.
2. Describe the SCM Framework, including upstream, internal, and downstream supply chain activities.
3. Explain the key principles of effective SCM, as suggested by industry practices.
4. Analyse how technology and digital integration transform SCM.
5. Define Electronic Supply Chain Management (e-SCM) and evaluate its components and benefits.
6. Identify challenges in implementing e-SCM in modern organisations.
7. Apply SCM and e-SCM concepts to real business situations through examples and case insights.

STRUCTURE:

10.1 MEANING AND DEFINITION TO SUPPLY CHAIN MANAGEMENT:

Supply Chain Management (SCM) is essential in today's fast-paced environment, overseeing the efficient movement of goods, information, and finances from suppliers of raw materials to the final consumers. It encompasses a series of complex, interrelated processes designed to ensure that products are produced and delivered in the right quantities, to the right locations, at the right time, and at optimal costs. In short Supply Chain Management (SCM) refers to the coordination and management of activities involved in sourcing raw materials, transforming them into finished goods, and delivering them to customers. It includes suppliers, manufacturers, warehouses, transporters, distributors, retailers, and customers has become a strategic business function that helps organizations reduce cost, improve efficiency, and gain a competitive edge in the global markets has evolved from a traditional logistics focus to a broader view that integrates procurement, production, distribution, and customer service. Digital transformation has further reshaped SCM into a real-time, data-driven system enabling better forecasting, visibility, and control.

Figure-10.1 A Conceptual Model of basic Supply Chain Management

Definition: Supply chain management definitions vary by author but generally describe it as the strategic coordination and integration of business functions to manage the flow of products, information, and finances from the raw material source to the end consumer. Key definitions include:

Mentzer: A systematic, strategic coordination of traditional business functions and tactics across companies within the supply chain to improve the long-term performance of individual companies and the supply chain as a whole.

Ellram and Cooper : An "integrating philosophy" to manage the total flow of a distribution channel from supplier to ultimate customer.

Council of Supply Chain Management Professionals (CSCMP): The planning and management of all activities related to the supply of resources, their transformation into products, and support management, including communication and cooperation between supply chain members to manage supply and demand.

10.2 KEY COMPONENTS OF A SUPPLY CHAIN

- **Suppliers:** Provide raw materials, components, and services required to produce finished products.
- **Manufacturers:** Transform raw materials into finished goods through various production processes.
- **Warehouses:** Store raw materials, intermediates, and finished products until they are needed further down the chain.
- **Distribution Centres:** Facilitate the efficient movement and distribution of goods to various locations.
- **Retailers:** Sell finished products directly to end customers.
- **Customers:** The final recipients of the products, whose demands drive the entire supply chain.

10.3 IMPORTANCE OF SUPPLY CHAIN MANAGEMENT:

The five key importances of supply chain management are cost reduction, customer satisfaction, competitive advantage, risk mitigation, and improved operational efficiency. Effective supply chain management optimizes processes to reduce costs, ensures products are delivered on time to boost customer loyalty, provides a competitive edge through agility, and prepares businesses for disruptions to ensure continuity.

1. Cost reduction

- Supply chain management helps reduce operational costs by optimizing inventory levels and streamlining transportation and distribution processes.

2. Customer satisfaction

- A well-managed supply chain ensures the timely and accurate fulfilment of customer orders, which improves satisfaction and builds brand loyalty.

3. Competitive advantage

- Efficient supply chains allow businesses to respond quickly to market changes, launch new products faster, and adapt to evolving customer demands, giving them a significant edge over competitors.

4. Risk mitigation

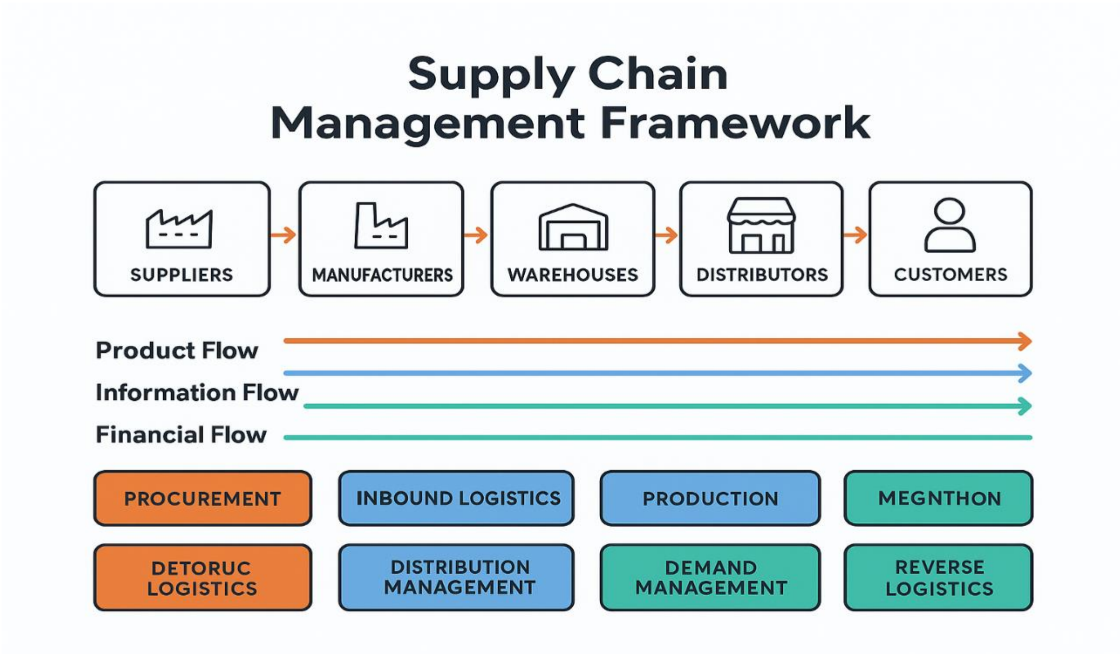
- It includes identifying and mitigating risks, such as supplier delays or disruptions, which helps maintain business continuity and protects a company's reputation.

5. Improved operational efficiency

- Supply chain management enhances overall efficiency by streamlining all stages of the process, from sourcing to delivery, leading to increased productivity and better performance.

10.4 SCM FRAME WORK

The Supply Chain Management (SCM) framework provides a structured way to understand, design, manage, and improve the flow of materials, information, and finances across the entire supply chain—from suppliers to end customers. It ensures that all activities are integrated and aligned to achieve efficiency, responsiveness, customer satisfaction, and competitive advantage.



Core Components of the SCM Framework

A. Supply Chain Network Structure

The structure defines how various entities in the supply chain are connected.

1. **Upstream (Suppliers):**
   - Raw material suppliers
   - Component manufacturers
   - Logistics service providers
2. **Internal Supply Chain:**
   - Production and operations
   - Inventory management
   - Warehousing
3. **Downstream (Customers):**
   - Distributors
   - Retailers
   - End consumers

This network determines the flow paths of products, information, and finances.

B. Supply Chain Business Processes

These processes form the operational side of SCM.

1. **Customer Relationship Management (CRM)**
   Managing customer needs, service levels, and demand patterns.
2. **Customer Service Management (CSM)**
   Handling inquiries, order status, and after-sales service.
3. **Demand Management**
   Forecasting customer demand and aligning supply.
4. **Order Fulfilment**
   Efficiently processing and delivering customer orders.
5. **Manufacturing Flow Management**
   Production planning, scheduling, flexibility, and capacity decisions.
6. **Supplier Relationship Management (SRM)**
   Selecting, evaluating, and collaborating with suppliers.
7. **Product Development and Commercialization**
   Integrating suppliers and customers in product design.
8. **Returns Management / Reverse Logistics**
   Handling returned goods, recycling, disposal, warranty, etc.

C. Supply Chain Management Components

These help implement and improve supply chain processes.

1. Physical Flow Components

- Raw materials
- Work-in-progress
- Finished goods
- Transportation
- Warehousing

2. Information Flow Components

- Demand information
- Order data
- Inventory levels
- Forecasts

- Real-time tracking

3. Financial Flow Components

- Payments
- Credit terms
- Pricing flows
- Cost management

2. Key Functional Areas in the SCM Framework

A. Procurement

- Sourcing
- Supplier selection
- Contract negotiation
- Vendor rating

B. Production

- Capacity planning
- Scheduling
- Quality control

C. Logistics

- Transportation
- Distribution
- Network design

D. Inventory Management

- EOQ
- Safety stock
- Reorder point

E. Information Technology

- ERP
- SCM software
- RFID, EDI
- Barcoding

3. Strategic, Tactical and Operational Levels of SCM

A. Strategic Level

Long-term decisions:

- Plant locations
- Supplier partnerships
- Distribution network design
- Technology choices

B. Tactical Level

Medium-term planning:

- Production plans
- Contracting with carriers
- Aggregate demand forecasting

C. Operational Level

Day-to-day operations:

- Order processing

- Dispatch scheduling
- Inventory control

10.5 INTEGRATED SCM MODEL

Integrated supply chain management (ISCM) is a process that connects and coordinates all stakeholders—from suppliers to customers—to manage the flow of goods, services, and information in a unified, efficient way. It aims to break down "silos" between different parts of the supply chain, using technology to enable real-time data sharing and collaboration to optimize operations, reduce costs, and improve customer satisfaction.
A fully integrated supply chain incorporates:

1. Collaboration
- Supplier collaboration (SRM)
- Customer collaboration (CRM)
- Cross-functional integration

2. Coordination
- Harmonized plans
- Shared information
- End-to-end visibility

3. Performance Measurement
- Cost metrics
- Service level metrics
- Time-based metrics

4. Technology Enablement
- ERP, SAP
- Cloud SCM
- RFID & IoT
- E-supply chain tools

5. Benefits of the SCM Framework
- Reduced costs
- Improved customer satisfaction
- Faster delivery
- Reduced inventory levels
- Higher agility and responsiveness
- Better supplier and customer relationships

10.6 PRINCIPLES OF EFFECTIVE SUPPLY CHAIN MANAGEMENT

Effective supply chain management (SCM) plays a pivotal role in helping businesses succeed in today's competitive landscape. Implementing key supply chain management (SCM) principles creates a strategic framework. This framework helps businesses ensure a seamless flow of goods and services. With a well-managed supply chain, organisations can fine-tune operations, reduce costs, and exceed customer expectations.

Incorporating these supply chain management principles can help build organisational resilience and adaptability. Furthermore, these principles enable businesses to anticipate market shifts, address risks and integrate innovative ideas.

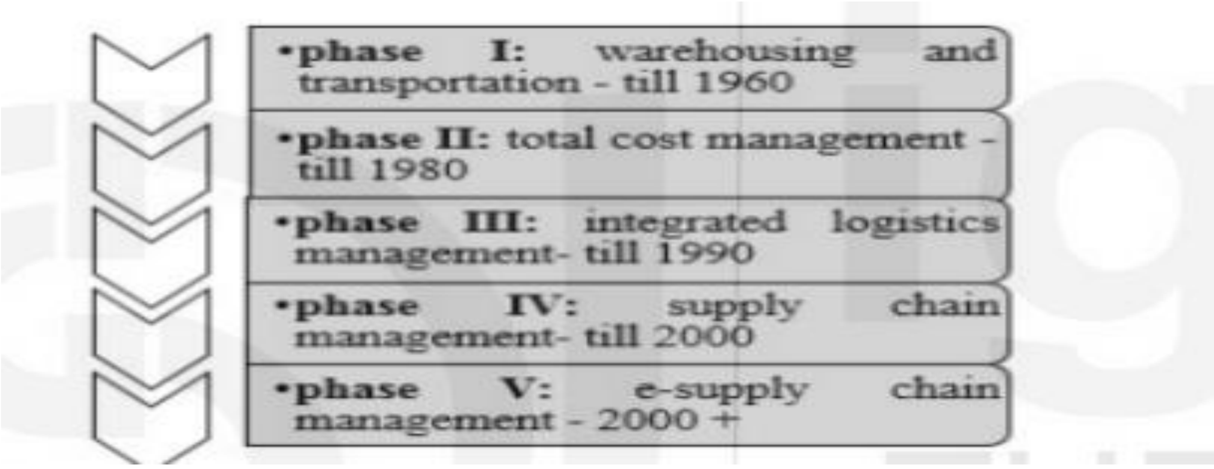
Core Principles of Effective SCM

- **Customer Focus and Segmentation:** Understand the diverse service needs of different customer groups and tailor the supply chain strategy and logistics network to serve those specific segments profitably. A single, blanket approach rarely works for all customers.
- **Demand Planning and Market Signals:** Continuously monitor and listen to market signals (like real-time demand data and trends) to drive demand planning across the entire supply chain. This ensures consistent forecasts and helps align production and procurement strategies accordingly.
- **Strategic Sourcing and Supplier Relationships:** Manage your supply sources strategically to minimize the total cost of ownership for materials and services, not just the purchase price. Building strong, collaborative, and transparent relationships with a diverse supplier base is vital for reliability and resilience against disruptions.
- **Integrated Technology Strategy:** Develop and implement a supply chain-wide technology strategy that supports multiple levels of decision-making. This includes using AI, automation, and real-time tracking (like IoT) to enhance efficiency, gain end-to-end visibility, and provide clear information flow across the entire network.
- **Risk Management and Resilience:** Identify potential threats (e.g., natural disasters, geopolitical issues, economic downturns) and develop robust contingency plans. Building resilience through flexible processes and a diversified network helps the supply chain adapt quickly to unexpected changes.
- **Collaboration and Communication:** Foster collaboration and open communication among all stakeholders, both internal (across departments like sales, production, and procurement) and external (suppliers, logistics providers, customers). This breaks down silos and ensures everyone is working toward shared objectives.
- **Performance Measurement and Data Analytics:** Adopt channel-spanning performance metrics (KPIs) to gauge collective success and identify bottlenecks or areas for improvement. Leveraging data analytics helps in making informed, data-driven decisions rather than relying on intuition alone.
- **Continuous Improvement and Adaptability:** The business and market landscapes are constantly evolving, so supply chains must be flexible and committed to continuous improvement. Fostering a culture of innovation and agility promotes ongoing process optimization and the ability to adapt to dynamic market demands.
- **Differentiation:** Differentiate product closer to the customer to speed conversion and better meet specific demands without overhauling the entire upstream production process.
- **Sustainability (Emerging Principle):** Integrate environmental, social, and governance (ESG) practices into supply chain design, such as using eco-friendly packaging and energy-efficient transport. This not only reduces environmental impact but also enhances brand reputation and long-term resilience.

10.7. ELECTRONIC SUPPLY CHAIN MANAGEMENT

e-SCM is an extension of the traditional SCM concept that arose in response to developing information technologies and redesigning business procedures within organisations to facilitate cooperation among business partners through the Internet. Having digitally enabled and coordinated business connections with customers, suppliers, and internal employees, as defined by Laudon and Laudon, makes these organisations digital. By capitalising on the synergies that emerge from the interdependence of the various parties involved, value can be added by deploying adaptive information systems and technologies. More information about e-SCM can be found in the following section, which provides definitions of the term.

Evolution of e-SCM:



Key components and technologies

- **Digital Platforms:** E-SCM uses software systems like Warehouse Management Systems (WMS) and Transport Management Systems (TMS) to optimize specific areas like warehouse space or delivery routes.
- **Data and Analytics:** Advanced data analytics provide real-time insights for better decision-making, risk management, and forecasting.
- **Artificial Intelligence (AI):** AI helps to anticipate problems, respond to changes, and automate processes within the supply chain.
- **Cloud Computing:** Enables seamless data sharing and collaboration between different partners, such as suppliers, manufacturers, and retailers.
- **Internet of Things (IoT):** Sensors can track goods and assets in real-time, providing end-to-end visibility.
- **Blockchain:** Can be used to enhance trust and transparency through a secure and shared record of transactions.

Planning and execution of e-SCM.

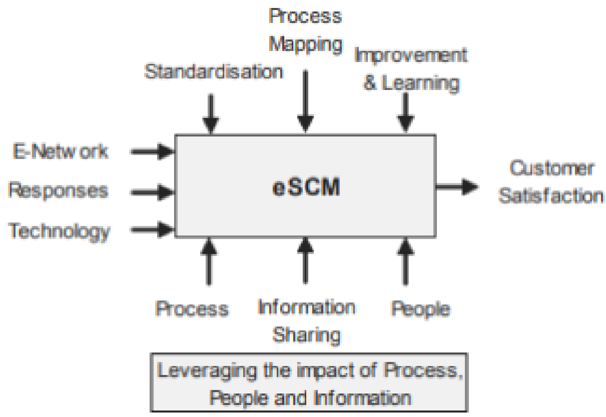
"Poirier and Bauer (2000) identify three components in the planning and execution of e-SCM".

I. **E-network:** "Ultimately, businesses should be able to meet the needs of their customers through a streamlined SC that benefits the end user".

II. **Responses**: SC planning revolves around hearing and responding to client feedback. The supply chain's worth rises dramatically when businesses combine to boost their profits through coordinated answers and innovative solutions.

III. **Technology**: With modern technology, especially online trade, each element above can contribute to the supply chain's overall mission. It is possible to think of the network, customer feedback, and technology as the "input" to e-SCM, all of which contribute to the supply chain's final objective (the "output") of satisfied customers.

e-SCM general mechanism-input output mechanism and control



Benefits of E-SCM

- **Increased Efficiency:** Automating processes and optimizing routes reduces waste and speeds up the flow of goods.
- **Cost Reduction:** Better inventory control, optimized logistics, and reduced errors lead to significant cost savings.
- **Improved Visibility:** Real-time data and tracking provide a clear view of the entire supply chain, allowing for better monitoring and risk mitigation.
- **Enhanced Collaboration:** Digital platforms connect all stakeholders, enabling faster communication and problem-solving.
- **Greater Agility:** E-SCM allows businesses to respond more quickly to changes in demand or supply disruptions.
- **Higher Customer Satisfaction:** Faster deliveries, better product availability, and increased transparency lead to a more positive customer experience

10.8 CHALLENGES IN IMPLEMENTING E-SCM

Challenges in electronic supply chain management, such as component shortages, rapid technological change, and demand volatility, can be overcome by strategically using technology and data, diversifying the supplier base, improving collaboration, and investing in workforce skills. Key solutions include implementing AI and IoT for real-time visibility and better demand forecasting, establishing multiple supplier relationships across different regions, fostering open communication with partners, and training employees to adapt to new digital tools.

Technology and data solutions

- **Use AI and ML:** Leverage artificial intelligence (AI) and machine learning (ML) for more accurate demand forecasting and risk management.
- **Implement IoT:** Utilize Internet of Things (IoT) sensors for real-time tracking of goods throughout the supply chain to optimize logistics and identify issues early.

- **Deploy RPA:** Employ Robotic Process Automation (RPA) to automate administrative tasks, increasing speed and accuracy for processes like invoice processing.
- **Integrate systems:** Use cloud-based supply chain management (SCM) and Enterprise Resource Planning (ERP) systems to integrate data and improve information flow between partners.

Sourcing and risk management solutions

- **Diversify suppliers:** Source components from multiple suppliers across different geographic regions to reduce reliance on a single source and mitigate geopolitical or localized disruptions.
- **Strengthen relationships:** Build long-term, transparent, and collaborative relationships with key suppliers to foster trust and improve resilience.
- **Vet suppliers carefully:** Work with trusted suppliers who have robust vetting processes to ensure component quality and reduce the risk of counterfeit parts entering the supply chain.
- **Build redundancy:** Avoid relying on single factories, ports, or transportation routes by building redundancy into the network.

Collaboration and workforce solutions

- **Enhance collaboration:** Improve data flow and communication between suppliers, manufacturers, and logistics companies to improve coordination and efficiency.
- **Upskill the workforce:** Invest in training to equip employees with the skills needed to adopt and manage new technologies effectively, addressing labor shortages and improving adaptability.
- **Improve forecasting and planning:** Implement advanced demand forecasting tools and methodologies to better predict demand and streamline inventory management, especially given shorter product lifecycles.

Other solutions

- **Focus on quality:** Implement strict quality control processes and traceability for all components, as even a single faulty part can lead to costly recalls.
- **Streamline processes:** Focus on improving sustainability reporting and practices by using technology for accurate data collection and auditing.
- **Improve infrastructure:** Invest in and advocate for improvements to logistics infrastructure, such as roads and ports, to increase overall efficiency.

10.9 APPLICATION OF SCM AND E-SCM CONCEPTS TO REAL BUSINESS SITUATIONS

Supply Chain Management (SCM) and Electronic Supply Chain Management (e-SCCM) help organizations improve efficiency, reduce costs, and respond quickly to market demands. Their application can be seen across manufacturing, retail, service, logistics, and global business operations. Below are the major real-world applications explained with examples.

1. Procurement and Supplier Management

SCM Application

- Companies use SCM for selecting suppliers, negotiating contracts, and ensuring timely supply of raw materials.
- **Example:** Toyota uses long-term partnerships and JIT (Just-in-Time) procurement to reduce inventory holding cost and increase quality.

e-SCM Application

- Firms use e-procurement portals, online tenders, and digital contract management.
- **Example:** Tata Motors uses automated supplier portals for RFQs, order tracking, and invoice verification.

2. Inventory Management

SCM Application

- SCM concepts help maintain optimum inventory levels through EOQ, safety stock, and demand forecasting.
- **Example:** Maruti Suzuki balances raw material and finished goods inventory to avoid shortages or overproduction.

e-SCM Application

- Use of real-time systems, RFID, barcoding to monitor stock levels.
- **Example:** Walmart uses RFID to track products across warehouses, reducing stock-outs and excess inventory.

3. Production Planning and Scheduling

SCM Application

- Firms use Master Production Scheduling (MPS), Material Requirement Planning (MRP), and lean manufacturing to optimize production.
- **Example:** Samsung Electronics coordinates production and component supply across global factories.

e-SCM Application

- ERP integration helps synchronize production with demand in real time.
- **Example:** Bosch uses SAP-based systems to adjust production immediately when orders change.

4. Logistics and Transportation

SCM Application

- Route planning, warehouse management, fleet scheduling, and cost-effective transportation.
- **Example:** DHL uses multimodal transportation and cross-docking to deliver goods quickly.

e-SCM Application

- Electronic tracking, GPS, TMS (Transportation Management Systems).
- **Example:** Amazon provides real-time tracking and optimized delivery routes using digital logistics technology.

5. Distribution and Retail Operations

SCM Application

- Ensuring efficient distribution channels, demand forecasting, and order fulfilment.
- **Example:** Hindustan Unilever (HUL) uses a vast distribution network to serve rural and urban markets**.**

e-SCM Application

- Integration of POS data with warehouses and suppliers.
- **Example:** Reliance Retail uses POS analytics for automatic replenishment from distribution centres.

6. Customer Service and Relationship Management

SCM Application

- On-time delivery, order accuracy, and after-sales service.
- **Example:** Dell Computers uses build-to-order systems to deliver configured products on time.

e-SCM Application

- Customer portals, online order status, chatbots, and digital communication.
- **Example**: Flipkart updates order status, delivery schedule, and returns on apps.

7. Collaboration and Integration Across the Supply Chain

SCM Application

- Close coordination among suppliers, manufacturers, and distributors.
- **Example:** Procter & Gamble (P&G) shares demand forecasts with retailers like Walmart to reduce the bullwhip effect.

e-SCM Application

- Cloud-based information sharing and collaborative planning.
- **Example:** Coca-Cola uses digital dashboards for real-time collaboration with bottlers, distributors, and retail partners.

8. Global Supply Chain Management

SCM Application

- Managing global sourcing, international logistics, and global production.
- **Example**: Apple Inc. sources components from multiple countries and assembles products in China.

e-SCM Application

- Digital trade documentation, electronic payments, and blockchain for traceability**.**
- **Example:** Maersk uses blockchain with IBM to digitalize international shipping documents.

9. Reverse Logistics and Sustainability

SCM Application

- Handling product returns, repairs, recycling, and waste reduction.
- **Example**: HP recovers used cartridges and reuses plastic to manufacture new ones.

e-SCM Application

- Online return processing and automated pick-up schedules.
- **Example:** Amazon offers online return labels and instant refund initiation through digital systems.

10. Improving Decision-Making Through Data

SCM Application

- Forecasting, capacity planning, cost optimization.
- **Example:** Nestlé uses SCM data for production planning and raw material procurement.

e-SCM Application

- Big Data, IoT, AI used for predictive analytics.
- **Example:** Farm-to-Home supply chains in India use IoT sensors to monitor cold chain temperature in real time.

10.10 SUMMARY

Supply Chain Management integrates procurement, production, logistics, warehousing, inventory, and distribution to deliver products efficiently to customers. Its framework consists of core processes, supporting functions, and integrated flows of materials, information, and finance. SCM is guided by principles such as customer focus, collaboration, information sharing, responsiveness, lean operations, and continuous improvement. Electronic SCM (e-SCM) uses digital tools like ERP, EDI, RFID, IoT, cloud systems, and analytics to automate activities, provide real-time visibility, reduce costs, and enhance coordination. Together, SCM and e-SCM help organizations achieve efficiency, flexibility, competitive advantage, and superior customer satisfaction.

10.11 KEY WORDS:

1. Logistics
The process of planning, implementing, and controlling the movement and storage of goods from origin to consumption. It includes transportation, warehousing, and distribution activities.

2. Just-in-Time (JIT)
An inventory strategy where materials are delivered exactly when needed in production. It minimizes inventory holding costs and reduces waste.

3. Electronic Data Interchange (EDI)
A digital communication system that allows business documents like purchase orders and invoices to be exchanged electronically between organizations. It reduces errors and speeds up transactions.

4. Vendor Managed Inventory (VMI)
A system where the supplier monitors and manages the inventory levels at the buyer's location. It reduces stockouts and improves supply chain efficiency.

5. Enterprise Resource Planning (ERP)
An integrated software system that connects various functions like procurement, production, finance, and logistics. It provides real-time information to support better decision-making across the supply chain.

10.12 SELF-ASSESSMENT QUESTIONS: A. SHORT ANSWER QUESTIONS:

1. Define Supply Chain Management and explain its main components.
2. What are the key principles of effective Supply Chain Management?
3. What is Electronic Supply Chain Management (e-SCM)? Mention any four of its advantages.
4. Distinguish between traditional SCM and electronic SCM.

B, Essay Questions:

1. Explain in detail the Supply Chain Management Framework. Discuss its structural elements, key processes, and integrating flows with suitable examples.
2. Describe the principles of Supply Chain Management. How do these principles help in improving efficiency and competitiveness of modern organizations?
3. Discuss the role of technology in Supply Chain Management. Explain how ERP, RFID, IoT, and data analytics support e-SCM with real business examples.
4. Elaborate on Electronic Supply Chain Management (e-SCM). Discuss its features, components, benefits, challenges, and its impact on business performance.

10.13 SUGGESTED READINGS:

1. Vinod V. Sopel," Supply Chain Management: Text and Cases", Pearson Education, India,2012.
2. Saikumari V. & Purushothaman S.," Logistics and Supply Chain Management", Sultan Chand and Sons India,2023
3. Joel D. Wisner, Keah-Choon Tan, G. Keong Leong," Cengage / South-Western",5th Edition, 2019, Cengage / South-Western.

Dr.K. Lalitha

LESSON-11
MATERIALS REQUIREMENT PLANNING

OBJECTIVES OF THE LESSON:

After completing this unit, the learner will be able to:

1. Understand the concept and purpose of Materials Requirement Planning (MRP) in production and inventory control.
2. Identify the key planning elements of MRP, including MPS, BOM, and inventory records.
3. Explain the inputs required for an effective MRP **system** and how they support material planning.

Apply MRP methods to simple numerical problems involving gross and net requirements.

STRUCTURE

11.1 INTRODUCTION TO MATERIALS REQUIREMENT PLANNING:

In a large-scale industry, materials management is so important that nonavailability of required material leads to several problems, such as stoppage of production, loss of reputation due to not meeting the demand, loss of worker efficiency, and so forth. To avoid this and for smooth flow of production, a good coordinated materials management system is required. Material Requirements Planning (MRP) is such a tool that integrates all the connected people of materials. Material Requirements Planning is a management tool to ensure that materials and components/parts are available at the right time so that the finished products can be completed according to master production schedules. Materials Requirement Planning (MRP) is a systematic approach used in manufacturing and production environments to ensure the timely availability of materials required for the production process

Definition:

MRP is a system designed to plan manufacturing production. It identifies necessary materials, estimates quantities, determines when materials will be required to meet the production schedule, and manages delivery timing—with the goal of meeting demands and improving overall productivity**.**

According to American Production and Inventory Control Society (APICS): "MRP constitutes a set of techniques that use bill of materials (BOM), inventory data, and master production schedule (MPS) to calculate the requirement of materials for making a good line".

11.2 HISTORY AND OBJECTIVES OF MRP

MRP initially devised by the General Electric and Rolls Royce, makers of aeroengine, during 1950s but not commercialized by them. Joseph Orlicky later on developed and commercialized MRP concept in the year 1964, as a response to the Toyota Manufacturing Program. Black & Decker was the first company to use the concept of MRP in 1964 with Dick Alban as project leader. Almost 700companies have been implemented MRP by 1975. The number has been increased to about 8000 by the year 1981. Oliver Wight, in 1983, took MRP to next level and developed the philosophy of manufacturing resource planning (MRP II), also known as material planning. By 1989, about one third of the software industry was MRP II software sold to American industry.

Objectives of MRP

MRP is designed to enhance the inventory efficiency of a business/organization by estimating quantities of raw material and scheduling timely deliveries. Its primary purpose is to keep adequate inventory levels, so that to required raw materials are available as they are needed. There are three basic objectives of material requirement planning (MRP) as stated below:

1. To ensure required materials are available for manufacturing and products/goods are available for delivery to customers
2. To maintain the lowest possible material and product levels in ware house
3. To plan production activities, delivery schedules and purchasing activities

11.3 FUNCTIONS OF MRP

Companies following a systematic framework for planning material may keep their production department, inventory control and purchasing department in order and ensures smooth flow of material through facility. MRP system may not run a production facility by its own, but it allows the company to maintain a steady flow of material through supply chain. Some of the functions of an MRP system include:

i. Inventory Management
ii. Cost Reduction
iii. Production Optimization

i. Inventory Management: Primary function of MRP is to look that the raw materials are available when they are required. This in turn helps in ensuring that company does not have too little or too much material in store. Inventory management is needed as maintaining too much material will incur storage costs and maintaining too little inventory leads to delays and shortages.

ii. Cost Reduction: By using MRP system effectively, there will be a significant reduction in cost for manufacturing facilities. First, by minimizing the time that the managers spend on manually calculating the quantities and time for each material. Second, via inventory management, as MRP will assure that the money is not lost by storing unnecessary material.

iii. Production Optimization: As MRP is intended to manage materials, it acts as a prominent tool to improve production process. When the material/parts/items flow through the production facility, companies can save time and decrease costs. Men and machines work with consistency at faster rate.

11.4 MRP PLANNING ELEMENTS

a. Master Production Schedule (MPS)

The Master Production Schedule (MPS) is the starting point of the entire MRP process. It is a detailed plan that specifies the quantities of finished products to be produced and the time periods in which they are needed.

Key Features of MPS

1. **Time-Phased Plan**: The MPS is prepared for weekly or daily time buckets, outlining when each product batch will be produced.
2. **Focus on End Items:** It lists only the final products or major assemblies that have independent demand, usually derived from customer orders or sales forecasts.
3. **Demand Management:** MPS balances customer demand with production capabilities, ensuring realistic and achievable schedules.
4. **Drives the MRP System:** All dependent demand calculations for components and subassemblies originate from the MPS.

Functions of MPS

- Establishes priorities for production.
- Converts sales forecasts into production quantities.
- Coordinates activities among production, procurement, and inventory teams.
- Helps identify capacity constraints and adjust plans accordingly.

Importance of MPS

A well-prepared MPS ensures stability in production, minimizes frequent schedule changes, and provides clarity for downstream planning processes. Inaccuracies at the MPS level will spread throughout the MRP system, leading to errors in material planning.

b. Bill of Materials (BOM)

The Bill of Materials (BOM) is a structured list that specifies all components, raw materials, subassemblies, and intermediate parts required to manufacture a finished product. It is an essential input for determining dependent demand.

Types of BOM

1. **Single-Level BOM:** Lists only the immediate components required to assemble the final product.
2. **Multi-Level BOM:** Shows the hierarchical structure of components and subassemblies, representing the product's full breakdown.

3. **Indented BOM**: Displays the product structure in a tree-like format with levels clearly marked.
4. **Modular BOM:** Groups components into modules used in assemble-to-order environments.

Functions of BOM

- Identifies the relationship between parent items and child components.
- Provides quantity per requirement for each component.
- Is used in BOM explosion, a key step in MRP to calculate gross requirements.

Importance of BOM

Accurate BOM records are crucial; even small errors in component quantities or structure can cause shortages or excessive inventory. BOM ensures transparency in product design and supports efficient procurement and production planning.

c. Inventory Status File (ISF) / Stock Records

The Inventory Status File (also known as Stock Records or Inventory Master File) contains all essential inventory-related information required to compute net material requirements.

Information Contained in the ISF

1. On-Hand Inventory: The available stock of each item.
2. Scheduled Receipts: Outstanding purchase or production orders due for arrival in upcoming periods.
3. Allocated Inventory: Stock reserved for existing orders.
4. Safety Stock Levels: Minimum quantity needed to avoid stockouts.
5. Lead Time: Time required to procure or produce the item.
6. Lot Size Data: Details on ordering policies such as fixed lot size or economic order quantity.

Functions of ISF

- Provides the current inventory position for every item.
- Helps calculate projected on-hand quantities.
- Supports netting calculations to determine exact requirements.
- Ensures MRP outputs remain accurate and reliable.

Importance of ISF

The accuracy of MRP depends heavily on the precision of inventory records. Any errors or outdated information in the ISF will distort net requirement calculations and lead to production inefficiencies**.**

d. Lead Time and Lot Sizing Rules

1. Lead Time

Lead time refers to the total time required to replenish an item, either through internal production or external procurement.

Types of Lead Time

1. Procurement Lead Time: Time taken to place and receive a purchase order.
2. Manufacturing Lead Time: Time required for processing, assembly, and inspection of components.
3. Cumulative Lead Time: Total lead time for multi-level products, considering all dependent components.

Role of Lead Time in MRP

- Determines when planned order releases should be scheduled.
- Ensures materials arrive exactly when needed, avoiding early arrivals or delays.
- Is essential for time-phasing requirements in the MRP table**.**

2. Lot Sizing Rules

Lot sizing rules specify the quantities to be ordered or produced when a requirement arises.

Common Lot Sizing Techniques

1. **LFL (Lot-for-Lot):**
   - Orders exactly the quantity required for each period.
   - Minimizes inventory but increases ordering frequency.
2. **FOQ (Fixed Order Quantity):**
   - Orders a fixed quantity every time an order is placed.
   - Helps achieve economies of scale but may increase inventory.
3. **EOQ (Economic Order Quantity):**
   - Determines order size that minimizes total inventory and ordering costs.
   - Not always ideal for time-phased MRP, but used for stable demand items.
4. **Periodic Order Quantity (POQ):**
   - Orders enough material to cover several periods at once.
   - Balances ordering costs and inventory carrying costs.

Importance of Lot Sizing

Proper lot sizing helps maintain optimal inventory levels, reduce cost, and ensure smooth production flow. Incorrect lot-sizing rules can lead to excess inventory, stockouts, or frequent ordering.

11.5 MRP INPUTS EXPLAINED

The main inputs for Material Requirements Planning (MRP) are the calculations that MRP performs are based on the data inputs. Inputs for MRP are master schedules, bill of materials, and inventory status records, these inputs work together to calculate when and how much of each raw material or component is needed for production.

Inputs of MRP

After going through the above information one can easily notice that the following are the inputs required for MRP:

i. Customer orders
ii. Forecast demand
iii. Master production schedule (MPS)
iv. Bill of material (BOM)
v. Inventory Records

i. Customer Orders: Customer orders refer to the specific information that the organization may receive from customers and includes one-offs and regular ordering patterns.

ii. Forecast Demand: This predicts how much probable demand there will be for a product or service. Basically, forecast demand is based on historic data and present trend.

iii. Master Production Schedule (MPS): Both forecast demand and customer orders feed into the master production schedule. The MPS is a plan that a company develops for production, staffing, or inventory. It is a comprehensive schedule of what is to be produced in a given period based on the accurate estimate of demand. It is a list of end products to be produced in a given period. It also includes production costs, inventory costs, inventory information, supply, lot size, lead time, and development capacity. An exemplary MPS used in construction and shop floor production shops is shown in the below Tables 11.1 and 11.2, respectively, in two different models.

Table 11.1. Exemplary master production schedule of a construction building

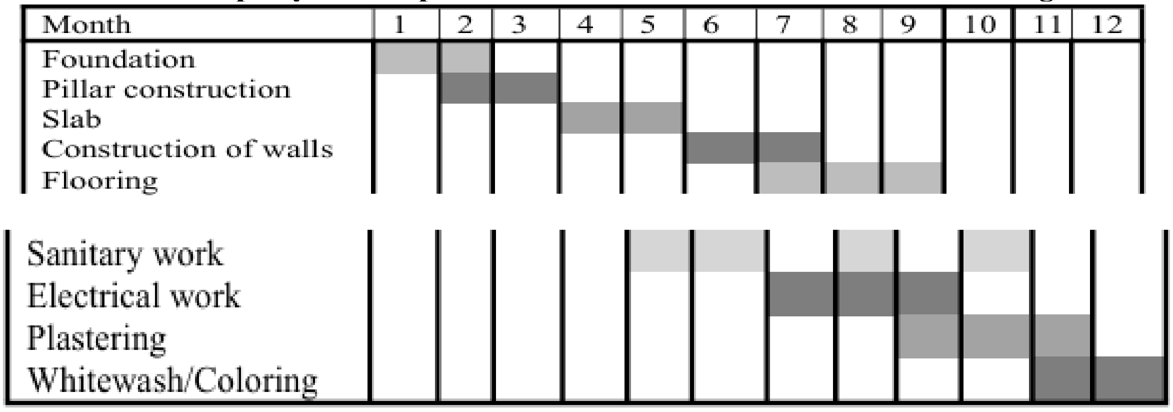
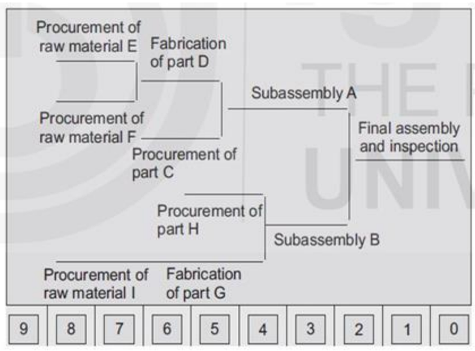


Table 11.2. Production Schedule in ABC shop floor

Month	April				May		
Week Number	**1**	**2**	**3**	**4**	**1**	**2**	**3**
Product 1		600	300		1200		200
Product 2	800	200				400	100
Product 3			500	800		400	500

iv. Bill of Materials (BOM): It is one of the three primary inputs of MRP and is a list of parts or components required for producing the final product, showing all the details of its required quantity at every level of its parts assembly/subassembly. The visual depiction of the requirements in a bill of materials where all components are listed by levels is called product structure tree (PST). The final product is designated generally by "0 level" while the raw material stage at the 10th level in BOM is as shown in the exemplary Figure 11.3 For a better understanding of PST and BOM, consider an example of a clipboard. General assembly clipboard components, their product structure tree, along with the levels of bill of materials are shown in Figure 3.4. Finally, the bill of materials for the clipboard is prepared as shown in Table 11.3

Figure 11.3: Exemplary product structure tree showing levels of BOM



v. Inventory Records: These are the raw materials and the completed products that you either have on hand or have already ordered. An exemplary inventory record of welding electrodes of a hypothetical company is given in Table 11.4 for reference.

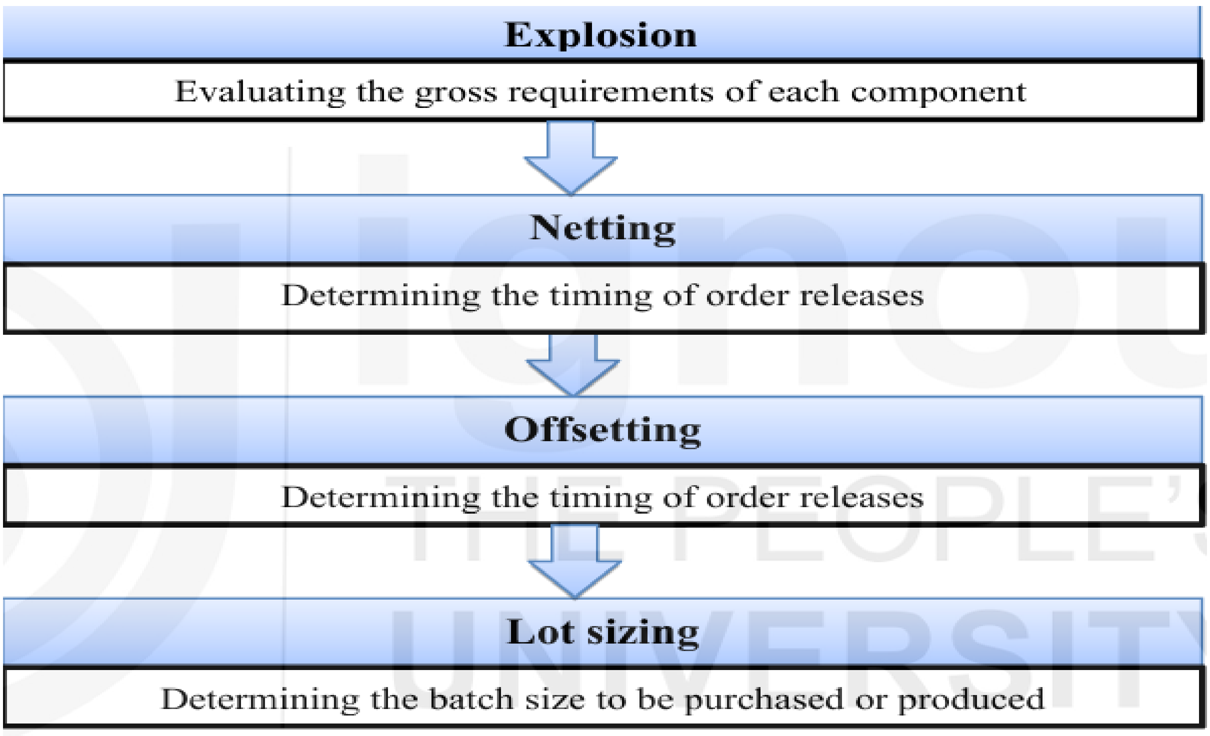
Table 11.4: Sample inventory record of welding electrodes

Days	1	2	3	4	5	6	7
Gross Requirement	120	-	20	-	150	50	-
Schedule receipt/in transit	50	20	-	30	70	50	-
On hand	70	50	50	60	50	-	-
Net requirement	70	-	10	40	120	50	-
Planned order release	80	-	10	50	120	50	-

Integrity of MRP Input Data 80 10 50 120 50 Data integrity refers timeliness, completeness, and accuracy. Input data for MPR should be provided by the concerned people and/or machine in time and accurately. If the data is entered into the system is incorrect, MRP may lead to false information. MRP should provide the organization and manager with credible data, but the presence of errors may destroy the credibility and results to ridiculous plan. Further, attitude, Discipline, and training are the keys entities to data integrity.

11.6 MRP PROCESS FLOW

The Material Requirements Planning (MRP) process is a structured approach to ensure the availability of materials for production and sales, avoiding stockouts while minimizing inventory costs. It involves a series of steps driven by master data and demand inputs to generate procurement or production proposals. The following is the flow chart:



Exploding:
This step uses the Bill of Materials (BOM). In this, components and its quantities required for each item is listed. Generally, BOM's are characterized by the number of levels it involves, followed by the structure of assemblies and sub-assemblies. The first level is represented by the MPS and is 'exploded' down to final assembly. Thus, a given number of finished products are exploded to see how many items are required at the final assembly stage.
Netting The next step is 'netting', in which any stock on hand is subtracted from the gross requirement determined through explosion, giving the quantity of each item needed to manufacture the required finished products.
Offsetting In offsetting, the timing of order released is calculated. In order to meet net requirements, an order release is offset by the production lead time or supplier delivery time.
Lot sizing Lot sizing is the step in which the batch size to be purchased or produced is determined.

11.7 NUMERICAL PROBLEMS IN MRP

Numerical Problems in MRP" generally refers to practical exercises in Material Requirements Planning, a production planning and inventory control system. These problems typically involve calculating material needs based on a production schedule, the bill of materials, and current inventory.

Key inputs for solving these problems include:
- **Master Production Schedule (MPS):** The quantity and timing of all end products to be produced over a specific period.
- **Bill of Materials (BOM):** A list of all raw materials, sub-assemblies, and components needed to create one unit of a product, including their quantities.
- **Inventory Status File:** Current inventory levels, scheduled receipts (orders expected to arrive), and lead times for each item.

Example Problem Structure and Solution Steps
A common problem requires filling out an MRP planning grid for each component of a product structure.
The basic calculation process involves several steps:
1. **Determine Gross Requirements:** The total demand for an item during a specific period. For a component, this is derived from the planned order releases of its parent item in the BOM.
2. **Account for Scheduled Receipts:** Add any orders that are expected to be received at the beginning of the period.
3. **Calculate Projected** On-Hand Inventory: The previous period's on-hand inventory plus scheduled receipts minus the gross requirement.
4. **Calculate Net Requirements**: If the projected on-hand inventory is insufficient to cover the gross requirement, a net requirement exists.
5. **Plan Order Releases:** Based on the net requirement, determine the size and timing of the order release (either production or purchase) using the specified lot-sizing procedure (e.g., lot-for-lot, fixed order quantity) and accounting for the item's lead time. The planned order release date for a component becomes the gross requirement date for its sub-components.

Problem-1:
Goal: Compute Net Requirements, Planned Receipts and Planned Releases.
Data

- Planning horizon: Weeks 1–6
- Gross requirements (finished item): 50, 60, 40, 70, 30, 50
- On-hand at start = 20 units
- Scheduled receipts = 0
- Lead time = **1 week**
- Lot sizing = **Lot-for-Lot (order exactly net requirement)**

Step-by-step
We process week by week. Projected on-hand at start = 20.
Week 1:

- Gross req = 50. Projected on-hand 20 < 50 → **Net requirement = 50 − 20 = 30**.
- Under L4L we plan a receipt of 30 in Week 1. (Because LT = 1, the order to get this
- receipt must have been released before the planning horizon.)
- Projected on-hand after meeting demand = 0.

Week 2:
- Gross = 60. Projected on-hand 0 → **Net = 60** → plan receipt 60 in Week 2. Projected on-hand 0.

Week 3:
- Gross = 40 → **Net = 40** → plan receipt 40.

Week 4:
- Gross = 70 → **Net = 70** → plan receipt 70.

Week 5:
- Gross = 30 → **Net = 30** → plan receipt 30.

Week 6:
- Gross = 50 → **Net = 50** → plan receipt 50.

Results (Weeks 1 → 6)

Week	**Gross Req**	**Projected On-hand (start)**	**Net Req**	**Planned Receipt**
1	50	20	30	30
2	60	0	60	60
3	40	0	40	40
4	70	0	70	70
5	30	0	30	30
6	50	0	50	50

Planned order releases (where you place the orders) = planned receipts **shifted back by lead time (1 week)**:

- Receipt in Week 1 → release **before period 1** (i.e., prior to the planning horizon).
- Receipt Week 2 → release Week 1.
- Receipt Week 3 → release Week 2.
- Receipt Week 4 → release Week 3.
- Receipt Week 5 → release Week 4.
- Receipt Week 6 → release Week 5.

With L4L and no scheduled receipts, every gross requirement beyond initial on-hand becomes a net requirement and is planned as an equal receipt. Always remember to shift releases back by the lead time.

Problem-2-
EOQ (Economic Order Quantity) example
Goal: Calculate EOQ, number of orders per year, and total relevant inventory cost.
Data

- Annual demand $D = 12{,}000$units
- Ordering cost $S = \$50$per order
- Holding cost per unit per year $H = \$2.50$

EOQ formula

$$\text{EOQ} = \sqrt{\frac{2DS}{H}}$$

$$\text{Annual number of orders} = \frac{D}{\text{EOQ}}$$

$$\text{Total relevant cost} = \frac{D}{\text{EOQ}} \cdot S + \frac{\text{EOQ}}{2} \cdot H$$

Calculation

$$\text{EOQ} = \sqrt{\frac{2 \times 12{,}000 \times 50}{2.5}} = \sqrt{\frac{1{,}200{,}000}{2.5}} = \sqrt{480{,}000} \approx 692.8 \text{ units}$$

Annual orders ≈ $12{,}000/692.8 \approx 17.3$orders per year.
Total relevant cost ≈ $\$1{,}732.05$per year (ordering + holding). EOQ gives the most economical fixed lot size when demand is steady and ordering & holding costs are known.

11.8 BENEFITS AND LIMITATIONS OF MRP

MRP system prioritizes materials based on the need and updates these priorities regularly. Thus, materials are ordered at the right time, and whenever changes occur, the MRP system revises the due dates and schedules with minimum delays. As a result, MRP enables to have right components in the right quantity at the right time. This minimizes unnecessary in-process inventory without any machinery, and manpower resources can be effectively utilized. Thus, the benefits due to MRP may be witnessed as follows:

- Reduction in finished goods inventory, in-process inventory, raw material, components and parts, and safety stock.
- Reduction in lead time.
- Reduction in past due orders.
- Advantage due to prioritization.
- Quick response to changes in demand.
- Improved customer service.
- Increased productivity.
- Increased inventory turnover.
- Effective utilization of capacity, machinery, and manpower
- Good control over production department.

LIMITATIONS OFMRP

1. There should be a valid master production schedule (MPS). Any inaccurate forecasts or sudden changes in demand may result in inaccuracy in MPS.
2. Bill of material and inventory status must be computerized to prevent manipulations.
3. Errors in external lead time (at suppliers) or internal lead time (at manufacturing) cause wrong MRP calculation.
4. Causes overdependence on MRP outputs due to highly computationally intensive approach. Any inaccuracy leads to failure of MRP to a large extent.
5. MRP system requires reliable data; otherwise MRP system will become a mess.
6. MRP is more materials management oriented, but it should be a manufacturing or assembly-oriented product structure.
7. The success of MRP system requires • maintenance of accurate stock records, • correct and timely reporting system about the completion of jobs and orders, and • integration of all concerned with MRP.

11.9 SUMMARY

Material Requirements Planning is a management tool to ensure that materials and components/parts are available at the right time so that the finished products can be completed according to master production schedules. It is designed to enhance the inventory efficiency of a business/organization by estimating quantities of raw material and scheduling timely deliveries. MRP system may not run a production facility by its own, but it allows the company to maintain a steady flow of material through supply chain. The calculations that MRP performs are based on the data inputs. Inputs for MRP are master schedules, bill of materials, and inventory status records, whereas outputs for MRP are purchase orders, material plan, work orders and reports' transforms inputs to outputs systematically following a sequential step namely explosion, netting, offsetting and lot sizing.

11.10 GLOSSARY OF TECHNICAL TERMS USED

1. Bill of materials (BOM): A bill of materials is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts, and the quantities of each needed to manufacture an end product

Gross Requirements (GR): This is the total demand for an item during a specific time period.

Product Structure Tree: This is a visual representation of the bill of materials, showing how many of each part and how many sub-parts required to produce the product process.

Low-Level Code: This is the lowest level code of an item in the bill of materials and indicates the sequence in which you run items through an MRP.

Netting: It is a process step of MRP where gross requirements are adjusted to account for on-hand inventory or quantity on order.

Projected on Hand (POH): This is the amount of inventory that is estimated to be available after meeting the gross requirement

Net Requirements (NR): This is the actual, required quantity to be produced in a particular time period.

Purchase Orders: It is the purchasing schedule that includes the order a company gives to the supplier to supply the material

11.11. SELF-ASSESSMENT QUESTIONS: A. SHORT ANSWER QUESTIONS

1. What is MRP?
2. Discuss the Benefits of MRP
3. BOM
4.Master Production Schedule

B. Essay Questions:

1. Explain the MRP Planning Elements in detail.
2. Discuss the key inputs of MRP: Master Production Schedule (MPS), Bill of Materials (BOM), and Inventory Status File (ISF).
3. Explain how each input supports the MRP process. Illustrate with a product structure diagram and numerical BOM explosion example.
4. Examine the MRP Planning Flow and give your insights with suitable examples.
5. EOQ, and POQ calculations) Examine the importance of Lead Time, Lot Sizing Rules, and Safety Stock in MRP. How do they affect planning decisions? Support your answer with numerical cases (e.g., L4L, FOQ,

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LESSON-12
PURCHASE MANAGEMENT

LESSON OBJECTIVES:

After Completion of the lesson the student will be able to

1. Understand the basic principles of purchase management.
2. Describe the steps in the purchase process.
3. Identify and differentiate types of purchase systems.
4. Recognize the role of purchasing in cost efficiency and supply chain performance.
5. Apply purchase management concepts to practical business situations.

STRUCTURE

12.1 INTRODUCTION TO PURCHASE MANAGEMENT

Purchase is an integral process in the majority of businesses. A manufacturing company purchases the raw materials or services needed to make its products. A retail company buys and sells items, while a wholesaler does the same in bulk. So, in both manufacturing and retail businesses purchasing drives the operation of the business. Therefore, purchasing and all its related processes should be managed for maximum quality and timeliness at the minimum cost. Purchase management is one of the most vital areas of a company’s operation that can directly affect the bottom line. It is essential to understand the objectives of purchasing management to get the best results for the business.

Purchase management is managing the purchase of the goods and services that the company requires from suppliers and vendors. It is often an integral part of the company’s operations and is an opportunity to improve the efficiency and profitability of the company. The purchase process is usually meant to acquire the raw materials, parts, machinery, equipment, and services that the company requires at the right time and at an advantageous price.

Definition:

According to Dr. Walters, **purchasing management** (or "scientific purchasing") is defined as: “The **procurement** by the purchase of the proper materials, machinery, equipment and **supplies** for stores used in the manufacture of a product adopted to marketing in the proper **quality** and **quantity** at the proper **time** and at the lowest **price**, consistent with the quality desired".

12.2 PRINCIPLES OF PURCHASE MANAGEMENT

The principles of purchase management, often referred to as the "Seven Rights" of purchasing, are fundamental guidelines for ensuring effective and ethical acquisition of goods and services. These principles aim to obtain the best value for money, maintain supply chain efficiency, and comply with legal and ethical standards.

The Seven Rights of Purchase Management

Effective purchasing is guided by ensuring every acquisition meets the following criteria:

- **Right Quality:** The quality of the material should be "just right," meaning it meets the specific requirements and standards needed for the intended purpose, without being unnecessarily high or too low. This ensures the final product or service also meets quality expectations.
- **Right Quantity:** Purchasing the correct amount of material is essential for avoiding both stockouts (which disrupt production) and overstocking (which ties up capital and storage space).
- **Right Price:** The goal is to procure materials at the best possible price without compromising on quality. This involves negotiation, comparison of bids, and leveraging bulk discounts to control costs and improve profitability.
- Right Time: Timely procurement ensures that materials are available when needed to prevent production delays or operational disruptions. This requires effective scheduling and reliable supplier lead times.
- **Right Source:** Selecting reliable and reputable suppliers is crucial for consistent quality and delivery. This involves evaluating vendor reputation, financial stability, and production capacity to build strong, long-term relationships.
- **Right Place:** Materials must be delivered to the correct location (e.g., the specific warehouse or facility) to prevent additional logistical costs, inefficiencies, or damage during transport.
- **Right Contract/Terms:** Establishing clear and fair purchase terms, including payment conditions, legal compliance, and ethical sourcing policies, is vital for managing risk and ensuring social responsibility.

Additional Guiding Principles

Beyond the core "Seven Rights," modern purchase management incorporates broader operational principles:

- **Accountability and Integrity:** All purchasing activities should be transparent, fair, and free from corruption. There must be clear accountability for decisions made during the procurement process.
- **Competition:** Utilizing a competitive process, such as comparing multiple bids, helps ensure the organization achieves the best value for its expenditures.
- **Efficiency:** The entire purchasing cycle should be streamlined to minimize administrative costs and reduce lead times for acquiring goods.
- **Supplier Relationship Management**: Building and maintaining strong relationships with key suppliers fosters collaboration, reduces risks, and can lead to better pricing and terms.
- **Centralized Purchasing:** Depending on the organizational structure, purchasing may be centralized to leverage bulk buying power and standardize processes across the company, or decentralized to meet specific local needs.

12.3 IMPORTANCE OF PURCHASE MANAGEMENT

Purchase management is crucial because it ensures a steady supply of quality goods at optimal costs, preventing production halts, boosting profits, enhancing supplier relations, and mitigating risks, ultimately driving overall operational efficiency and strategic success by aligning procurement with business goals. It's not just buying; it's strategic resource optimization that impacts everything from cash flow to customer satisfaction.

Key Reasons for its Importance:

1. **Cost Savings & Profitability:** Secures best prices through negotiation, reduces waste, and improves asset turnover, directly impacting the bottom line.
2. **Operational Continuity:** Ensures timely availability of materials, preventing stockouts or overstocking, which keeps production and service delivery smooth.
3. **Quality Assurance:** Guarantees that purchased goods meet required specifications, maintaining product quality and customer satisfaction.
4. **Risk Management:** Minimizes supply chain disruptions by vetting suppliers, building alternative sources, and managing market volatility.
5. **Supplier Relationship Management:** Builds strong, reliable partnerships with vendors, leading to better terms and innovation.
6. **Strategic Advantage:** Contributes to broader business objectives, such as sustainability and import substitution, through smart sourcing.
7. **Transparency & Control:** Creates clear audit trails, improves accountability, and helps coordinate with other departments (finance, production).

In essence, effective purchase management transforms a transactional activity into a strategic function that safeguards resources and fuels growth.

12.4 PURCHASE PROCESS

The purchase process is a standardized series of steps a business takes to acquire goods or services, typically from identifying a need to paying the vendor. Key steps include: recognizing the need, specifying requirements, finding and selecting a supplier, getting order approval, placing the order, receiving and inspecting the goods, and processing the payment. A formal process ensures consistency, proper authorization, and helps manage spend.

Steps in the purchasing process

Below are the steps of a typical purchasing process:

1. Identify the need

The purchasing process begins when the business recognizes that they have a need for a product, tool or service that will enhance their operations. Team members can help identify needs as they complete their daily work by notifying their supervisors of any challenges they encounter. Once the organization identifies a need, they can begin the purchasing process.

2. Specify the requirement

During this stage, leaders investigate the need further and come up with a plan for exactly what they require. For example, a frequent shortage of printer paper becomes the need for weekly deliveries of 500 sheets of inkjet printer paper to ensure a continuous supply. The person who identified the need often works with other team members and management to come up with the right solution to the problem, especially when concerning a larger purchase. For example, the employee who identified the need for more printer paper may have the power to specify the requirement on their own, while the need for new computer systems throughout the entire office likely requires input from others.

3. Find and choose a supplier

Find potential suppliers who can provide the specific product or service you want to purchase. You can conduct your own research online or contact those in your professional network to ask for recommendations. If shipping costs are a factor in your purchase, look for businesses in your local area. During this stage, it is a good idea to consider several suppliers and compare them against one another. When necessary, contact the supplier and request a quote or proposal from them. As you are considering suppliers, consider factors such as cost, reliability and delivery time.

4. Negotiate costs

In many situations, it is possible to negotiate costs with a supplier, especially when placing high-priced orders or orders you expect to recur regularly. Contact the supplier you are considering and ask if they are open to negotiating the price. Suppliers may negotiate if it means they can secure a large or long-term contract for their business.

5. Get order approval

Before your business can initiate the transaction, you may need to get approval for the order. This could include working with upper management and the accounting department to ensure there are enough available funds within the budget for the purchase. In some scenarios, the business may also need to establish a line of credit with the supplier. If you haven't already, explain to management why this purchase is necessary and how you achieved a reasonable price from the supplier.

6. Place the order

Once both sides agree to the transaction, you can formally place the order. Have both sides agree to the specific details, such as price, delivery times, fees and installations. Get everything in writing and have representatives from both organizations sign it. Then keep a copy of this agreement in your files for future reference.

7. Receive and approve the order

When the order arrives, check for any issues with the product or anything the supplier failed to deliver on. Timeliness is key because if there are any problems, the supplier should address them before you release the rest of the payment.

8. Review supplier performance

Whether you work with a supplier on a one-time transaction or set up recurring transactions, make it a regular practice to review your suppliers' deliveries for quality and timeliness. A record of these reviews can help you identify and track any issues that might arise later in your contract. Continue relationships with suppliers who continue to meet your business's needs.

12.5 TYPES OF PURCHASE SYSTEMS

The main types of purchasing systems, in terms of organizational structure, are centralized, decentralized, and hybrid. Other types relate to the method or system of ordering, such as manual vs. automated, or market purchasing vs. contract purchasing.

Organizational Structure Systems

These models define where purchasing authority lies within an organization:

- **Centralized Purchasing:** All purchasing activities are managed by a single, dedicated department or location.
  - **Advantages:** This system often leads to volume discounts due to bulk purchasing, better control over spending, consistent policy enforcement, and specialized purchasing expertise.
  - **Disadvantages**: It can be less responsive to urgent local needs, may involve more bureaucracy, and might not leverage local supplier relationships effectively.
- **Decentralized Purchasing:** Purchasing authority is distributed among different departments, branches, or local business units.
  - **Advantages:** This model offers greater flexibility, faster decision-making, better communication with local suppliers, and more responsiveness to specific departmental needs.
  - **Disadvantages:** It can result in higher costs due to a lack of bulk purchasing power, potential duplication of effort, less control over overall spending, and inconsistency in processes across the organization.
- **Hybrid Purchasing:** This model combines elements of both centralized and decentralized systems. Strategic procurement activities (like setting policies, managing key supplier relationships, and major contract negotiations) are handled

centrally, while day-to-day, low-value purchases are managed locally. This approach aims to balance efficiency with flexibility.

Other Types of Purchasing Systems/Methods

Beyond organizational structure, purchasing systems can also be classified by their operational method:

- **Manual Purchasing System:** A traditional, paper-based process using physical documents for requisitions, approvals, and orders. This system is simple but prone to human error and inefficiency.
- **Automated Purchasing System:** Uses software (e.g., e-procurement or ERP systems) to streamline the process digitally, reducing paperwork and improving efficiency, accuracy, and compliance.
- **Market Purchasing**: Involves buying from the open market to take advantage of price fluctuations or immediate availability, typically for non-contracted items.
- **Contract Purchasing / Rate Contract:** A long-term agreement is established with a supplier for specific goods at a set price over a period, often used in government or public sectors.
- **Just-in-Time (JIT) Purchasing:** An inventory management strategy where materials are purchased and received just as they are needed for production or sale, minimizing holding costs.

12.6 FACTORS INFLUENCING PURCHASE DECISIONS

The factors influencing consumer purchase decisions can be broadly categorized into five major groups: psychological, social, cultural, personal, and economic. These factors interact in complex ways to shape a consumer's behaviour and choices.

Key Factors Influencing Purchase Decisions

Psychological Factors

These factors relate to the individual's mind and internal processes.

- **Motivation:** The internal drive that prompts a person to satisfy a need. Purchases are often driven by fulfilling specific needs, from basic survival to self-esteem.
- **Perception:** How a consumer interprets information and forms a meaningful picture of the world and products. Marketing messages and brand image are filtered through individual perception.
- **Learning:** Changes in an individual's behaviour arising from experience. Consumers learn about product quality, price, and features over time, which influences future decisions.
- **Beliefs and Attitudes:** A consumer's consistent evaluations, feelings, and tendencies toward an object or idea. These are often deep-seated and can be difficult for marketers to change.

Social Factors

These influences stem from a consumer's interactions with others.

- **Family:** One of the most significant influences, as family members shape values, attitudes, and purchasing habits from an early age.
- **Reference Groups:** Friends, social groups, and professional associations that individuals look to for guidance. Peer pressure and the desire to conform heavily influence choices, especially for visible products like clothing or technology.
- **Social Status/Role:** An individual's position within society or various groups (e.g., occupation, family role) often dictates specific purchasing behaviours that align with perceived status.
- **Social Proof/Reviews:** The opinions and reviews of other consumers, especially online ratings and testimonials, heavily influence modern purchase decisions by providing validation and reducing uncertainty.

Cultural Factors

Culture and subcultures provide the broadest and deepest influence on behaviour.

- **Culture:** The shared values, beliefs, perceptions, and behaviours passed down through generations. It defines what is considered acceptable or desirable within a society.
- **Subculture**: Smaller groups within a culture with shared values and experiences (e.g., religion, geographic region, race).
- **Social Class:** Division of society into hierarchical groups based on income, education, and occupation. Different classes often share similar product and brand preferences.

Personal Factors

These are individual characteristics that influence choices.

- **Age and Life Cycle Stage:** Purchasing habits change throughout one's life, from teenage years to retirement, focusing on different needs like education, family homes, or health.
- **Occupation and Income:** A person's job and financial situation directly determine their purchasing power and the types of products they can afford.
- **Lifestyle:** A person's pattern of living as expressed in their activities, interests, and opinions. Health-conscious individuals, for example, will prioritize organic food and fitness products.
- **Personality and Self-Concept:** An individual's unique psychological characteristics that lead to relatively consistent responses to their environment. Consumers often choose brands that align with their self-image.

Economic and Marketing Factors

These external factors relate to price, availability, and promotion.

- **Price and Perceived Value:** A key determinant of purchase intention; consumers balance cost against the perceived value and quality of the product.
- **Promotions and Advertising:** Marketing efforts, including discounts, promotions, and messaging, influence awareness and create a sense of urgency.
- **Product Quality and Features:** The inherent quality, durability, and specific benefits a product offers play a crucial role in long-term satisfaction and repeat purchases.
- **Ease of Purchase/Availability:** Convenience and a smooth purchasing experience, from an easy-to-use website to stock availability, significantly reduce cart abandonment and encourage sales.

12.7 MODERN TRENDS IN PURCHASING

The purchasing function has transformed significantly due to globalization, digital technology, increasing customer expectations, sustainability requirements, and the need for cost competitiveness. Modern purchasing aligns procurement with organizational strategy, integrates technology to improve efficiency, and emphasizes collaboration with suppliers to achieve long-term value. Modern purchasing is driven by technology, data, sustainability, and strategic partnerships. Organizations that adapt to these trends achieve better cost efficiencies, improved supplier performance, higher transparency, and stronger supply chain resilience.

Modern Trends in Purchasing – Detailed Explanation

1. E-Procurement and Digital Purchasing

E-procurement refers to conducting procurement activities electronically using dedicated platforms or ERP systems. E-Procurement (Electronic Procurement) refers to the use of internet-based information systems, digital tools, and automated workflows for performing procurement activities such as requisitioning, tendering, ordering, contracting, invoicing, and payment. It replaces manual, paper-based systems with online platforms that ensure speed, accuracy, transparency, and cost efficiency.

KEY FEATURES

- Online requisitioning and approval workflows
- E-tendering, e-bidding, reverse auctions
- Electronic Request for Quotation (e-RFQ)
- Digital purchase orders and e-invoicing
- Vendor self-service portals

Technologies Used in E-Procurement

- ERP systems (SAP, Oracle, Microsoft Dynamics)
- Cloud-based procurement platforms (SAP Ariba, Coupa, Jaggaer)
- Artificial Intelligence (AI) for automation
- RPA (Robotic Process Automation) for routine tasks
- Digital signatures and e-authentication

- Blockchain for secure transactions
- Mobile apps for approvals and tracking

5. Process of E-Procurement (Step-by-Step)

1. Identification of need
2. Online requisition creation
3. Digital approval workflow
4. E-sourcing or tendering
5. Supplier evaluation and selection
6. System-generated purchase order
7. Delivery tracking and goods receipt
8. E-invoice submission
9. Automated three-way matching
10. Online payment processing
11. Audit trail and reporting

6. Advantages of E-Procurement

a. Speed and Efficiency

- Faster approvals and reduced cycle time
- Real-time communication with suppliers

b. Cost Savings

- Lower administrative and transaction costs
- Better negotiation through reverse auctions

c. Transparency and Compliance

- Every activity is recorded in an audit trail
- Reduces fraud, corruption, and manipulation

d. Improved Accuracy

- Minimizes manual errors
- Standardized formats and automated checks

e. Enhanced Supplier Management

- Supplier performance tracking
- Centralized database of suppliers

f. Better Decision-Making

- Advanced analytics on spend, price trends, supplier risks

Limitations / Challenges of E-Procurement

- High initial implementation cost
- Need for staff training
- Resistance to change from traditional practices
- Data security risks
- Dependence on internet connectivity
- Integration challenges with legacy systems

Applications of E-Procurement in Industry

- Manufacturing: raw materials, spare parts, tools
- Healthcare: medical supplies, medicines, equipment
- Retail: merchandise ordering and replenishment
- Government: transparent public procurement
- IT industry: software licenses, hardware procurement

Impact of E-Procurement on the Purchasing Function

- Shifts purchasing from clerical work to strategic roles
- Greater focus on supplier performance, analytics, and compliance
- Reduces paperwork and manual intervention
- Enhances buyer–supplier collaboration

Future Trends in E-Procurement

- AI-driven autonomous purchasing
- Predictive analytics for demand and price forecasting
- Increased use of blockchain for traceability
- Mobile-first procurement ecosystems
- Seamless integration with supply chain platforms

2. Strategic Sourcing

Strategic sourcing focuses on long-term, data-supported procurement decisions.
Components

- Spend analysis
- Supplier market research
- Supplier evaluation and ranking
- Total Cost of Ownership (TCO) analysis
- Developing sourcing strategies (single/dual sourcing)
- Negotiation and contract management

Outcomes

- Cost savings
- Better supplier quality and reliability
- Greater alignment with corporate strategies

3. Global Sourcing

Organizations source materials from international markets to gain cost and quality benefits.

Drivers

- Price advantage in foreign markets
- Access to advanced technology
- Competitive quality and variety
- Reduction in domestic supply dependency

Risks

- Currency fluctuations
- Lead-time delay due to logistics
- Cultural and legal differences
- Trade barriers and tariffs

Strategies for Success

- Supplier auditing
- Logistics and transportation planning
- Compliance with international trade laws

4. Supplier Relationship Management (SRM)
SRM emphasizes managing supplier relationships proactively.

SRM Activities
- Setting performance metrics (quality, delivery, cost)
- Joint development programs
- Regular supplier meetings and reviews
- Vendor rating and scorecard systems
- Continuous improvement projects

Benefits
- Improved supplier reliability
- Enhanced innovation through collaboration
- Reduced supply risks

5. Just-in-Time (JIT) Purchasing

JIT aims to reduce inventory and purchase materials exactly when they are needed for production. Just-in-Time (JIT) Purchasing is a purchasing strategy where materials, components, and supplies are ordered and received *exactly when they are needed* in the production process—not earlier and not later.

It eliminates the need for maintaining large inventories and reduces wastage, storage costs, and carrying costs. JIT is closely linked with lean manufacturing and originated from the Toyota Production System.

Requirements

- Highly reliable suppliers
- Accurate forecasting
- Close coordination between purchasing and production

Advantages
- Reduced inventory holding cost
- Lower storage and handling cost
- Improved cash flow

Challenges
- Vulnerability to disruptions
- Requires strong logistics

IT Purchasing vs Traditional Purchasing

Traditional Purchasing	JIT Purchasing
Large inventory	Very low/no inventory
Bulk purchases	Small, frequent deliveries
Short-term, price-focused suppliers	Long-term relationships
Low dependency on suppliers	High dependency on supplier reliability

Traditional Purchasing	JIT Purchasing
Inspection after receiving	High-quality materials expected always
Higher storage cost	Lower total cost

9. Industry Applications of JIT Purchasing

- Automobile manufacturing (Toyota, Honda, Ford)
- Electronics (Apple, Samsung)
- Retail and supermarkets (Walmart, Big Bazaar)
- Pharmaceuticals and medical supplies
- Aviation component manufacturing

Benefits to Suppliers

- Predictable demand
- Long-term contracts
- Better planning of resources
- Continuous relationship with buyers

Impact of JIT Purchasing on the Purchasing Function

- Purchasing becomes more strategic and collaborative
- Greater focus on supplier development and evaluation
- Shift from price negotiation to partnership-based agreements
    - Need for real-time communication and visibility in supply chain

6. Green and Sustainable Purchasing
Sustainable purchasing considers environmental, ethical, and social impact.
Practices

- Buying eco-friendly and recyclable materials
- Selecting suppliers with sustainable practices
- Reducing packaging waste
- Ensuring energy-efficient production
- Compliance with environmental laws (ISO 14001, RoHS)

Importance

- Enhances corporate social responsibility (CSR)
- Meets stakeholder expectations
- Reduces environmental footprint

7. Use of Purchasing Analytics, Big Data & AI
Modern procurement uses data to make informed decisions.
Applications

- Spend analysis and trend identification
- Price forecasting using predictive analytics
- Supplier risk assessment
- Demand forecasting using AI
- Identifying cost-saving opportunities

Advantages

- Better negotiation
- Lower procurement costs
- Reduced uncertainty and risks

8. Outsourcing Procurement (Procurement-as-a-Service – PaaS)
Many businesses outsource procurement activities to specialized agencies.
Reasons

- Lack of internal expertise
    - Need for highly skilled sourcing professionals
- Cost reduction through economies of scale

Services Covered

- Supplier identification
- Contract negotiation
- Inventory planning
- Logistics management

Benefits

- Faster decision-making
- Use of advanced tools and global networks

9. Vendor Managed Inventory (VMI)
In VMI, suppliers take responsibility for managing the buyer's inventory.

Process

- Supplier monitors stock levels using shared data
- Supplier plans replenishment
- Purchaser receives materials automatically

Advantages

- Reduced stockouts
- Lower safety stock requirement
- Improved buyer–supplier coordination

10. Robotics Process Automation (RPA) and Artificial Intelligence
Automation tools handle routine procurement tasks.

Examples

- Auto-generation of purchase orders
- Automating invoice processing
- AI-enabled supplier evaluation
- Chatbots for vendor communication

Impact

- Reduced manpower burden
- Faster processing
- Improved accuracy and compliance

11. Blockchain Technology in Procurement
Blockchain ensures security, transparency, and trust in purchasing transactions.
Uses

- Tamper-proof contract management
- Tracking product origin

- Ensuring authenticity of materials
- Enhancing supply chain traceability (food, pharma, diamonds)

Benefits

- Eliminates fraud
- Builds trust among stakeholders
- Enhances regulatory compliance

12. Cloud-Based Procurement Platforms

These platforms provide centralized, real-time procurement operations.

Examples

- SAP Ariba
- Oracle Procurement Cloud
- Coupa
- Jaggaer

Features

- Contract lifecycle management
- Spend analytics
- Supplier database management
- Automated approval workflows

13. Collaborative & Consortium Purchasing

Multiple organizations pool their purchase requirements to gain volume discounts.

Use Cases

- Hospitals, educational institutions, SMEs
- Standard items like stationery, fuel, medical supplies

Advantages

- Economies of scale
- Better negotiation power
- Reduced procurement cost

14. Ethical Purchasing & Compliance Requirements

Companies must follow ethical standards while purchasing.

Elements

- Anti-corruption and anti-bribery laws
- Supplier code of conduct
- No child labour / forced labour
- Compliance with labour and safety regulations
- Ensuring fair pricing and transparency

15. Supply Chain Risk Management in Purchasing

Risk management is crucial due to global uncertainties.

Types of Risks

- Natural disasters
- Political instability
- Supplier bankruptcy
- Logistics delays

Risk Mitigation Strategies

- Dual sourcing
- Safety stock for critical items
- Supplier diversification
- Insurance and hedging

12.8 SUMMARY

Purchase management ensures that materials and services are acquired efficiently, economically, and ethically. Understanding the principles, adopting a systematic purchase process, and selecting an appropriate purchase system are essential for improving cost efficiency and operational performance. In modern organizations, purchasing goes beyond buying—it is a strategic function that adds value, enhances competitiveness, and strengthens supply chain resilience.

12.9 KEY WORDS

1. Procurement
The overall process of acquiring goods, services, or works from external sources through purchasing, sourcing, negotiation, and contracting.
2. E-Procurement
Electronic or digital procurement conducted via online platforms, ERP systems, and automated workflows.
3. Purchase Requisition
A formal internal document requesting the purchase department to procure specific goods or services.
4. Purchase Order (PO)
A legally binding document issued by the buyer to the supplier authorizing delivery of goods at agreed terms.
5. Request for Quotation (RFQ)
A document sent to suppliers asking for price quotations for specific materials or service
6. Request for Proposal (RFP)
A document inviting suppliers to submit detailed proposals including pricing, specifications, timelines, and capabilities.
7. Just-in-Time (JIT) Purchasing
A purchasing system where materials are ordered and received exactly when needed in the production process.

12.10 SELF-ASSESSMENT QUESTIONS

(A) Short Answer Questions

1. Explain the Five Rights of Purchasing.
2. Describe the steps involved in the purchase process.
3. What is a Rate Contract? Explain its advantages.
4. Differentiate between centralized and decentralized purchasing.
5. Define e-procurement and outline its benefits.

(B) Essay Questions

1. Discuss the principles of purchase management and their importance.
2. Explain the purchase process in detail with suitable examples.
3. Describe various types of purchase systems and evaluate their merits and demerits.
4. Examine the role of purchase management in modern supply chain performance.
5. How does supplier evaluation contribute to effective purchase management? Discuss with examples.

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LESSON-13
STORES MANAGEMENT

OBJECTIVES OF THE LESSON:

After completing this lesson, the learner will be able to:

1. Understand the concept and importance of Stores Management in supporting organizational efficiency and material availability.
2. Describe the key functions of the stores department, including receiving, storage, issue, and maintaining proper records.
3. Identify and evaluate the factors influencing the location of stores to ensure smooth material flow and cost efficiency.
4. Explain the principles of store layout design for optimal space utilization, safety, and ease of operations.
5. Understand and apply basic store accounting procedures, including documentation, codification, stock verification, and ledger maintenance.

13.1. STRUCTURE:

13.2 INTRODUCTION

Stores Management is an important component of Materials Management. In any manufacturing or service organization, the store acts as a central hub where materials are received, inspected, stored, protected, and issued as required. The objective of stores management is to ensure that the required materials are available in the right quantity, in good condition, and at the right time. Efficient stores management contributes to uninterrupted production, better inventory control, cost reduction, and improved organizational performance. Store management requires specific skills to successfully handle the demanding and often challenging job of managing a retail or wholesale outlet. Effective management helps increase sales and retain customers. Learning about the different elements of the role and how technology can simplify many tasks can help a business run efficiently. In this article, we define store management and explain how it helps businesses maintain control and creates a positive work environment for employees.

13.3. MEANING OF STORE AND ITS CLASSIFICATION

A *store* is a physical location where materials are kept safely until they are required for use. It includes raw materials, spares, components, tools, consumables, and finished goods. A store is a place (physical or online) or a supply where goods are sold to consumers, ranging from a small shop to a large department store, while also meaning a stock of items kept for future use, like a food store or data storage. Examples include grocery stores (Publix, Walmart), specialty stores (bookstores, jewellers, electronics shops), department stores (Macy's, Nordstrom), and even online platforms like Amazon's storefronts.

1.Department Stores: Department are large establishments offering a diverse range of products, including home goods, clothing, electronics, and cosmetics, all under one roof. **Examples** of department stores include Bloomingdale's, Macy's, and Nordstrom. These stores cater to distinct needs and preferences, providing shoppers with a wide selection of items to choose from in a single location.
2. Specialty Stores: Specialty Stores focus on a specific range of products but excel in-depth and expertise, providing specialized goods and personalized service. **Examples** of specialty stores include Sephora, Nike, and Kay Jewellers. These stores offer a curated selection of products, allowing customers to find unique items tailored to their interests and preferences.
3. Chain Stores: Chain Stores are part of a network of retail outlets operating under the same brand, offering a standardized shopping experience across multiple locations. **Examples** range from multinational giants to regional favourites. These stores provide consistency in products, pricing, and customer experience, making them easily recognizable and accessible to consumers.
4. Discount Stores: Discount Stores cater to budget-conscious shoppers by offering a wide variety of products at significantly reduced prices. **Examples** of discount stores include

Target, Walmart, and Dollar General. These stores appeal to value-seeking customers, providing affordable options for everyday essentials and other items.

5. Boutiques: Boutiques are independently owned shops that curate a carefully selected range of unique products, focusing on personalized service and distinctive shopping experiences. These stores offer a curated selection of products not typically found in larger retailers, often showcasing items from local artisans and designers.

6. Supermarkets: Supermarkets are large self-service stores specializing in groceries and household items, emphasizing product assortment and display to attract customers. **Examples** of supermarkets include Target, Walmart, and Kroger. These stores offer a wide range of food and household products, catering to the everyday needs of consumers.

7. Convenience Stores: Convenience are small shops offering a limited selection of items like snacks, beverages, and tobacco products at premium prices, focusing on convenience and quick service. **Examples** of convenience stores include Circle K, 7-Eleven, and Wawa. These stores cater to customers looking for quick and easy access to everyday essentials.

8. Hypermarkets or Superstores: Hypermarkets or Superstores are larger than supermarkets, offering various categories of products under one roof. **Examples** of hypermarkets include Asda, Tesco, and Costco. These stores provide a wide range of products, including electronics, clothing, groceries, and household items, rivalling the size of malls.

9. Warehouse Stores: Warehouse Stores sell limited stock in bulk at discounted rates, relying on visual merchandising and lower prices to attract customers. These stores offer products in large quantities, making them popular among businesses and individuals looking to save money on bulk purchases.

10. E-Commerce Stores: E-commerce Stores are virtual platforms permitting customers to shop online, offering a wide range of products with user-friendly interfaces and secure payment systems. **Examples** of e-commerce stores include Etsy, Amazon, and eBay. These platforms will offer accessibility and convenience, permitting consumers to shop from the comfort of their houses.

11. Drug Stores/Pharmacies: Drug Stores or Pharmacies are retail stores specializing in selling medications and health-related products. **Examples** of drug stores include Walgreens, CVS, and Rite Aid. These stores provide essential health and wellness products and are often located in high-traffic areas for easy accessibility.

12. Outlet Stores: Outlet Stores sell discounted merchandise from other stores, usually from previous seasons or overstocked items. **Examples** of outlet stores include Coach Outlet, Nike Factory Store, and Saks Off 5th. These stores offer discounted prices on brand-name products, attracting bargain-seeking shoppers.

13. Home Improvement Stores: Home Improvement Stores sell products and tools for home improvement projects, such as hardware, tools, and building materials. **Examples** of home improvement stores include Lowe's, Home Depot, and Ace Hardware. These stores cater to homeowners and contractors, providing everything needed for DIY projects and renovations.

14. Pop-Up Stores: Pop-up Stores are temporary retail spaces set up for a limited time to promote a product or event. **Examples** of pop-up stores include holiday gift shops or seasonal Halloween stores. These stores offer unique and limited-time shopping experiences, often attracting customers with exclusive products or promotions.

13.4 CONCEPT OF STORES MANAGEMENT

Stores Management refers to the systematic process of receiving, storing, issuing, and controlling materials in an organization. It ensures smooth flow of materials while minimizing costs and preventing wastages. Store management requires specific skills to successfully handle the demanding and often challenging job of managing a retail or wholesale outlet. Effective management helps increase sales and retain customers. Learning about the different elements of the role and how technology can simplify many tasks can help a business run efficiently. In this article, we define store management and explain how it helps businesses maintain control and creates a positive work environment for employees.

13.5. COMPONENTS OF STORES MANAGEMENT

Store management components cover inventory control, staff management, customer experience, sales & marketing, financial oversight, and physical operations, all working together for efficiency, profitability, and satisfying customers by balancing stock, motivating teams, optimizing layout, and driving sales through smart strategies and technology. Key areas include procurement, merchandising, security, and ensuring smooth daily operations from receipt of goods to sale and service.

Key Components of Store Management

1. **Inventory Management:**
- Procuring, receiving, storing, tracking, and issuing stock.
- Maintaining optimal stock levels to avoid overstocking or stockouts.
- Minimizing waste, damage, and pilferage.

2. **Staff Management:**
- Recruiting, training, scheduling, and motivating employees.
- Assigning roles, conducting performance appraisals, and fostering a positive work environment.

3. **Customer Experience & Service:**
- Providing excellent service to build loyalty.
- Managing customer feedback, complaints, and creating a welcoming atmosphere.

4. **Sales & Marketing:**
- Developing strategies to drive traffic and revenue.
- Implementing promotions, visual merchandising, and effective store layouts.

5. **Financial Management:**
- Budgeting, cost control, pricing strategies, and sales analysis.

6. **Operations & Facilities:**
- Managing daily tasks, store hours, cleanliness, security, and maintenance.
- Handling payment processing and managing supplies and equipment.

7. **Technology & Data:**
- Utilizing POS systems, management software, and analytics for decision-making.

8. **Security & Loss Prevention:**
- Implementing measures against theft, fraud, and damage.

13.6. FUNCTIONS OF STORES MANAGEMENT

Store management functions encompass overseeing daily operations, staff, and finances to ensure smooth running, customer satisfaction, and profitability, focusing heavily on inventory control, sales & marketing, staff management, store layout/visuals, and customer service, all while managing costs and driving revenue through effective processes like receiving, storing, issuing, and record-keeping of goods.

Core Functions

- **Inventory Management:**
  Tracking, ordering, organizing, storing, and minimizing stock to prevent overstock/stockouts; includes receiving, warehousing, and issuing materials.
- **Sales & Marketing:**
  Setting prices, implementing promotions, managing cash operations, analysing competition, and driving sales performance.
- **Human Resources:**
  Hiring, training, motivating, and scheduling staff, plus managing payroll and performance.
- **Customer Service:**
  Ensuring a positive customer experience through efficient service, a clean environment, and addressing complaints.

  Operational Functions
- **Store Layout & Merchandising:**
  Designing the store's physical layout, display, and visual appeal to enhance shopping and sales.
- **Financial Management:**
  Handling cash flow, daily reconciliations, budgeting, and expense control.
- **Supply Chain/Vendor Management:**
  Coordinating with suppliers, managing deliveries, and ensuring quality of incoming goods.
- **Security & Compliance:**
  Implementing procedures for store opening/closing, securing assets, and adhering to regulations.

  Key Processes (Materials/Goods Focus)
- **Receiving:** Accepting, inspecting, and documenting incoming goods.
- **Storage:** Organizing and preserving materials safely and efficiently.
- **Issuing**: Distributing materials as needed, with proper documentation.
- **Record Keeping:** Maintaining accurate stock cards, bin cards, and inventory records.
- **Stock Verification:** Regularly counting and reconciling physical stock with records.
  In essence, store management is about balancing operational efficiency with strategic goals like customer satisfaction and profitability by managing people, products, and processes effectively.

13.7 STORES ORGANIZATION STRUCTURE

A well-designed stores organization structure ensures the smooth flow of materials, accurate inventory control, efficient handling, and timely availability of items required for production and operations. It defines authority, responsibility, communication channels, and coordination among store personnel. Proper structure reduces delays, minimizes pilferage, enhances accountability, and improves overall material management effectiveness.

Objectives of Stores Organization

- To ensure systematic storage and retrieval of materials.
- To define clear roles and responsibilities for store personnel.
- To maintain internal control over issuing, receiving, and record-keeping.
- To facilitate coordination between purchase, finance, and production.
- To improve efficiency, accuracy, and material accountability.

Need for a Store Organization Structure

- To manage increasing volume and variety of materials.
- To ensure compliance with standard procedures and inventory policies.
- To maintain control over **receipts, storage, issues, safety, and records**.
- To implement segregation of duties to prevent errors and fraud.
- To support modern inventory systems like ABC, VED, JIT, EOQ, MRP.

Types of Stores Organization Structure

```
GENERAL MANAGER
|
STORES MANAGER
|
----------------------------------------------------
|               |                 |
RECEIVING SECTION    STORAGE SECTION          ISSUE SECTION
|               |                 |
Receiving Officer    Store Supervisor         Issue Supervisor
|               |                 |
Receiving Clerk      Storekeepers             Issue Clerks
|               |                 |
Inspectors (QC)     Helpers / Handlers        Dispatch Assistants
|
RECORDS SECTION
|
Inventory Records Clerk
|
Stock Verification Team
|
SECURITY STAFF
```

A. Centralized Store Structure

- All materials stored at one central location.
- Common in small to medium organizations.

Advantages:

- Better control and supervision
- Lower duplication of equipment and manpower
- Uniform procedures and records

Disadvantages:

- Longer distance for departments to collect materials
- Time delays and congestion at central stores

B. Decentralized Store Structure

- Multiple storage points across departments or locations.

Advantages:

- Quick issue of materials
- Reduced congestion
- Suitable for large plants and multi-location operations

Disadvantages:

- Requires more manpower and space

- Duplication of records and higher cost

C. Combined (Hybrid) Store Structure

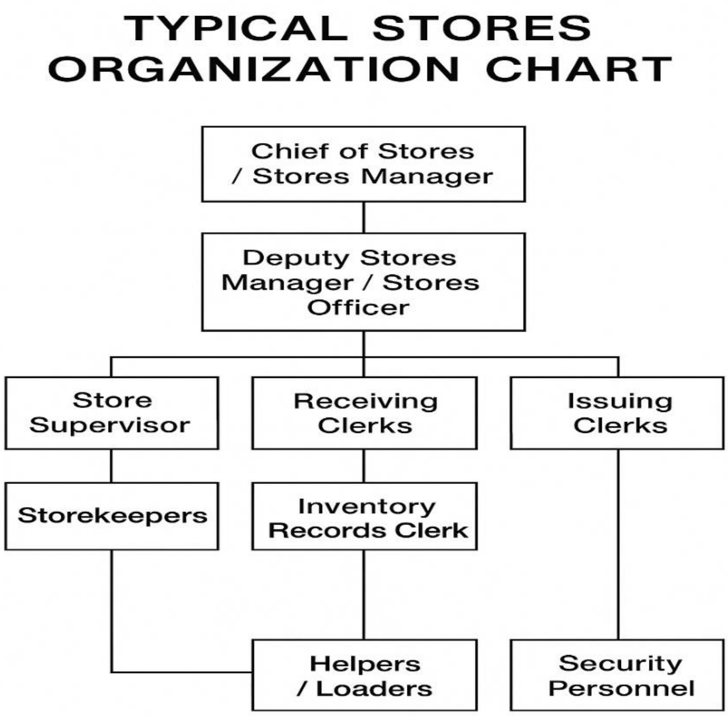
- Mix of centralized control with decentralized issue points.

Advantages:

- Efficient material availability
- Central control with localized convenience

Typical Stores Organization Chart:

A Typical Stores Organisation Chart is a visual representation that shows the hierarchy, roles, responsibilities, and reporting relationships within the stores department of an organization. It helps to understand who does what, who reports to whom, and how the flow of work is organized in the stores function. It outlines the structure of the stores department by presenting different positions



A. Chief of Stores / Stores Manager

- Overall head of store function
- Responsible for policy implementation, planning, budgeting, and audit

B. Deputy Stores Manager / Stores Officer

- Assists stores manager
- Supervises departments such as receiving, storage, issuing, and record-keeping

C. Store Supervisor / Section In charge

- Manages day-to-day operations
- Allocates work, monitors stock levels, ensures safety

D. Storekeepers

- In charge of a specific section (raw materials, tools, spares, finished goods)
- Responsible for entries, receipts, issues, binning, and documentation

E. Receiving Clerks

- Check incoming materials

- Prepare goods receipt notes
- Coordinate with purchase, quality control, and transport

F. Issuing Clerks

- Handle material withdrawal
- Verify requisitions, update stock cards

G. Inventory Records Clerk

- Maintains bin cards, stores ledger, computer entries
- Reconciles physical and book balances

H. Helpers / Loaders

- Assist with material handling, stacking, cleaning, packing

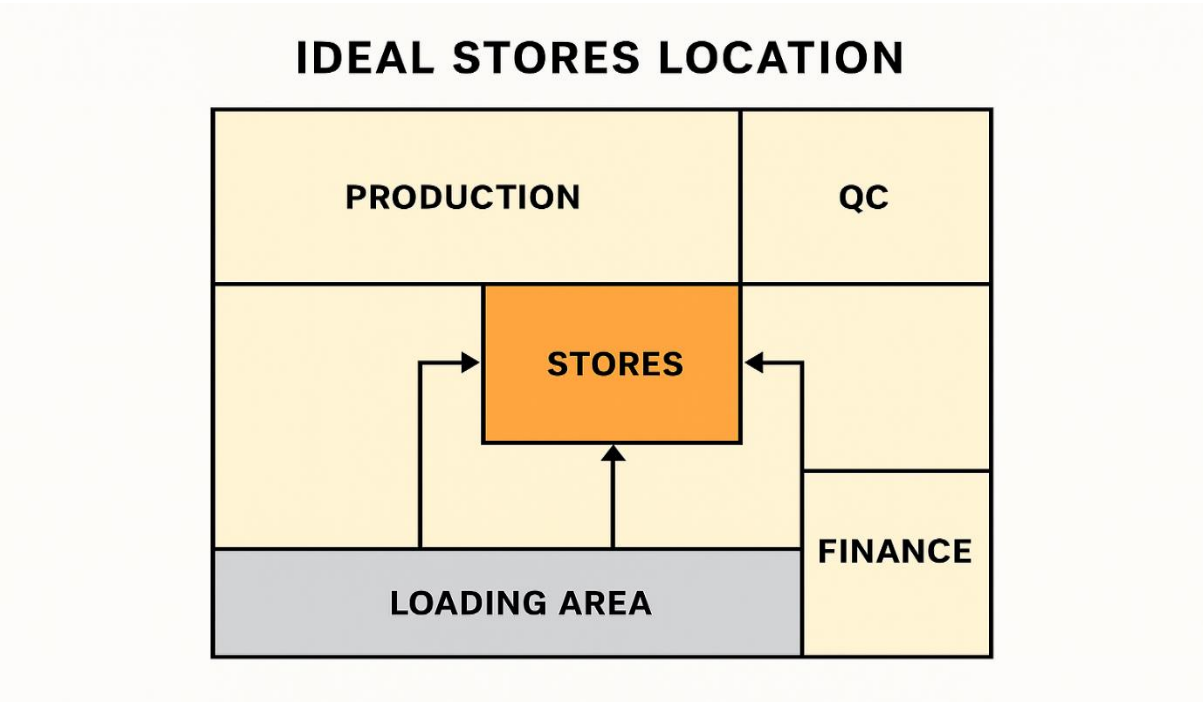
I. Security Personnel

- Ensures safety of materials, prevents unauthorized access

13.8. STORE LOCATION

The location of stores refers to the physical placement or positioning of the storehouse within an organization's premises. Selecting the right store location is crucial for ensuring smooth flow of materials, minimum handling costs, safety of inventory, and efficient coordination between various departments like purchase, production, and finance.

A strategically chosen store location improves productivity, reduces material movement, minimizes delays, and enhances overall efficiency of materials management. The **location of stores** plays a major role in determining the efficiency of materials handling and inventory management. An ideal store location should be accessible, safe, spacious, and close to the production areas. Proper planning of stores location reduces cost, saves time, improves safety, and contributes to smooth operations of the organization.



Objectives of Proper Stores Location

- To enable **quick and easy access** to materials.

- To **minimize transportation and material handling costs**.
- To ensure **safety and security** of stored inventory.
- To reduce **time spent** in receiving and issuing materials.
- To facilitate **coordination with production and other departments**.
- To avoid congestion and ensure **smooth material flow**.

3. Factors Influencing Selection of Store Location

1. Proximity to Production Areas

- Stores should be located **close to production departments** to reduce material movement.
- Shorter distance leads to time savings and increased productivity.

2. Accessibility

- Easy approach for vehicles delivering materials.
- Adequate space for loading and unloading activities.

3. Availability of Space

- Sufficient floor space for storage, inspection, issue counters, and material movement.
- Possibility of future expansion if material volume increases.

4. Safety and Security

- Location should avoid fire-prone, flood-prone, or hazardous areas.
- Must be safe from theft, pilferage, or unauthorized access.

5. Layout Requirements

- Store's location must support scientific layout planning.
- Should allow free movement of forklifts, trolleys, pallets, and systematic bin arrangement.

6. Environmental Conditions

- For temperature-sensitive materials, storage area must be free from excessive heat, humidity, or dust.
- Materials like chemicals, paints, and food items need controlled conditions.

7. Proximity to Other Departments

- Stores must stay well-connected with:
  - **Purchase department** (for receiving)
  - **Quality Control (QC)** (for inspection)
  - **Finance / Accounts** (for material verification and payments)

8. Nature of Materials

- Heavy, bulky, or hazardous materials need special storage areas such as open yards, covered sheds, or bonded stores.

4. Types of Stores Based on Location

A. Centralized Location

- One main store for the entire organization.
- Suitable for small and medium organizations.

Advantages:

- Better control, low duplication, standardized procedures.

Disadvantages:

- Longer distance for departments to obtain materials.

B. Decentralized Location

- Multiple stores located near different departments.

Advantages:

- Quick material availability, reduced congestion.

Disadvantages:

- Higher cost, duplication of equipment and staff.

C. Combined (Hybrid) Location

- Mix of centralized control with decentralized service points.

5. Characteristics of an Ideal Stores Location

- Near production and inspection areas
- Away from dust, heat, vibration, and noise
- Spacious enough for future expansion
- Equipped with good ventilation and lighting
- Easy vehicular access
- Proper drainage and flooring
- Secure perimeter with surveillance
- Separate receiving and issuing sections
- Reduces total material handling cost

Importance of Proper Stores Location

- Ensures timely availability of materials
- Improves productivity in manufacturing
- Reduces risk of damage and wastage
- Supports efficient warehouse layout and storage system
- Enhances safety and minimizes accidents
- Facilitates faster receiving and issuing operation

13.9. STORES LAYOUT:

Store layout is the design of a store's floor space and the placement of items within that store. ... Store owners choose where the best spots are to place their merchandise, and this helps them design their customer flow, as well as the ambiance (ambiance also plays a huge role in restaurants as well!) within their space. It is the blueprint of the shopping journey, balancing aesthetic appeal with functional design to influence customer behaviour and boost sales, touching on layout types, key zones, and merchandising strategies.

Meaning of Stores Layout

Stores layout refers to the **systematic physical arrangement** of different areas within a store or warehouse to ensure efficient movement of materials, maximum space utilization, quick identification, and safe handling of goods. A good layout supports receiving, storage, issue, inspection, accounting, and record-keeping functions with minimum cost and time.

Objectives of Stores Layout

- To ensure **smooth flow** of materials from receiving to issue.
- To **minimize handling cost** and movement time.
- To **maximize space utilization** through scientific arrangement.
- To facilitate **easy identification**, **quick retrieval**, and **stock control**.
- To ensure **safety**, **security**, and **protection** of materials.
- To support **efficient supervision** and **record management**.

Factors Influencing Stores Layout

1. **Nature of materials** (size, weight, perishability, hazard level).
2. **Volume of transactions** (turnover rate).
3. **Frequency of movement** (fast-, medium-, slow-moving items).

4. **Material handling equipment** used (forklifts, pallet trucks).
5. **Space availability** and building structure.
6. **Safety & statutory requirements** (for chemicals, inflammable items).
7. **Environmental needs** (temperature, ventilation, humidity).

Essential Sections in an Ideal Stores Layout

A. Receiving Area
- First point of entry for all incoming materials.
- Should be close to the main entrance.
- Includes weighing, inspection, unloading space.

B. Inspection Area
- Quality checks of materials.
- Must be adjacent to receiving and quarantine area.

C. Quarantine Area
- Temporary holding for items waiting for approval.
- Prevents mixing with approved stocks.

D. Main Storage Area
- Core storage section.
- Includes racks, bins, shelves, pallets.
- Organized by coding, classification, and turnover rate.

E. Bulk Storage Area
- For heavy, voluminous, or slow-moving items.
- Often floor-stacked.

F. Issue/Dispatch Area
- Should be near the exit gate.
- Facilitates quick withdrawal and transport.

G. Tool/Spare Parts Room
- Separate area for special tools, maintenance parts.

H. Records Room / Store Office
- Houses bin cards, ledgers, electronic systems, staff desks.

I. Security & Safety Area
- Fire extinguishers, emergency exits, security checkpoints.

5. Stores Layout – Standard Diagram (Flow-Based Layout)

```
MAIN ENTRANCE
|
-----------------
| RECEIVING AREA |
-----------------
|
-------------------
| INSPECTION AREA |
-------------------
|
```



```
----------------------
| QUARANTINE STORAGE |
----------------------
|
-------------------------------------------------
```

```
|              MAIN STORAGE AREA           |
|  ----------------   ------------------------  |
|  | FAST MOVING |   | SLOW/BULK STORAGE AREA | |
|  |   ITEMS     |   |   Pallets / Floor      | |
|  ----------------   ------------------------  |
|
-----------------------------------------------
|
----------------------
|  ISSUE / DISPATCH |
----------------------
                                                          |
                                                     EXIT GATE
```

6. Alternative Layout Diagram (U-Shaped Warehouse Flow)

This is widely used in modern warehouses for **logical material flow**:

```
RECEIVING DOCK
|
-------------------------------
|                      |
|      STORAGE AREA          |
| (Racks, shelves, bins)
|
|                      |
-------------------------------
|
DISPATCH AREA
|
SHIPPING DOCK
```

Advantages of U-Shape Layout:

- Efficient one-way flow
- Easy supervision
- Reduced congestion
- Ideal for medium to large stores

7. Guidelines for Designing an Effective Stores Layout

- Keep **fast-moving items near issue point**.
- Keep heavy or bulky items on **lower racks or floor level**.
- Follow **FIFO**, **LIFO**, or **FEFO** requirements while arranging.
- Place hazardous materials in **isolated, ventilated areas**.
- Ensure wide aisles for forklifts.
- Use **coding systems**, colour labels, and signage.

8. Advantages of a Good Stores Layout

- Reduced handling and movement cost.
- Better space optimization.
- Faster identification and retrieval.
- Improved material safety and security.
- Reduced risks of accidents.

- Enhanced efficiency in receiving and issuing activities.

Importance of Store Layout

The importance of stores layout lies in its ability to deliver **efficiency, safety, cost reduction, space optimization, and better control** over materials. It ultimately improves productivity and ensures smooth functioning of the entire materials management system.

A sound layout increases the stores' output and contributes to the organization's efficiency.

1. **Efficient Material Flow:**
   Ensures smooth movement of materials from receiving to storage to issue without delays.
2. **Reduced Handling Cost:**
   Minimizes unnecessary movement and labour, lowering overall handling expenses.
3. **Better Space Utilization:**
   Helps in optimal use of available floor and vertical space through systematic arrangement.
4. **Quick Identification & Retrieval:**
   Proper layout enables faster locating, picking, and issuing of materials.
5. **Improved Inventory Control:**
   Supports accurate record-keeping, stock monitoring, and implementation of FIFO/FEFO.
6. **Enhanced Safety & Security:**
   Reduces accidents, prevents congestion, and ensures safe storage of hazardous items.
7. **Better Supervision:**
   Makes it easier to control stock movement and prevent pilferage or misuse.
8. **Faster Receiving & Dispatching:**
   Strategic location of receiving and issue areas speeds up material processing.
9. **Supports Use of Equipment:**
   Facilitates smooth operation of forklifts, pallet trucks, and other handling equipment.

Principles of Effective Store Layout

- Adequate space for movement
- Logical grouping of materials
- Proper lighting and ventilation
- Clearly marked storage areas
- Minimum cross-movement
- Easy access to frequently used items

Components of a Typical Store Layout

- Receiving area
- Inspection area
- Storage racks
- Tool rooms
- Issue counter
- Office/record area
- Hazardous materials zone
- Loading/unloading docks

Material Handling and Flow

Efficient layout ensures a smooth, unidirectional flow:

Receiving → Inspection → Storage → Issue → Dispatch

13.10. STORE ACCOUNTING PROCEDURES

The store plays a vital role in the functioning of a company. The main function of a store is to provide uninterrupted supply to the manufacturing departments. Stores accounting is the process of recording details of stock movements and balance in value. It is sometimes undertaken by the finance department, but there is much to be said for it being handled by the store functionaries. Store accounting procedures refer to the **systematic methods used to record, monitor, value, and control** the movement of materials into and out of the stores. These procedures ensure accuracy in stock levels, prevention of losses, and proper coordination with finance and production departments.

Store accounting procedures involve the entire set of documents, records, and methods used to maintain accurate stock levels, control costs, and ensure the efficient operation of the stores department. These procedures form a critical part of materials management and contribute to organizational efficiency.

Objectives of Store Accounting

- To maintain **accurate records** of receipts, issues, and balances.
- To provide **real-time stock information** to management.
- To ensure **proper valuation** of materials.
- To control **pilferage, loss, or misuse** of materials.
- To support **cost control and budgeting**.

Key Documents Used in Store Accounting

A. Purchase Requisition (PR)

- Raised by user departments requesting materials to be purchased.

B. Purchase Order (PO)

- Issued by the purchase department to suppliers.

C. Goods Receipt Note (GRN) / Materials Receipt Report (MRR)

- Prepared when materials are received.
- Confirms quantity received and condition.

D. Inspection Report

- Quality check details for accepted/rejected materials.

E. Stores Issue Voucher (SIV) / Materials Issue Note (MIN)

- Authorized document for issuing materials from stores.

F. Return to Stores (RTS)

- For materials returned back to stores from the user department.

G. Bin Cards

- Maintained at every bin/rack showing receipts, issues, and balance.

H. Stores Ledger / Stock Ledger

- Central record maintained by the stores accountant.
- Shows quantity and value of each material.

3. Store Accounting Procedures

A. Procedure for Receipt of Materials

1. Materials arrive at the receiving bay.
2. Quantity verification using invoice, PO, and delivery challan.
3. Inspection team checks quality.
4. GRN/MRR is prepared.

5. Accepted materials are coded and moved to storage.
6. Bin card is updated.
7. Stores ledger is updated with quantity and value.

B. Procedure for Issuing Materials

1. User department submits **Stores Requisition** or **SIV**.
2. Stores officer verifies authorization.
3. Material is picked from correct bin.
4. Issue details are entered in:
   - Bin Card
   - Stores Issue Voucher
   - Stores Ledger
5. Material is delivered to user department.

C. Procedure for Returning Materials

1. Unused or rejected materials returned with **RTS (Return to Stores)** note.
2. Storekeeper checks condition.
3. Accepted items are moved back to appropriate bin.
4. Bin card and ledger are updated accordingly.

D. Stock Valuation Methods

Valuation is necessary for costing and financial reporting.

1. FIFO (First In First Out)

- Oldest stock issued first.
- Suitable for perishable or time-sensitive items.

2. LIFO (Last In First Out)

- Newest stock issued first.
- Matches current costs with current production.

3. Weighted Average Price

- Issues valued at average unit cost of available stock.
- Common in large manufacturing units.

4. Standard Price Method

- Issues made at predetermined standard price; variances recorded.

5. Market Price Method

- Valued at prevailing market rate.

E. Procedure for Stock Verification

1. Conducted periodically (monthly/quarterly/annually).
2. Physical stock counted and compared with book records.
3. Discrepancies (shortages/excesses) reported.
4. Adjustments made after approval.
5. Helps detect errors, theft, and deterioration.

Types of Stock Verification:

- Continuous stock-taking (cycle counting)
- Annual stock-taking
- Surprise checks

4. Control Systems in Store Accounting

A. Bin Card vs. Stores Ledger

- **Bin Card** → Quantity only (maintained by storekeeper).
- **Stores Ledger** → Quantity + Value (maintained by stores accountant).

Maintaining both ensures **internal control** and **cross-verification**.

B. Code Numbering / Material Codification
- Each item given a unique code for easy identification.

C. Budgetary Control
- Control consumption against standard norms or budgets.

D. ABC Analysis
- A: High-value
- B: Moderate-value
- C: Low-value

Used for prioritizing control efforts.

Importance of Store Accounting Procedures
- Ensures **accurate material records**.
- Helps maintain **optimum inventory levels**.
- Prevents **stockouts, overstocking, and losses**.
- Supports **costing, auditing, and budgeting**.
- Improves **coordination** among stores, purchase, accounts, and production

13.11. MODERN TRENDS IN STORES MANAGEMENT

Modern stores management has moved beyond traditional record-keeping and manual handling. Digital technologies, automation, data analytics, and integrated systems now play a major role in improving accuracy, speed, and cost efficiency.

1. Computerised Inventory Management

Most organizations use **ERP**, **MRP-II**, or specialized inventory software to automate:
- Stock records
- Issue and receipt entries
- Real-time stock visibility
- Automatic reorder alerts

Benefits: Accuracy, speed, elimination of paperwork, better decision-making.

2. Barcoding and QR Coding

Every item is tagged with a **barcode or QR code** for quick scanning during:
- Receiving
- Storage
- Issuing
- Stock verification

Advantages: Reduces manual errors, speeds up transactions, improves traceability.

3. RFID (Radio Frequency Identification)

RFID tags allow **automatic, contactless tracking** of materials using radio waves.

Features:
- Items tracked in real time
- Faster inventory counting
- Useful for high-value and fast-moving materials

Trend: Increasing adoption in retail, pharmaceuticals, and large warehouses.

Automated Storage and Retrieval Systems (AS/RS)

Computer-controlled systems for:
- Storing materials in high racks

- Automatically retrieving items
- Reducing manual handling

Benefits:

- Saves space
- Improves speed
- Enhances worker safety
- Reduces labour cost

Use of Drones in Inventory Checking

Large warehouses use drones equipped with scanners to perform **cycle counting**.

Advantages:

- Faster verification
- Access to high or deep storage racks
- Minimizes human effort **Just-in-Time (JIT) Inventory**

Materials are supplied **exactly when required**, minimizing inventory levels.

Impact on stores:

- Lower carrying cost
- Reduced space requirements
- Strong coordination with suppliers

Vendor Managed Inventory (VMI)

The supplier monitors buyer's inventory and replenishes stock automatically.

Role in stores:

- Fewer stock-outs
- Lower administrative work
- Better supplier relationships

E-Procurement and Digital Documentation

Use of:

- E-tenders
- Online purchase orders
- Electronic invoices
- Digital records

Benefits: Faster processing, transparency, reduced paperwork.

Cloud-Based Stores Management

Cloud systems allow:

- Access to real-time stock data from anywhere
- Integration with procurement, finance, and production
- High data security

Trend: Growing adoption due to mobility and flexibility.

Warehouse Management Systems (WMS)

Advanced WMS includes:

- Slotting optimization
- Wave/batch picking
- Real-time analytics
- Integration with robotics

Outcome: Higher accuracy and reduced cycle times.

Robotics in Stores

Robots are increasingly used for:

- Picking and packing
- Palletizing
- Moving materials across the warehouse

Benefits: Speed, 24/7 operation, reduced human fatigue.

Internet of Things (IoT) in Stores

IoT sensors help monitor:

- Stock levels
- Temperature and humidity
- Equipment condition

Useful for perishable, chemical, and pharmaceutical materials.

Sustainable Stores Management (Green Practices)

Modern focus areas:

- Eco-friendly packaging
- Energy-efficient lighting
- Recycling and waste reduction
- Reuse of pallets and bins

Purpose: Reduce environmental impact and operational cost.

. Cross-Docking

Goods are **not stored** but immediately transferred from receiving to dispatch.

Advantages:

- Reduces storage cost
- Speeds up delivery
- Minimizes handling

Omnichannel Logistics

Stores are integrated with:

- Online orders
- Offline sales
- Real-time order tracking

13.12 SUMMARY

Stores Management plays a key role in ensuring availability of materials for production and service delivery. Efficient stores operations involve proper receiving, inspection, storage, preservation, issue, stock control, and documentation. Correct store location and layout can significantly improve material flow and reduce costs. Modern technologies like RFID and ERP systems have transformed traditional storekeeping into highly efficient, digital operations.

13.13. GLOSSARY OF TECHNICAL TERMS USED:

1. **Bin Card** – Record of quantity of items stored.
2. **GRN** – Document recording material receipt.
3. **FIFO** – Method of issuing oldest stock first.
4. **Codification** – Assigning codes to items.
5. **Store Ledger** – Financial record of material transactions

13.14. SELF-ASSESSMENT QUESTIONS

Short Answer Questions

1. Explain the functions of stores management.
2. What are the factors influencing store location?
3. Describe the importance of store layout.
4. What are the major documents used in stores accounting?
5. Explain codification and its advantages.

ESSAY QUESTIONS

1. Discuss in detail the functions of stores management with examples.
2. Compare centralized and decentralized store systems.
3. Explain the components and principles of an effective store layout.
4. Describe store accounting procedures and modern trends in computerized stores.
5. Evaluate the role of documentation and inventory valuation in stores management.

13.15 SUGGESTED READINGS

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LESSON-14
INVENTORY MANAGEMENT

OBJECTIVES:

After going through this unit you should be able to:

- Understand the concept and definition of inventory
- Explain the types and functions of inventory.
- Understand about the inventory costs, and
- Understand the inventory models

Structure:

14.1 INTRODUCTION

In any business organization, various functions are interlinked and connected to each other and are often overlapping. Some key aspects like supply chain management, logistics and inventory form the backbone of the business function. Therefore these functions are extremely important to marketing managers as well as finance controllers in particular and other managers in general.

Inventory management is a very important function that determines the health of the supply chain as well as the impacts the financial health of the balance sheet. Every organization constantly strives to maintain optimum inventory to be able to meet its requirements and avoid excess inventory or under inventory that can impact the financial figures.

Inventory is always dynamic. Inventory management requires constant and careful evaluation of external and internal factors and control through planning and review. Most of the organizations have a separate department or job function called inventory planners who continuously monitor, control and review inventory and interface with production, procurement and finance departments.

Definition: Inventory is an idle stock of physical goods that contain economic value, and are held in stock in various forms by an organization in its custody awaiting packing, processing, transformation, use or sale in a future point of time.

Inventory can be defined as below:

- It is the stock of any items or resources held in an organization for sale or use.
- It can also be defined as materials in a supply chain or in a segment of supply chain; expressed in quantities, locations/sites and/or values.

There is a distinction between manufacturing and service firm with regard to inventory. Manufacturing firm’s inventory refers to all items held in inventory that contributes to or become part of organizations products e.g. raw materials, finished goods, supplies, work in progress and piece parts. Service firm’s inventory refers to all tangible goods to be sold (stock in trade) and the supplies necessary to administer the service, e.g. a mobile phone company such as Safaricom keeps stock of scratch cards, SIM cards, packaging material etc. in order to offer competitive services to its clients.

14.2 INVENTORY DECISIONS:

Inventory Management is a critical function performed by planners to balance the inventory holding so as to ensure that optimum inventory levels are maintained. Any excess inventory will result in incremental costs of maintaining inventory and affects the financials of the company as it blocks working capital. Under inventory on the other hand can seriously hamper the market share. Any customer order that is not fulfilled due to a stock out is not at all a good sign. Therefore the responsibility of striking a fine balance in holding lean inventory calls for smart planning and continuous monitoring of the inventory levels coupled with quick decision making.

To be successful, most businesses other than service businesses are required to carry inventory. In these businesses, good management of inventory is essential. The management of inventory requires a number of decisions. Poor decision making regarding inventory can cause:

a. Loss of sales because of stock outs.
b. Depending on circumstances, inadequate production for a period of time.
c. Increases in operating expenses due to unnecessary carrying costs or loss from discarding obsolete inventory.
d. An increase in the per unit cost of finished goods.

Specifically, inventory decisions involve how much to order, the so-called economic order quantity, when to order, the reorder point issue combined with the safety stock quantity, and finally, the special questions associated with perishable products. Cost factors, uncertainty, and revenues all contribute to the decision analysis.

Generally the decisions pertaining to inventory management are: 1) Production Budget, 2) Order Size for Raw Materials, 3) Number of Times to Order for Raw Materials, 4) Reorder Point, and 5) Safety Stock.

The following basic inventory decisions are generally taken by managers:

i). When to replenish the inventory of that item.
ii). How much of an item to order when the inventory of that item is to be replenished.
iii) What to stock: The purchasing professional, at the very minimum, must meet the requirements and needs of the manufacturer on distribution operation.
iv). How much to invest: The purchasing professional must first review the level of capital support for inventory. This decision is usually made at the vice president level.
v). How much service to offer: What level of protection against stock outs is acceptable for the competitive environment? It is impossible to achieve a service level of 100 percent.

14.3 TYPES OF INVENTORIES

Inventory in an organization can be classified based on its purpose, stage in production, or nature. The main types include:

Raw Materials Inventory **(RM)**

- Materials purchased from suppliers but not yet used in production.
- Examples: Steel sheets, chemicals, cotton, electronic components.
- Importance: Ensures uninterrupted production; must be controlled for cost and availability.

Work-in-Progress Inventory **(WIP)**

- Items currently under production but not yet finished goods.
- Examples: Partially assembled machines, semi-finished garments.
- Importance: Indicates production progress; high WIP may increase storage and handling costs.

Finished Goods Inventory **(FG)**

- Products completed and ready for sale or dispatch.
- Examples: Packaged food, electronics, furniture.
- Importance: Meets customer demand; excessive FG increases carrying costs, insufficient FG leads to stockouts.

Maintenance, Repair, and Operating Inventory **(MRO)**

- Items used in maintenance or production support but not part of finished products.
- Examples: Lubricants, tools, cleaning supplies, spare parts.
- Importance: Ensures smooth operations; prevents breakdowns.

Packing and Packaging Inventory

- Materials used for packaging finished goods for storage, shipping, or sale.
- Examples: Cartons, bottles, labels, wrapping material.
- Importance: Protects goods, supports branding, and facilitates logistics.

Transit or Pipeline Inventory

- Inventory in movement between suppliers, warehouses, and customers.
- Examples: Goods in trucks, containers, or rail.
- Importance: Reduces supply chain disruption; needs tracking for delivery planning.

Buffer or Safety Inventory

- Extra inventory kept to prevent stock outs due to demand or supply variability.
- Examples: Additional raw material to handle supplier delay.
- Importance: Protects production and customer service but increases carrying cost.

Speculative or Anticipation Inventory

- Stock held to take advantage of expected price changes or seasonal demand.
- Examples: Grains before harvest, toys before festive season.
- Importance: Reduces procurement cost or ensures supply during high demand.
- Decoupling Inventory
- Stock maintained to decouple different stages of production.
- Examples: Components stored between two production processes with different cycle times.
- Importance: Smoothens workflow and reduces production delays.

14.4 FUNCTIONS OF INVENTORY

Inventory plays a vital role in ensuring the smooth operation of production and supply chain activities. It acts as a buffer between supply and demand, helping organizations meet customer needs, maintain uninterrupted production, and manage uncertainties in supply or market conditions. Properly managed inventory supports cost control, operational efficiency, and timely availability of materials, forming the foundation for effective production planning and business operations.

(i). To Meet Anticipated Customer Demand: These inventories are referred to as anticipation stocks because they are held to satisfy planned or expected demand.

(ii).To Smooth Production Requirements: Firms that experience seasonal patterns in demand often build up inventories during off-season to meet overly high requirements during certain seasonal periods. Companies that process fresh fruits and vegetable deal with seasonal inventories

(iii). To Decouple Operations: The buffers permit other operations to continue temporarily while the problem is resolved. Firms have used buffers of raw materials to insulate production from disruptions in deliveries from suppliers, and finished goods inventory to buffer sales operations from manufacturing disruptions.

(iv). To Protect against Stock-Outs: Delayed deliveries and unexpected increases in demand increase the risk of shortages. The risk of shortages can be reduced by holding safety stocks, which are stocks in excess of anticipated demand.

(v). To Take Advantage of Order Cycles: Inventory storage enables a firm to buy and produce in economic lot sizes without having to try to match purchases or production with demand requirements in short run.

(vi). To Hedge against Price Increase: The ability to store extra goods also allows a firm to take advantage of price discounts for large orders.

(vii).To Permit Operations: Production operations take a certain amount of time means that there will generally be some work-in-process inventory.

14.5 INVENTORY COSTS

Inventory procurement, storage and management is associated with huge costs associated with each these functions. Inventory costs are basically categorized into three headings: (a) Ordering Cost; (b) Carrying Cost; and (c) Shortage or Stock-Out Cost & Cost of Replenishment.

(a). Ordering Cost: Ordering Cost is cost involving ordering and receiving material. These include determining how much is needed, preparing invoices, inspecting goods upon arrival for quality and quantity, and moving the goods to temporary storage. Examples of ordering cost factors are:
Processing and inspecting incoming inventory
Developing and sending purchase orders
Bill paying
Inventory inquiries
Utilities, phone bills, and so on, for the purchasing department
Salaries and wages for the purchasing department employees Supplies such as forms and paper for the purchasing department

(b). Carrying Cost: Holding or Carrying Cost is the cost to carry on an item in inventory for a length of time usually a year. Cost includes interest, insurance, taxes, depreciation, obsolescence, deterioration, spoilage, pilferage, breakage, etc. Examples of carrying cost factors are:
Cost of capital
Taxes
Insurance
Spoilage
Theft
Obsolescence
Supplies such as forms and paper for the warehouse
Utilities and building costs for the warehouse
Salaries and wages for warehouse employees

(c). Inventory Storage Cost: Storage Cost is cost resulting when demand exceeds the supply of inventory on hand. These costs can include the opportunity cost of not making a sale, loss of customer goodwill, late charges, and similar costs.

(a). Shortage Costs: These are incurred as a result of the item not being in stock. Examples of shortage cost factors are:

- Loss of goodwill; could lead to loss of customers.
- Contribution lost, due to not making a sale.
- Back order costs - these are costs of dealing with disappointed customers.
- Costs of idle resources e.g.:- production personnel being paid when there's a raw material missing.
- Cost of having to speed up orders e.g. personnel working overtime, using a faster transportation mode (and hence more costly)

(d).Purchase Costs: This is what is paid to the supplier / seller by the buyer in exchange of the product. Inventory is usually a large investment for many firms. It is normally the second largest item in the balance sheet among the assets after fixed assets. Thus, inventory should only be held if the benefits (service to customers) exceed the inventory costs. Also in inventory modelling, purchase costs are a relevant factor to inventory policy due to availability of quantity discounts. Thus, for inventories:

Total Cost (TC) = Purchase Cost + Holding Cost + Ordering Cost + Shortage Cost

14.6 INVENTORY MODELS

Inventory models are systematic approaches used to manage stock efficiently by determining optimal quantities and timing for procurement or production. They are broadly classified into Purchasing Models and Manufacturing Models based on the nature of operations.
In purchase models, the organization procures goods from an external supplier. The assumption is that the entire ordered quantity is received at once, making inventory levels rise sharply upon delivery. The most commonly applied model in this category is the Economic Order Quantity (EOQ) model, which helps determine the optimal ordering quantity by balancing ordering cost, carrying cost, and sometimes shortage cost. Purchase models may be further categorized as with shortages allowed **or** without shortages, depending on whether temporary stock outs are acceptable in the system. When shortages are not allowed, the goal is to ensure uninterrupted inventory availability; when shortages are allowed, the model incorporates penalty or backordering cost.

Conversely, manufacturing or production models apply when the organization produces inventory internally rather than purchasing it. Unlike purchase models, inventory accumulates gradually during production instead of arriving in a single batch. These models consider production rate**,** setup cost**,** carrying cost, and shortage cost when applicable. The well-known model under this category is the Economic Production Quantity (EPQ) model. Similar to purchase models, production models can also be evaluated under conditions of allowed or disallowed shortages. These models help balance production schedules, minimize idle time, prevent excessive inventory build-up, and ensure cost efficiency throughout the production

cycle.
Model I: Purchasing model without shortages
Model II: Purchasing model with shortages
Model III: Manufacturing model without shortages
Model IV: Manufacturing model with shortages

14.6.1 MODEL I: PURCHASING MODEL WITHOUT SHORTAGES

The Purchasing Model without Shortage assumes that stock outs or shortages never occur. The organization always maintains sufficient inventory to meet demand, ensuring uninterrupted production or sales. This model is commonly applied when stockouts are highly undesirable due to critical operations, customer service requirements, or high penalty costs.

Key Features:
Continuous Supply: Inventory is replenished before it reaches zero, preventing any shortage.
Fixed Demand: Demand rate is known and constant over time.
Instantaneous Replenishment: Ordered stock is received in full immediately when inventory reaches the reorder point.

Objective: Minimize the total cost, which includes ordering cost and holding cost, without considering shortage costs.
Assumptions:

- Demand (D) per year is known and is uniform
- Ordering cost(S) per order remains constant
- Carrying cost(C) per unit remains constant
- Purchase price (P) per unit remains constant
- No Shortages are allowed.
- As soon as the level of inventory reaches zero, the inventory is replenished back.
    - Lead time is Zero

Formula (EOQ without Shortage):

$$EOQ = \sqrt{2\ D\ S / H}$$

Where:

- D = Annual demand (units)
- S= Ordering cost per order
- H = Holding cost per unit per year

Illustration 14.1: A company needs 1,200 units of raw material per year. The ordering cost per order

is ₹100, and holding cost per unit per year is ₹10

Solution: D = Annual demand (units) = 1200
S= Ordering cost per order = ₹100
H = Holding cost per unit per year = ₹10

$$EOQ = \sqrt{2\ D\ S / H}$$

$$EOQ = \sqrt{(2 \times 1200 \times 100) / 10}$$

$$= \sqrt{24000} = 155 \text{ Units per order}$$

Thus, the company should order **155 units each time** to minimize total inventory cost while avoiding shortages.

Illustration 14.2: Find the Optimum Quantity for the following EOQ model.

Annual usage	500 pieces
Cost per piece	Rs. 100
Ordering cost	Rs. 10 per order
Inventory holding cost	20% of Average Inventory

Solution:
Given that Demand (D) = 500 pieces
Set up cost (S) = 10,
Purchasing cost (P) =100
Holding cost (H) =IXP= 100 X 20% = Rs. 20

$$EOQ = \sqrt{2\ D\ S / H} = \sqrt{(2 \times 500 \times 10) / 20}$$

EOQ = 22 pieces (rounded)

14.6.2: Model II: Purchasing model with shortages

The Purchasing Model with Shortage allows for stock outs or shortages to occur temporarily. This model is used when occasional shortages are tolerable and the cost of holding inventory

is high compared to the cost of shortage. It helps balance ordering cost, holding cost, and shortage cost to minimize the total inventory cost.
Key Features:

Permissible Shortage: Stock outs are allowed, but the demand during the shortage is either backordered or lost.
Fixed Demand: Demand rate is constant and known.
Replenishment: Inventory is replenished in full at the end of the shortage period.
Objective: Minimize total cost, which includes ordering cost, holding cost, and shortage cost.

Assumptions

- Demand(D) per year is known and is uniform
- Ordering cost(S) per order remains constant
- Carrying cost(C) per unit remains constant
- Purchase price(P) per unit remains constant
- Shortages are allowed. As soon as the level of inventory reaches zero, the inventory is replenished back with lead time.
- Shortage cost (sh) per unit remains constant

Formula (EOQ with Shortage):

EOQ = √ (2 D S (H +p)) / (Hxp)

Where D = Annual demand (units)
S = Ordering cost per order
H = Holding cost per unit per year
p = Shortage cost per unit per year

I
llustration 14.3: A company has an annual demand of 1,200 units. Ordering cost is ₹100 per order, holding cost is ₹10 per unit per year, and shortage cost is ₹20 per unit per year.

Solution: D = Annual demand (units) = 1200
S = Ordering cost per order = ₹100
H = Holding cost per unit per year = ₹10
p = Shortage cost per unit per year = ₹20

EOQ = √ (2 D S (H +p)) / (H x p)
= √ (2 x 1200 x 100 (10 + 20)) / (10 x 20)
= √ (2 x 1200 x 100 (30)) / 200
= √ (2 x 1200 x 3000) / 200
= √ 7200000 / 200
= √ 36000 = 190 Units (approximately)

Thus, the company should order **190 units per order**, allowing temporary shortages to reduce overall cost.

14.6.3 Model III: Manufacturing model without shortages

Manufacturing inventory models without shortages refer to production situations where items are manufactured internally and demand is met continuously without allowing any stock out at any point. These models assume that production begins before inventory is fully depleted, ensuring that the system always maintains enough stock to satisfy demand during the production cycle. The most widely used model under this category is the EPQ / POQ (Economic Production Quantity / Production Order Quantity) Model.

In such systems, the production rate is higher than the consumption (demand) rate, allowing inventory to accumulate gradually while production is on-going. Once production stops, the inventory is depleted only by demand until it reaches the minimum level, after which a new production run begins. The aim is to determine the optimal production lot size that minimizes the total cost of setup and inventory holding, while maintaining uninterrupted supply.
These models are especially relevant for manufacturing firms, assembly units, fabrication shops, and process industries where production occurs in batches rather than continuous mass production.

Assumptions

Demand(D) per year is known and is uniform
Setup cost (S) per production run remains constant
Carrying cost(C) per unit remains constant
Production cost per unit(P) per unit remains constant
No Shortages are allowed. As soon as the level of inventory reaches zero, the inventory is replenished back.

Illustration 14.4: The following Data is given and Find EPQ?:

Annual demand D=12,000 units
Setup (ordering) cost S=₹200 per run
Holding cost H=₹5 per unit per year
Production rate p= 20,000 units/year
Demand rate d=D=12,000 units/year

Solution:

Formula for EPQ = √ (2 D S) / (H (1 – d/p))
EPQ = √ (2 x 12000 x 200) / (5 (1 – 12000/20000))
= √ (4800000) / (5 – (1 – 0.6))
= √ (4800000) / (5 x 0.4)
= √ 4800000 / 2
= √ 2400000 = 1549.19 Units

14.6.4 Model IV: Manufacturing model with shortages

A Manufacturing Model with Shortages refers to a production inventory system where temporary stock outs are permitted during the production cycle. Unlike traditional EPQ models that assume no shortage at any time, this model recognizes that in many manufacturing environments, it is economically feasible to allow backorders rather than maintain high inventory levels.

Shortages are not lost sales; instead, they are backlogged, meaning that pending customer orders will be fulfilled as soon as production resumes or inventory becomes available. The main objective of this model is to determine the optimal production quantity, the maximum inventory level, and the maximum shortage level that minimize the sum of setup, holding, and shortage costs.

Key Features

Shortages (backorders) are allowed but not lost.
Backordered demand is fulfilled later when inventory is produced.
Inventory builds up only after the backlog has been cleared.
The production rate is greater than the demand rate.
Aim: Minimize **total cost** = setup + holding + shortage cost.

Assumptions

- Demand rate (d) is constant and known.
- Production rate (p) is constant and higher than demand (p > d).
- Shortage cost per unit per year (C_s) is known.
- Setup (or production run) cost is constant.
- A portion of the cycle time is spent in shortage/backlog and the remaining in positive inventory.
- Lead time is negligible or included in production time.

The optimal production quantity (EPQ with shortages) is:

$$Q^* = \sqrt{((2\,DS / H(1-d/p)) \times ((H+C_s)/C_s)}$$

Where D = Annual demand
S= Setup/production run cost
H = Holding cost per unit/year
Cs = Shortage (backorder) cost per unit/year
p = Production rate
d = Demand rate

Illustration 14.5: A factory manufactures a spare part with an annual demand D=12,000 units. Production is in batches; each production run incurs a setup cost S=₹800. The holding cost is H=₹5 per unit per year. The production line can produce at rate p=40,000 units/year while demand occurs at d=12,000 units/year. Shortages (backorders) are permitted and the shortage (backorder) cost is Cs=₹20 per unit per year.
Find the optimal production quantity **Q*** (EPQ with shortages).

Solution:

Given D =12,000 units/year
S = ₹800 per setup
H = ₹5 per unit-year
Cs = ₹20 per unit-year
P = 40,000 units/year,
d=12,000units/year

$$Q^* = \sqrt{((2\,DS / H(1-d/p)) \times ((H+C_s)/C_s)}$$
$$= \sqrt{((2 \times 12000 \times 800) / 5\,(1 - 12000/40000)} \times ((5 + 20)/ 20)$$
$$= \sqrt{((2 \times 12000 \times 800) / 5\,(1 - 0.30))} \times (25/ 20)$$
$$= \sqrt{((2 \times 12000 \times 800) / 5 \times 0.70) \times (1.25)}$$
$$= \sqrt{(19200000 / 3.5) \times 1.25}$$
$$= \sqrt{5,485,714.2857 \times 1.25}$$
$$= \sqrt{6,857,142.8571}$$
$$= 2,618.61 \text{ units (approximately)}$$

14.7 SUMMERY

Inventory management plays a crucial role in ensuring smooth business operations by balancing supply with demand while minimizing associated costs. It is an essential function for organizations as it influences customer satisfaction, production continuity, and financial performance. Inventory refers to the idle stock of physical goods held for future use or sale and includes raw materials, work-in-progress, finished goods, packaging materials, and goods in transit. Effective inventory management requires careful planning and decision-making to determine *what*, *when*, and *how much* to order or produce.

Managers must consider multiple decisions, such as reorder levels, safety stock, order size, investment level, and acceptable service levels. Improper inventory decisions can lead to stock outs, production disruptions, higher carrying costs, and loss of sales. Inventory also performs several important functions such as meeting customer demand, smoothing production fluctuations, avoiding stock outs, taking advantage of price benefits, and supporting continuous operations.

Maintaining inventory involves several cost components—ordering costs, carrying costs, shortage costs, and purchase costs. These cost factors guide organizations in determining optimal inventory levels.

To assist in decision-making, inventory models help determine the economic order quantity and timing for replenishment. These models are broadly classified into:

- **Purchasing Models**: Used when inventory is bought from external suppliers. These may assume shortages *not allowed* or *allowed* depending on business policy.
- **Manufacturing (Production) Models**: Used when items are produced internally and inventory builds gradually. These too may allow or avoid shortages.

Overall, inventory models provide a structured approach to optimize stock levels, reduce cost, and improve operational efficiency, ensuring that organizations remain competitive, financially sound, and capable of meeting market demand effectively.

14.8 TECHNICAL TERMS

Inventory

The stock of goods, materials, and supplies held by a business for production or sale.

Economic Order Quantity (EOQ)

The optimal quantity of inventory to order at one time that minimizes total ordering and holding costs.

Reorder Point (ROP)

The inventory level at which a new order must be placed to avoid stockouts.

Carrying Cost (Holding Cost)

Cost of maintaining inventory including storage, insurance, interest, and deterioration.

Ordering Cost / Setup Cost

The cost incurred every time an order is placed or production batch is started.

Work-in-Progress (WIP)

Items that are currently being processed in production but not yet completed.

Safety Stock

Extra quantity of inventory kept as a buffer to protect against uncertainty in demand or lead time.

EPQ (Economic Production Quantity)

The optimal batch size to produce internally while minimizing production setup and holding costs.

14.9 SELF-ASSESSMENT QUESTIONS

1) What is the main purpose of using inventory models in business operations?
2) Economic Order Quantity (EOQ). What assumptions are typically made in the basic EOQ model?
3).Describe the concept of shortages allowed versus shortages not allowed in inventory models.
4) What is the Economic Production Quantity (EPQ) model, and how does it differ from EOQ?
5) Provide an example of a situation where a manufacturing inventory model is more suitable than a purchasing model.

14.10 SUGGESTED READINGS

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LESSON-15
SELECTIVE INVENTORY CONTROLLING TECHNIQUES

OBJECTIVES:

After going through this unit you should be able to:

- Understand the need for selective inventory control
- Explain the meaning and purpose of major selective inventory techniques such as
- ABC, FSND, VED, HML, SDE, GOLF, SOS and XYZ.
- Describe the criteria and principles used in each method, and
- Basic steps of ABC analysis

STRUCTURE:

15.1 INTRODUCTION:

In any medium to large industrial organization, the inventory typically consists of thousands of diverse items—ranging from high-value machinery components and critical spare parts to low-cost consumables such as nuts, bolts, and paint cans. These items differ widely in terms of value, usage rate, criticality, size, and procurement difficulty. Because of this diversity, it is neither practical nor economical to apply the same level of control and monitoring to every item in the inventory. Attempting to maintain uniform and tight control over all items leads to excessive administrative effort, unnecessary documentation, and inefficient use of managerial time.

To address this complexity, the principle of Management by Exception is adopted. This principle suggests that management attention should focus mainly on items that significantly influence overall inventory cost, production continuity, and service levels. Selective inventory control techniques help categorize materials based on their importance and characteristics, enabling managers to apply different control measures where needed. This approach ensures systematic monitoring, reduces wastage, and improves operational efficiency without overwhelming the organization.

15.2 NEED FOR SELECTIVE INVENTORY CONTROL TECHNIQUES

Selective inventory control techniques are essential because every item in the inventory does not require the same degree of attention. These techniques help organizations prioritize and control materials effectively based on their value, criticality, and usage. The need arises due to the following reasons:

1. Wide Variety of Inventory Items
Industries handle thousands of items with varying importance. It is impractical to monitor all items equally. Selective techniques help identify the few critical items that deserve stronger control.
2. Optimum Use of Managerial Time
Management by Exception ensures that managerial effort is directed only toward items that significantly impact costs or operations. This prevents wastage of valuable management time on routine or low-value items.
3. Reduction of Excessive Controls
Excessive controls create confusion, delays, paperwork, and inefficiency. By focusing on selected categories of items, organizations maintain discipline without overburdening the system.
4. Different Importance Levels of Materials
Not all materials contribute equally to production or cost. High-value or critical components require strict monitoring, whereas inexpensive or non-critical items require simpler controls. Selective techniques make this differentiation clear.
5. Better Inventory Planning and Cost Reduction
By identifying materials that form the bulk of investment (for example, A-category in ABC analysis), companies can take measures such as closer control, lower safety stock, and better forecasting, thereby reducing overall inventory cost.
6. Improved Production Continuity
Critical items whose shortage can halt production (e.g., V-category in VED analysis) must be monitored carefully. Selective control ensures such items are never out of stock, thus preventing production stoppages.
7. Tailor-Made Control Procedures
Each class of material requires a different control strategy—tight control for vital or high-value items, moderate control for essential items, and simple controls for low-value or non-critical items. Selective techniques provide a systematic basis for applying these varied controls.

15.3 METHODS USED IN THE SELECTIVE INVENTORY CONTROL

a) ABC (also known as Always Better Control or Pareto's Law),
b) b). FSND (Fast moving, Slow moving, Non- moving, Dead),
c) c). VED (Vital, Essential, Desirable),

d) HML (high, medium, low),
e) SDE (Scarce, Difficult and Easy to obtain),
f) f). GOLF (Government, Open market, Local and Foreign source),
g) g). SOS (Seasonal and Off-Seasonal), and
h) h).XYZ (based on the value of the inventory stored).

15.3.1) ABC ANALYSIS:

ABC analysis stands for 'Always Better Control* analysis. It is based on the concept: thick on the best and thin on the rest. The objective of ABC control is to vary the expenses associated with maintaining appropriate control according to the potential savings associated with proper level of such control. It is one of the widely used techniques of inventory control.

This analysis categorizes items based on their annual consumption value; sometimes Inventory Managers can use Pareto's Principle for classification. Pareto's Principle classifies the important items in a certain group that usually constitute a small portion of the total items in the group. The majority of the items, as a whole, will seem to be of minor significance.

The ABC approach is a means of categorizing inventory items into 3 classes: A, B and C according to the potential amount to be controlled.

CLASS A: 15% of total inventories contributing towards 70% of total consumption value.
CLASS B: 30% of total inventories, which account for about 25% of total consumption value.
CLASS C: 55% of total inventories, which account for only 5% of total consumption value.

Category	**Label**	**Quantity(%)**	**Cost(%)**
A	Outstanding Important	15	70
B	Average Importance	30	25
C	Relatively Unimportant	55	5

The purpose of classifying inventory in to A, B and C category is to identify where to expend money on inventory and where should be saved. Where care should be taken more and where inventory doesn't demand extra care. During application of this concept, following points should be always considered by a retailer:

i. Category 'A' items are subject to strict inventory control. Therefore, continuous cooperation and interaction is must so that the time spent on placing the order and receiving the inventory should be minimum to the extent possible.
ii. For category 'B' items moderate control should be used. As category 'B' items are subject to an intermediate inventory control.
iii. Due to low usage value and low costs 'C' items should be procured infrequently and in sufficient quantities. Therefore, strict control is not recommended. Such items are normally kept in an open area inside the store, from where customers can take them according to their requirement. But a periodic monitoring mechanism is established for such items, and quantities almost double the EOQ are ordered at one time.

The task is to identify the materials that have the highest annual consumption value regarding their portion of their annual consumption. Thus what we have to do is to conduct an ABC - analysis in order to structure the product range in A, B and C items. For this example the procedure is the following:

The steps of ABC analysis are presented below:
Step-1: Input the following:
- Total number of items.
- Item code, Annual consumption in terms of units and unit price for each of the items.

Step-2: For each item, compute annual consumption value in terms of rupees by multiplying, its annual consumption units with its unit price.
Step-3: Arrange the items and their details in descending order of the annual consumption values computed in Step-2.
Step-4: Compute cumulative values of the annual consumption values.
Step-5: Group the items into A,B and C classes by dividing the items into 70%,20% and 10% of the annual consumption values, respectively from top to bottom in the sorted list of Step3.

Illustration 15.1:
The following is the table which gives you the list of materials used by one industrial unit. Classify the items into A, B and C categories.

Symbol	**Item**	**Annual Consumption(units)**	**Price per unit in rupees**
A	Benzyl Penicilian	5000	10
B	Dexamethasome	650	10
C	Mannitol	1800	18
D	Chiorxylenol	4200	1
E	Ampicillian	60	8
F	Gentamycin	6500	6
G	Tetracycine	2500	5
H	Triflyperazine	4200	1
I	Imipramine	50	10
J	Diazepam	100	7
K	Streptapenicillian	100	35
L	Oxytetracycline	50	8
M	Phenobarbitane	2000	0..25
N	Analgin	20	10
O	Prednisalane	30	6
P	A.P.C	80	0.15
Q	Sulphane	200	0.50
R	Vitamin C	750	4
S	Aluminium Hydroaxide	300	7
T	Aspirin	20	10

Solution:

The first step is to construct a ranking table by assigning ranks in descending order to annual usage of the inventory items.(starting which the highest annual usage value)

Symbol	Item	Annual Consumption(units)	Price per unit in rupees	Annual Usage in Rupees	Rank
A	Benzyl Penicilian	5000	10	50000	1
B	Dexamethasome	650	10	6500	5
C	Mannitol	1800	18	32400	3
D	Chiorxylenol	4200	1	4200	6
E	Ampicillian	60	8	480	14
F	Gentamycin	6500	6	39000	2
G	Tetracycine	2500	5	12500	4
H	Triflyperazine	4200	1	4200	7
I	Imipramine	50	10	500	12
J	Diazepam	100	7	700	11
K	Streptapenicillian	100	35	3500	8
L	Oxytetracycline	50	8	400	15
M	Phenobarbitane	2000	0..25	500	13
N	Analgin	20	10	200	16
O	Prednisalane	30	6	180	18
P	A.P.C	80	0.15	12	20
Q	Sulphane	200	0.50	100	19
R	Vitamin C	750	4	3000	9
S	Aluminium Hydroaxide	300	7	2100	10
T	Aspirin	20	10	200	17

Soon thereafter, cumulative annual usage and cumulative percentage are calculated in the 3rd and 4th columns.. Items

Symbol	Item	Annual Usage in Rupees	Cumulative Annual Usage in Rupees	Cumulative Annual Usage in percentage	Category
A	Benzyl Penicilian	50000	50000	31.12	A
F	Gentamycin	39000	89000	55.39	A
C	Mannitol	32400	121400	75.55	A
G	Tetracycine	12500	133900	83.34	B
B	Dexamethasome	6500	140400	87.38	B
D	Chiorxylenol	4200	144600	89.99	B
H	Triflyperazine	4200	148800	92.61	C
K	Streptapenicillian	3500	152300	94.79	C
R	Vitamin C	3000	155300	96.66	C
S	Aluminium Hydroaxide	2100	157400	97.96	C

J	Diazepam	700	158100	98.40	C
I	Imipramine	500	158600	98.71	C
M	Phenobarbitane	500	159100	99.02	C
E	Ampicillian	480	159580	99.32	C
L	Oxytetracycline	400	159980	99.57	C
N	Analgin	200	160180	99.69	C
T	Aspirin	200	160380	99.82	C
O	Prednisalane	180	160560	99.93	C
Q	Sulphane	100	160660	99.99	C
P	A.P.C	12	160672	100	C

Items A,F and C account for 75.5 percent of total annual consumption and are therefore ‘A ‘category items(15 percent).

Items G,B and D (another 15 percent) contributes approximately 15 percent to annual consumption. therefore’ category items

The remaining 70 percent items contribute roughly 10 percent to annual consumption and are therefore ‘C’ category items.

15.3.2) FSND ANALYSIS:

This analysis classifies inventory based on quantity, rate of consumption and frequency of issues and uses. Here is the basic depiction of FSN Analysis: F stands for Fast Moving, S for Slow Moving and N for Normal Moving items and D for Dead Items or Non-Moving Items. Fast Moving (F) = Items that are frequently issued/used Slow Moving (S) = Items that are issued/used less for certain period of time Normal Moving (N) = Items that are not issued/used for more than certain duration Dead Items or Non-Moving Items (D) = Items not issued at all for a long time

The following steps are undertaken while doing the FSN analysis:

i. Calculation of average stay and the consumption rate of the material in warehouse
ii. FSN Classification of materials based on average stay in the inventory
iii. FSN Classification of the material based on consumption rate
iv. Finally classifying based on above FSN analysis.

Calculation of consumption rate and average stay of the material in the inventory

Consumption Rate - Total Issue Qty/Total Period Duration
Average stay of the material *» Cumulative No of Inventory Holding Days/ (Total quantity received + Opening Balance)

FSN Analysis is helpful in identifying active items which need to be reviewed regularly and surplus items which have to be examined further. Non-moving items may be examined further and their disposal can be considered.

This helps in preventing obsolescence and ensures disposal of dead stock. Some authors classify the items as FSN where ‘F stands for fast, ‘S’ stand for slow moving, ‘N’ stand for non- moving materials & parts. This will automatically reduce inventory costs.

15.3.3) VED ANALYSIS:

In addition to the intrinsic or the market value of materials which is invested in the materials, there is sometimes a ‘nuisance' value to the materials.

The nuisance value is the cost associated with the materials due to their absence. Certain materials are important by their absence and not necessarily by their presence.

If they are not available, they hold up production and, therefore, there are high costs of shut-down or slow-down of production. By themselves, these materials may not be priced high in the market. The investment in these materials may be small but for lack of any of them, the production process may come to a grinding halt. These are critical items which are required in adequate quantity.

Thus, there is another kind of classification of materials which has to deal with the critical nature of the items, i.e., whether they are 'vital' to the production process, or 'essential' or just 'desirable'. In addition to the conventional ABC analysis, the VED analysis is of great importance. Such VED ranking can be done on the basis of the shortage costs of materials which can be either quantified or qualitatively expressed.

This is an analysis whose classification is dependent on the user’s experience and perception. This analysis classifies inventory according to the relative importance of certain items to other items, like in spare parts. In VED Analysis, the items are classified into three categories which are:

Vital: inventory that consistently needs to be kept in stock.
Essential: keeping a minimum stock of this inventory is enough.
Desirable: operations can run with or without this, optional.

The VED analysis is done to determine the criticality of an item and its effect on production and other services. It is specially used for classification of spare parts. If a part is vital it is given 'V' classification, if it is essential, then it is given 'E* classification and if it is not so essential, the part is given 'D' classification.

For 'V' items, a large stock of inventory is generally maintained in view of their extreme critical nature. The stock-out costs associated with such materials are very high and therefore, the service levels will be very high for this class of materials. The service levels for the subsequent E and D class materials will be lower and lowest respectively. The D class items are easily available in the market. They do not hold up production and can be substituted as well. Therefore, we can manage with small inventories of these items without drastic consequences on the running of the production line.

VED (Vital, Essential, Desirable) analysis examines the items from the importance of plant operations and is not related to the value of annual usage. Spares related to machinery on single line operations are very important. Their non-availability can result in stoppage of the plant. These spares may be of very low value but have great importance in plant operations. Spares therefore should also be examined from the point of view of vital, essential or desirable nature. The ideal decision for the quantity to be purchased would be based on a balanced, combined approach of ABC and VED analyses. The attention to each item in the inventory to be purchased would be determined on the consideration of the matrix of ABC and VED. For example, highest attention is to be given to 'A' category items in the category of 'Vital', next to be given to 'B' category items in the 'Essential' category and lowest attention is to be given to 'C' category items in the 'Desirable' category. For explaining this point, values of the inventory are given in the matrix as below:

	V	E	D
A	80	70	60
B	70	60	50
C	60	50	40

15.3.4) HML ANALYSIS:

The High, Medium and Low (HML) classification follows the same procedure as is adopted in ABC classification. Only difference is that in HML, the criterion of classification is the unit value and not the annual consumption value.

HML Analysis classifies inventory based on how much a product costs/its unit price.

The classification is as follows:

High Cost (H) = Item with a high unit value.
Medium Cost (M) = Item with a medium unit value.
Low Cost (L) = Item with a low unit value.
The items of inventory should be listed in the descending order of unit value and it is up to the management to fix limits for the three categories. For example, the management may decide that all units with unit value of Rs.2000 and above will be H items, Rs.1000 to 2000 M items and less than Rs.1000, L items.

The HML analysis is useful for keeping control over consumption at departmental levels, for deciding the frequency of physical verification, and for controlling purchases.

15.3.5) SDE ANALYSIS:

The SDE analysis is based upon the availability of items and is very useful in the context of scarcity of supply.
This analysis classifies inventory based on how freely available an item or scarce an item is, or the length of its lead time. This is how the inventory is classified:

Scarce (S) = Items which are imported and require longer lead time.
Difficult (D) = Items which require more than a fortnight to be available, but less than 6 months' lead time.
Easily available (E) = Items which are easily available

The SDE classification, based on problems faced in procurement, is vital to the lead time analysis and in deciding on purchasing strategies.

15.3.6) GOLF ANALYSIS:

The GOLF classification of inventory items is done considering the nature of suppliers. As the source of supply of different items are different, with a view to determining the lead time, order quantities, safety stock and terms of purchase and payment. Here, under this classification:

G = Government controlled supplies
O = Open market supplies
L = Local supplies
F = Foreign market supplies.

15.3.7) SOS ANALYSIS:

SOS analysis is based on the nature of suppliers and period of their availability. This is useful for deciding the time of purchase or procurement, so that the cost of materials and the holding cost may be balanced. Here, the two classes are:
S = Seasonal items
OS = off seasonal items i.e., items available throughout the year.

Seasonal items are those that are **available only during a specific season or limited period**, depending on supplier availability. Their supply depends on natural, agricultural, or climatic cycles.

Off-seasonal items are those that are **not available during specific periods** because suppliers **stop production or distribution** in the off-season

The analysis helps in identifying items that are available only during a particular season for e.g. raw mangoes are only available only during a summer and identifying items that are non- seasonal.

15.3.8) XYZ ANALYSIS:

It is based on the closing inventory value of different items. Such classification is done every year at the time of annual stock taking and items having highest inventory- valuation are classified as ‘X’, while those with low investment in them are termed as ‘Z’ items. Other items are ‘Y items whose inventory value is neither too high nor too low. This type of analysis is particularly useful in identifying the items requiring maximum care and attention during storage.

Classification Techniques for Inventory Control

Sl No	Name	Criteria
1	ABC Analysis (Always Better Control)	Annual value of consumption of the items
2	FSND (fast moving, Slow moving, Non moving, Dead)	Criteria is issuing from the stores

3	VED (Vital, Essential, Desirable)	The critical nature of component or material with respect to production
4	HML(High, Medium, Low)	Unit price of the material
5	SDE(Scarce, Difficult, Easy)	Criteria is Procurement difficulties
6	GOLF (Government, Ordinary, Local , Foreign)	It is the source from where the material is obtained
7	SOS (Seasonal, Off seasonal)	Criteria is seasonolity
8	XYZ (Stable, Moderate, Highly variable)	Based on the variability and predictability of the inventory demand

15.4 SUMMERY

In medium and large industries, inventory consists of thousands of items—ranging from high-value equipment components to low-cost consumables. These items differ greatly in cost, usage, criticality, and availability. Applying the same level of control to all items is neither practical nor economical. Excessive control causes unnecessary paperwork, wastes managerial time, and leads to confusion without adding value. Therefore, industries follow the **principle of Management by Exception**, where tight control is applied only to items that significantly affect cost or production.

Selective inventory control techniques are needed because only a small percentage of items contribute majorly to inventory value or production continuity. By classifying items based on their characteristics—such as value, criticality, movement, price, availability, or seasonality—management can focus attention where it matters most. This helps minimize stock-outs of critical items, avoid over-investment in low-value items, reduce carrying costs, prevent accumulation of obsolete materials, and improve overall inventory efficiency.

Techniques such as **ABC, VED, HML, FSND, XYZ, SDE, GOLF, and SOS analyses** help managers determine what level of control each item requires. For example, ABC focuses on consumption value, VED on criticality, FSND on movement rate, and SOS on seasonal availability. Using these techniques ensures systematic classification, better planning, optimized inventory levels, and effective utilization of managerial effort.

15.5 TECHNICAL TERMS

Inventory Control – Systematic regulation of stock levels to ensure availability while minimizing costs.

Management by Exception – Focusing managerial attention only on items that significantly impact cost or operations.

Selective Control – Applying different levels of control to different inventory items based on set criteria.

ABC Analysis – Classifying items into A, B, and C categories based on annual consumption value.

VED Analysis – Categorization of items into Vital, Essential, and Desirable based on criticality to operations.

FSND Analysis – Classification into Fast-moving, Slow-moving, Normal-moving, and Dead stock based on issue frequency.
HML Analysis – Grouping items based on unit cost into High, Medium, and Low categories.
XYZ Analysis – Classification based on closing inventory value or stock value distribution.
SDE Analysis – Categorizing items as Scarce, Difficult, or Easily available depending on procurement complexity.
GOLF Analysis – Identifying items by their source of supply—Government, Open market, Local, or Foreign.
SOS Analysis – Classification of items into Seasonal and Off-Seasonal based on supplier availability.
Criticality Analysis – Evaluating how essential an item is for uninterrupted production.

15.6 SELF-ASSESSMENT QUESTIONS

1) Explain the need of selective inventory control techniques?
2) Differentiate between ABC Analysis and VED Analysis?
3) How does FSND Analysis help in identifying obsolete or dead stock items?
4) What is SOS Analysis?
5) How does HML Analysis support decision-making in pricing and procurement?
6) Explain how SDE Analysis helps in planning for items with long lead times or procurement Difficulties?

15.7 SUGGESTED READINGS

1) S. A. Chunnawala, D. R. Patel, 'Production and Operations Management', 7th Edition, Himalaya Publishing House. New Delhi.
2) Aswathappa K., Sridhara Bhatt, 'Production and Operations Management', 7th Edition, Himalaya Publishing House.
3) S. N. Chary, 'Production and Operations Management', Tata McGraw Hill Publishing Company.
4) Kanishka Bedi, 'Production and Operations Management', Oxford University Press.

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LESSON-16
WORK STUDY

OBJECTIVES:

After going through this unit you should be able to:

- Understand the meaning and relevance of work design; gain insights into the components of work
- study and its advantages;
- Know the meaning and importance of method study, the steps involved in it,
- The recording techniques for method study and also the charts used in it

STRUCTURE:

16.1 INTRODUCTION

Work is the basic source of our livelihood. It also nourishes the human personality. We regard work differently at different points of time. Work systems set boundaries to what must be managed. Work systems result from people machines interface or technical competence and equipment interface. This interface is in an organizational context to achieve certain objectives.

Work design is used to assess how tasks or the entire job is organised within the work environment, and then ensure these are well-matched to the attributes of the employee. While both terms, job design and work (place) design are used interchangeably, job design has a focus on those administrative changes that are required to improve working conditions, with work design having a more pragmatic approach and addressing those adjustments that may be required to workstations, tools, and body positions to allow the worker to function more effectively . A properly designed job guarantees that the worker is able to accomplish what is required in a safe and healthy fashion, and thereby reduce physical and psychological strain. Further, it helps with the organisation of work, e.g. in identifying issues such as: work overload, repetitiveness, and limited control over work; and thereby improve on occupational safety and health (OSH) within organisations. A well-designed job could result in more engaged, healthy and productive employees, and these outcomes would benefit both employees and organisations.

Design of work systems is an important component in Production and Operations Management. It forms the basis and explains the importance of work design. Design of work systems is used to describe the two basic approaches to job design, the first approach focuses on efficiency through job specialization and the other focuses behavioural approaches to job design. Design of work system also entails method analysis which in turn centres on how jobs are performed. Motivation and trust also form an important dimension in design of work systems as this alone provides an opportunity to the organization to develop effective teams who can achieve organizations short and long term objectives. Motivation and trust observations also emphasizes working conditions that in turn lead to work measurements which leads to reward and compensation of the individual working for the organization.

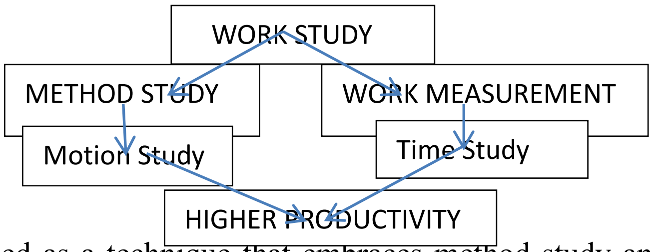
Work System Design consists of job design, work measurement, establishment of time standards and worker compensation. The interesting fact is that even in decisions in other areas of design can affect the work design system or even a change in the work design system can change the decisions in other areas. Similarly, product or service design and layout decisions will also affect design of work systems. It is thus logical to ensure that SYSTEMS approach is followed in a decision for DESIGN, so a decision in one part of the system is equally replicated and acceptable to all the system (for ex., Product or Service Design would require proper people with standardized job description)

16.1.1: WORK STUDY

Work Study is the systematic examination of the methods of carrying out activities such as to improve the effective use of resources and to set up standards of performance for the activities carried out.

Work study is a means of enhancing the production efficiency (productivity) of the firm by elimination of waste and unnecessary operations. It is a technique to identify non-value adding operations by investigation of all the factors affecting the job. It is the only accurate and systematic procedure oriented technique to establish time standards. It is going to contribute to the profit as the savings will start immediately and continue throughout the life of the product. Method Study and Work Measurement are techniques of Work Study (Figure - 16.1). Part of Method Study is Motion Study and Time Study is one of the important techniques of Work Measurement.

FIG 16.1: A Frame work of Study



Work study is defined as a technique that embraces method study and work measurement which are employed to ensure the best possible use of human and material resources in carrying out the specified activity.

Method Study is systematic recording and critical examination existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs.

Work Measurement is 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.

There is a close link between Method Study and Work Measurement. Method study is concerned with the reduction of the work content and establishing the one best way of doing the job where as work measurement is concerned with investigation and education of any ineffective time associated with the job and establishing time standards for an operation carries out as per standard method.

Work study forms the basis for work system design. The purpose of work design is to identify the most effective means of achieving necessary functions. This work-study aims at improving the existing and proposed ways of doing work and establishing standard times for work performance

16.1.2 ADVANTAGES OF WORK STUDY

Following are the advantages of work study:

1) It helps to achieve the smooth production flow with minimum interruptions.
2) It helps to reduce the cost of the product by eliminating waste and unnecessary operations.
3) Better worker-management relations.
4) Meets the delivery commitment.
5) Reduction in rejections and scrap and higher utilization of resources of the organization.
6) Helps to achieve better working conditions.
7) Better workplace layout.
8) Improves upon the existing process or methods and helps in standardization and simplification.
9) Helps to establish the standard time for an operation or job which has got application in manpower planning, production planning.

16.2: METHOD STUDY

Method study enables the industrial engineer to subject each operation to systematic analysis. The main purpose of method study is to eliminate the unnecessary operations and to achieve the best method of performing the operation. Method study is also called methods engineering or work design.

Method engineering is used to describe collection of analysis techniques which focus on improving the effectiveness of men and machines. According to British Standards Institution (BS 3138): "Method study is the systematic recording and critical examination or existing and proposed ways of doing work as a means of developing and applying easier and more effective methods and reducing cost."

Fundamentally method study involves the breakdown of an operation or procedure into its component elements and their systematic analysis. In carrying out the method study, the right attitude of mind is important. The method study man should have:

- The desire and determination to produce results.
- Ability to achieve results.
- An understanding of the human factors involved

The scope of Method Study lies in improving work methods through process and operation analysis, such as:

- Manufacturing operations and their sequence;
- Workmen;
- Materials, tools and gauges;
- Layout of physical facilities and work station design;
- Movement of men and material handling; and
- Work environment.

The areas to which method study can be applied successfully in manufacturing are:

- To improve work methods and procedures;
- To determine the best sequence of doing work;
- To smoothen material flow with minimum of back tracking and to improve layout;
- To improve the working conditions and hence to improve labour efficiency;
- To reduce monotony in the work;
- To improve plant utilization and material utilization;
- To eliminate waste and unproductive operations; and
- To reduce the manufacturing costs through reducing cycle time of operations

16.2.1: STEPS INVOLVED IN METHOD STUDY

The basic approach to method study consists of the following eight steps:

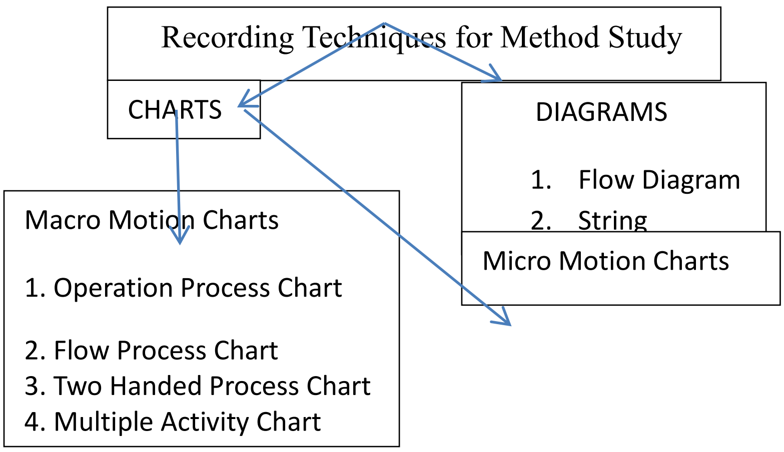
1) Select the work to be studied and define its boundaries.
2) Record the relevant facts about the job by direct observation and collect such additional data as may be needed from appropriate sources.

3) Examine the way the job is being performed and challenge its purpose, place sequence and method of performance.
4) Develop the most practical, economic and effective method, drawing on the contributions of those concerned.
5)Evaluate different alternatives to developing a new improved method comparing the cost effectiveness of the selected new method with the current method with the current method of performance.
6)Define the new method, as a result, in a clear manner and present it to those concerned, i .e., management, supervisors and workers.
7) Install the new method as a standard practice and train the persons involved in applying it.
8) Maintain the new method and introduce control procedures to prevent a drifting back to the previous method of work

16.2.2: **RECORDING TECHNIQUES FOR METHOD STUDY**

The next step in basic procedure, after selecting the work to be studied, is to record all facts relating to the existing method. In order that the activities selected for investigation may be visualized in their entirety and in order to improve them through subsequent critical examination, it is essential to have some means of placing on record all the necessary facts about the existing method. Records are very much useful to make before and after comparison to assess the effectiveness of the proposed improved method
The recording techniques are designed to simplify and standardise the recording work. For this purpose charts and diagrams are used

Figure 16.2: Recording Techniques for Method Study



16.2.3: CHARTS USED IN METHOD STUDY

This is the most popular method of recording the facts. The activities comprising the jobs are recorded using method study symbols. A great care is to be taken in preparing the charts so that the information it shows is easily understood and recognized. The following information should be given in the chart. These charts are used to measure the movement of operator or work (i.e., in motion study):

- Adequate description of the activities;
- Whether the charting is for present or proposed method;
- Specific reference to when the activities will begin and end;
- Time and distance scales used wherever necessary, and
- The date of charting and the name of the person who does charting

Charts can be broadly divided into: (A) Macro Motion Charts and (B) Micro Motion Charts. Macro motion charts are used for macro motion study and micro motion charts are used for micro motion study. Macro motion study is one which can be measured through 'stop watch' and micro motion study is one which cannot be measured through stop watch.

16.2.3.1: Macro Motion Charts:

Following four charts are used under this type:

(1).Operation Process Chart: It is also called outline process chart. An operation process chart gives the bird's eye view of the whole process by recording only the major activities and inspections involved in the process. Operation process chart uses only two symbols, i.e., operation and inspection. Operation, process chart is helpful to:

a) Visualize the complete sequence of the operations and inspectio ns in the process.
b) Know where the operation selected for detailed study fits into the entire process.
c) In operation process chart, the graphic representation of the points at which materials are introduced into the process and what operations and inspections are carried on them are shown.

(2) Flow Process Chart: Flow process chart gives the sequence of flow of work of a product or any part of it through the work centre or the department recording the events using appropriate symbols. It is the amplification of the operation process chart in which operations; inspection, storage, delay and transportation are represented. However, process charts are of three types:

a) Material Type— which shows the events that occur to the materials.
b) Man Type—Activities performed by the man.
c) Equipment Type— how equipment is used.

The flow process chart is useful:

-To reduce the distance travelled by men (or materials).
-To avoid waiting time and unnecessary delays.
-To reduce the cycle time by combining or eliminating operations.
-To fix up the sequence of operations. and
-To relocate the inspection stages.

Like operation process chart, flow process chart is constructed by placing symbols one below another as per the occurrence of the activities and are joined by a vertical line. A brief description of the activity is written on the right hand side of the activity symbol and time or distance is given on the left hand side.

(3).Two Handed Process Chart: A two handed (operator process chart) is the most detailed type of flow chart in which the activities of the workers hands are recorded in relation to one another. The two handed process chart is normally confined to work carried out at a single workplace. This also gives synchronized and graphical representation of the sequence of manual activities of the worker. The applications of this chart are:

a).To visualize the complete sequence of activities in a repetitive task; and
b).To study the work station layout.

(4).Multiple Activity Chart: It is a chart where activities of more than subject (worker or equipment) are each recorded on a common time scale to show their inter-relationship. Multiple activity chart is made:

a).To study idle time of the man and machines,
b).To determine number of machines handled by one operator, and
c).To determine number of operators required in teamwork to perform the given job.

16.2.3.2: MICRO-MOTION STUDY CHART:

Micro-motion study provides a technique for recording and timing an activity. It is a set of techniques intended to divide the human activities in a groups of movements or micro-motions (called Therbligs) and the study of such movements helps to find for an operator one best pattern of movements that consumes less time and requires less effort to accomplish the task. Therbligs were suggested by Frank O. Gilbreth, the founder of motion study. Micro-motion study was mainly employed for the job analysis. It's other applications include:

- As an aid in studying the activities of two or more persons on a group work;
- As an aid in studying the relationship of the activities of the operator and the machine as a means of timing operations;
- As an aid in obtaining motion time data for time standards, and
- Acts as permanent record of the method and time of activities of the operator and the machine.

The micro-motion group of techniques is based on the idea of dividing human activities into division of movements or groups of movements (Therbligs) according to purpose for which they are made. Gilbreth differentiated 17 fundamental hand or hand and eye motions. Each Therbligs has a specific colour, symbol and letter for recording purposes. The Therbligs of micro-motion study involves the following steps:

- Filming the operation to be studied; and
- Analysis of the data from the film.

The recording of the data through SIMO chart is done as micro motion chart.

Simultaneous Motion Cycle Chart (SIMO Chart) is a recording technique for micro motion study. A SIMO chart is a chart based on the film analysis, used to record simultaneously on a common time scale the Therbligs or a group of Therbligs performed by different parts of the body of one or more operators.

It is the micro-motion form of the man type flow process chart. To prepare SIMO chart, an elaborate procedure and use of expensive equipment are required and this study is justified when the saving resulting from study will be very high.

FIG 16.3: SIMO Chart Symbols

Sl. No	Code	Name	Description	Colour
1	SH	SEARCH	Locate and article	Black
2	F	FIND	Mental reaction at end of search	Grey
3	ST	SELECT	Selection from a member	Light grey
4	G	GRASP	Taking hold	Red
5	H	HOLD	Prolonged group	Gold ochre
6	TL	TRANSPORTED LOADED	Moving an article	Green
7	P	POSITION	Placing in a definite location	Blue
8	A	ASSEMBLE	Putting parts together	Violet
9	U	USE	Causing a device to perform its function	Purple
10	DA	DISASSEMBLE	Separating parts	Light Violet
11	I	INSPECT	Examine or test Burnt	Ochre
12	PP	PREPOSITION	Placing an article ready for use	Pale Blue
13	RL	RELEASE LOAD	Release article	Carmine Red
14	TE	TRANSPORT EMPTY	Movement of a body member	Olive Green
15	R	REST	Pause to overcome fatigue	Orange
16	UD	UNAVOIDABLE DELAY	Idle-outside person control	Yellow
17	PN	PLAN	Mental plan for future action	----

16.2.4: DIAGRAMS USED IN METHOD STUDY

Diagrams are of two types: (A) Flow Diagram and (B) String Diagram.

16.2.4.1:Flow Diagram:

Flow diagram is a drawing, of the working area, showing the location of the various activities identified by their numbered symbols and are associated with particular flow process chart either man type or machine type. The routes followed in transport are shown by joining the symbols in sequence by a line which represents as nearly as possible the path or movement of the subject concerned. Following are the procedures to make the flow diagram:

a).The layout of the workplace is drawn to scale.
b).Relative positions of the machine tools, work benches, storage, and inspection benches are marked on the scale.
c).Path followed by the subject under study is tracked by drawing lines.
d).Each movement is serially numbered and indicated by arrow for direction.
e).Different colours are used to denote different types of movements.

16.2.4.2:String Diagram:

The string diagram is a scale layout drawing on which, length of a string is used to record the extent as well as the pattern of movement of a worker working within a limited area during a certain period of time. The primary function of a string diagram is to produce a record of an existing set of conditions so that the job of seeing what is actually taking place is made as simple as possible.

One of the most valuable features of the string diagram is the actual distance travelled during the period of study to be calculated by relating the length of the thread used to the scale of drawing. Thus, it helps to make a very effective comparison between different layouts or methods of doing job in terms of the travelling involved. The main advantages of string diagram compared to flow diagram is that respective movements between work stations which are difficult to be traced on the flow diagram can be conveniently shown on string diagram.

Following are the procedures to draw string diagram:
a).A layout of the work place of factory is drawn to scale on the soft board;
b).Pins are fixed into boards to mark the locations of work stations, pins are also driven at the turning points of the routes;
c).A measured length of the thread is taken to trace the movements (path); and
d).The distance covered by the object is obtained by measuring the remaining part of the thread and subtracting it from original length.

16.2.5: METHOD STUDY SYMBOLS

Graphical method of recording was originated by Gilberth, in order to make the presentation of the facts clearly without any ambiguity and to enable to grasp them quickly and clearly. It is useful to use symbols instead of written description

O — OPERATION
□ — INSPECTION
→ — TRANSPORTATION
D — DELAY
∇ — STORAGE

(A).Operation: An operation occurs when an object is intentionally changed in one or more of its characteristics (physical or chemical). This indicates the main steps in a process, method or procedure. An operation always takes the object one stage ahead towards completion. Examples of operation are:

- Turning, drilling, milling, etc.
- A chemical reaction.
- Welding, brazing and riveting.
- Lifting, loading, unloading.
- Getting instructions from supervisor.

(B).Inspection: An inspection occurs when an object is examined and compared with standard for quality and quantity. The inspection examples are:

- Visual observations for finish.
- Count of quantity of incoming material.
- Checking the dimensions.

(C).Transportation: A transport indicates the movement of workers, materials or equipment from one place to another.
Example: Movement of materials from one work station to another; Workers travelling to bring tools, etc.

(D).Delay (Temporary Storage): A delay occurs when the immediate performance of the next planned thing does not take place.
Examples: Work waiting between consecutive operations; Workers waiting at tool cribs; Operators waiting for instructions from supervisor, etc.

(E).Storage: Storage occurs when the object is kept in an authorized custody and is protected against unauthorized removal. For example, materials kept in stores to be distributed to various work.

Illustration16.1: Develop a Process Chart for making a cheese sandwich.
Solution: The following chart is one possible solution. The level of detail in process charts depends upon the requirements of the job. Time is often included to aid analysis of value added.

Process Chart: Distance in Symbol Process Description Meter:

Distance in Metre	**Symbol**	**Process description**
10	⇨	Move to Cabinet
–	O	Get loaf of bread
–	O	Remove two slices of bread
–	O	Lay slices on counter-top

–	O	Close loaf of bread
–	O	Replace loaf of bread on shelf
–	O	Open butter
–	O	Spread butter on top slice of bread
–	□	Inspect sandwich
10	⇨	Move to serving area
–	O	Serve sandwich

Illustration 16.2: Develop a Multiple Activity Chart for doing three loads of laundry; assume that you will have access to one washing machine and one dryer.

Solution:
The following chart is one possible solution. The level of detail in process charts depends upon the requirements of the job. Time is often included to aid analysis of value added

Time	**Operator**	**Machine 1 washer**	**Machine 2 Dryer**
	Load clothes and detergent into Machine 1	Being loaded	Idle
	Idle		
	Remove clothes from Machine 1	Run	Idle
		Being unloaded	Idle
	Load clothes into Machine 2		
		Idle	Being loaded
Repeat Cycle	Load clothes and detergent into Machine 1		
	Idle	Being loaded	Run
	Remove clothes from Machine 2	Run	Run
	Hang clothes		
		Idle	Being unloaded
		Idle	
			Idle

16.3 SUMMARY

Work system design focuses on organizing tasks, jobs, and work environments so employees can work safely, efficiently, and with minimal strain. It includes job design, work measurement, time standards, and compensation, and must follow a systems approach because decisions in layout, product design, and processes influence one another. Work Study is a key tool for improving work systems. It systematically examines how work is performed to eliminate waste, simplify tasks, and set performance standards. Work Study consists of Method Study and Work Measurement, of which Method Study is the core technique.

Method Study aims to find the best and most economical way of doing a job. It involves the systematic recording and critical examination of existing or proposed work methods to remove unnecessary motions, improve workflow, and reduce effort and cost. Its scope includes analyzing operations, sequences, materials, tools, workplace layout, and movement of men and materials. Method Study follows eight steps: selecting the job, recording facts, examining activities, developing improved methods, evaluating alternatives, defining the new method, installing it, and maintaining it through control procedures.

To support analysis, Method Study uses various recording techniques such as operation process charts, flow process charts, two-handed process charts, and multiple activity charts, which help visualize operations, movements, and delays. Micro-motion study using filmed observations and Therbligs provides deeper insight into small movements for high-precision tasks. Diagrams like flow diagrams and string diagrams further help in studying movement patterns and improving layout efficiency.
Overall, Method Study is essential for designing effective work systems, improving productivity, reducing costs, and ensuring optimal use of human and material resources.

16.4 Technical Terms:

Work Study: It is the systematic examination of the methods of carrying out activities such as to improve the effective use of resources and to set up standards of performance for the activities carried out.

Method Study: It is a systematic recording and critical examination existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs.

Work Measurement: It refers to 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.

Operation Process Chart: It is also called outline process chart. An operation process chart gives the bird's eye view of the whole process by recording only the major activities and inspections involved in the process.

Flow Process Chart: It gives the sequence of flow of work of a product or any part of it through the work centre or the department recording the events using appropriate symbols.

A Two Handed (Operator Process Chart): It is the most detailed type of flow chart in which the activities of the workers hands are recorded in relation to one another. The two handed process chart is normally confined to work carried out at a single workplace.

Flow Diagram: It is a drawing of the working area, showing the location of the various activities identified by their numbered symbols and are associated with particular flow process chart either man type or machine type.

String Diagram: It is a scale layout drawing on which, length of a string is used to record the extent as well as the pattern of movement of a worker working within a limited area during a certain period of time.

Therbligs: 17 basic motion elements identified by Frank and Lillian Gilbreth to analyze human movements in industrial tasks. Each Therblig represents a specific action—such as search, grasp, or transport—that helps identify unnecessary or inefficient motions. By studying Therbligs, organizations can simplify work, reduce fatigue, and increase productivity.

SIMO Chart: Simultaneous Motion Cycle Chart is a recording technique for micro motion study. A SIMO chart is a chart based on the film analysis, used to record simultaneously on a common time scale the Therbligs or a group of Therbligs performed by different parts of the body of one or more operators

16.5 SELF-ASSESSMENT QUESTIONS:

1) Define Work Design?
2) Define Method study and discuss where method study can be applied?
3) What are the recording techniques of Method Study?
4) Distinguish between Micro and Macro Motion Charts?
5) What is SIMO Chart? Give the symbols of SIMO Chart?
6) What is String Diagram? Describe the procedure to draw the String Diagram?
7) What is Flow Diagram? Describe the procedure to draw the String Diagram?

16.6 SUGGESTED READINGS:

1) S. A. Chunnawala, D. R. Patel, ‘Production and Operations Management’, 7th Edition, Himalaya
Publishing House. New Delhi.
2) Aswathappa K., Sridhara Bhatt, ‘Production and Operations Management’, 7th Edition, Himalaya
Publishing House.
3) S. N. Chary, ‘Production and Operations Management’, Tata McGraw Hill Publishing Company.
4) Kanishka Bedi, ‘Production and Operations Management’, Oxford University Press

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LESSON-17

WORK MEASUREMENT

OBJECTIVES:

After going through this unit you should be able to:

- Understand the concept of work measurement
- Understand the objectives and techniques of work measurement;
- Discuss the steps involved in time study and also the computation of standard time,

STRUCTURE:

17.1 INTRODUCTION:

Work measurement is a fundamental technique in industrial engineering used to determine the time required for a qualified worker to complete a task under defined conditions and at a standard pace. It forms the backbone of efficient work system design by providing a reliable basis for planning, scheduling, costing, and improving productivity. By establishing standard times for various operations, work measurement helps organizations identify delays, eliminate inefficiencies, and ensure optimal utilization of manpower, machines, and materials.

In modern workplaces, where competitiveness and cost-effectiveness are critical, work measurement supports managers in evaluating performance, balancing workloads, and setting realistic targets. It also provides essential inputs for incentive schemes, resource allocation, process redesign, and method improvement. When combined with method study, work measurement enables a scientific approach to analysing tasks and achieving higher operational efficiency.

Overall, work measurement acts as a vital managerial tool that facilitates systematic control over work processes, enhances employee productivity, and contributes to continuous improvement within an organization.

17.1.1 OBJECTIVES OF WORK MEASUREMENT

The use of work measurement as a basis for incentives is only a small part of its total application. The objectives of work measurement are to provide a sound basis for:

1) Comparing alternative methods.
2) Assessing the correct initial manning (manpower requirement planning).
3) Planning and control.
4) Realistic costing.
5) Financial incentive schemes.
6) Delivery date of goods.
7) Cost reduction and cost control.
8) Identifying substandard workers. and
9) Training new employees

17.1.2 TECHNIQUES OF WORK MEASUREMENT

For the purpose of work measurement, work can be regarded as:

(A).Repetitive Work: The type of work in which the main operation or group of operations repeat continuously during the time spent at the job. These apply to work cycles of extremely short duration.
(B).Non-repetitive Work: It includes some type of maintenance and construction work, where the work cycle itself is hardly ever repeated identically.

Various techniques of work measurement are: (1) Time Study (stop watch technique); (2) Synthesis; (3) Work Sampling; (4) Predetermined Motion and Time Study; and (5) Analytical Estimating.

Time Study and Work Sampling involve direct observation and the remaining are data based and analytical in nature

1).Time Study: It is a work measurement technique for recording the times and rates of working for the elements of a specified job carried out under specified conditions and for analyzing the data so as to determine the time necessary for carrying out the job at the defined level of performance. In other words measuring the time through stop watch is called time study

2).Synthesis: Another technique of work measurement is Synthetic Data which is used for building up the time for a job or pans of the job at a defined level of performance by totalling element times obtained previously from time studies on other jobs containing the elements concerned or from synthetic data.

3).Work Sampling: A technique in which a large number of observations are made over a period of time of one or group of machines, processes or workers is known as Work Sampling Technique. Each observation records what is happening at that instant and the percentage of observations recorded for a particular activity, or delay, is a measure of the percentage of time during which that activities delay occurs.

4).Predetermined Motion Time Study (PMTS): It is another work measurement technique whereby times established for basic human motions (classified according to the nature of the motion and conditions under which it is made) are used to build up the time for a job at the defined level of performance. The most commonly used PMTS is known as Methods Time Measurement (MTM).

5).Analytical Estimating: A work measurement technique, being a development of estimating, whereby the time required to carry out elements of a job at a defined level of performance is estimated partly from knowledge and practical experience of the elements concerned and partly from synthetic data. The work measurement techniques and their applications are shown in the following table

FIG 17.1: Work Measurement Techniques and Their Application

Techniques	**Applications**	**Unit of Measurement**
1)Time Study	Short cycle repetitive jobs Widely used for direct work	Centi minute (0.01min)
2)Synthetic Data	Short cycle repetitive jobs	Centi minutes
3)Working Sampling	Long cycle jobs heterogeneous operations	Minutes
4)MTM	Manual operations confined to one work centre	TMU (1 TMU= 0.006min)
5)Analytical Estimation	Short cycle non- repetitive job	Minutes

17.2 TIME STUDY

Time Study is one of the most widely used techniques under work measurement. It involves the systematic observation, recording, and analysis of the time taken by a skilled worker to perform a specific job using the best-known method. By measuring the time required for each element of a task, Time Study helps establish a standard time that serves as a benchmark for planning and controlling work.

As an extension of work measurement, Time Study enables managers to identify avoidable delays, unproductive motions, and variations in performance. It provides factual data for improving work methods, balancing assembly lines, fixing wage incentives, and estimating manpower needs. The technique uses tools such as stopwatches, time study sheets, and rating factors to determine normal time and standard time with accuracy.

In today’s competitive work environment, Time Study plays a crucial role in achieving higher productivity by ensuring that work is performed efficiently and consistently. It supports continuous improvement and builds a scientific foundation for effective work system design.

17.2.1 STEPS IN MAKING TIME STUDY

Time study is essential for both planning and control of operations. According to British Standard Institute, time study has been defined 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."

Stop watch time is the basic technique for determining accurate time standards. They are economical for repetitive type of work.

Steps in taking the time study are:

- Select the work to be studied;
- Obtain and record all the information available about the job, the operator and the working conditions likely to affect the time study work;
- Breakdown the operation into elements. An element is a instinct part of a specified activity composed of one or more fundamental motions selected for convenience of observation and timing;
- Measure the time by means of a stop watch taken by the operator to perform each element of the operation. Either continuous method or snap back method of timing could be used;
- At the same time, assess the operator's effective speed of work relative to the observer's concept of 'normal' speed. This is called performance rating;
- Adjust the observed time by rating factor to obtain normal time for each element according to the formula given below:

Normal Time= (Observed Time) x (Rating Percentage)

- Add the suitable allowances to compensate for fatigue, personal needs, contingencies etc. to give standard time for each element;
- Compute allowed time for the entire job by adding elemental standard times considering frequency of occurrence of each element;
- Make a detailed job description describing the method for which the standard time is established; and
- Test and review standards wherever necessary. The basic steps in time study are represented by a block diagram in the figure 17.2 "Steps in time study"

FIG 17.2: Steps in Time Study

SELECT
The Job to be timed

↓

DEFINE
The elements, break the Job into elements convenient for timing

↓

OBTAIN AND RECORD
Details regarding method,Operator,Job and Working Conditions

↓

EXTEND
Observed Time into normal time(Basic time)

↓

MEASURE
Time duration for each element and asses the rating

↓

COMPUTE
Standard time for the operation for defined job

↓

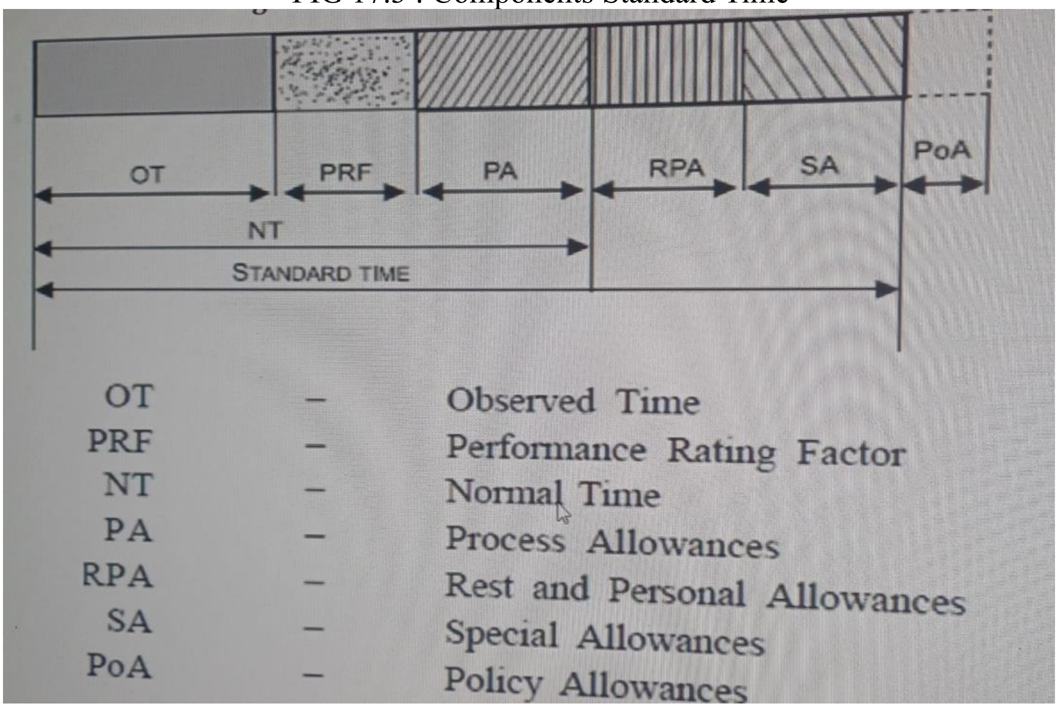
DETERMINE
Relaxation and personal allowances

17.3 COMPUTATION OF STANDARD TIME

Standard time may be defined as the amount of time required to complete a unit of work:
(a) Under existing working conditions,
(b) Using the specified method and machinery,
(c) By an operator, able to the work in a proper manner, and
(d) At a standard pace.
Standard time is the time allowed to an operator to carry out the specified task under specified conditions and defined level of performance. The various allowances are added to the normal time as applicable to get the standard time are known as "Components Standard Time" (Figure).

Standard Time = Normal Time + Allowances
Thus, the basic constituents of standard time are:
1) Elemental (observed time);
2) Performance rating to compensate for difference in pace of working;
3) Relaxation allowance;
4) Interference and contingency allowance; and
5) Policy allowance.

FIG 17.3 : Components Standard Time



17.4 Allowances

The normal time for an operation does not contain any allowances for the worker. It is impossible to work throughout the day even though the most practicable, effective method has been developed. Even under the best working method situation, the job will still demand the expenditure of human effort and some allowance must therefore be made for recovery from fatigue and for relaxation. Allowances must also be made to enable the worker to attend to his personal needs. The allowances are categorized as:

- Relaxation Allowance,
- Interference Allowance,
- Contingency Allowance, and
- Policy Allowance.

(A). Relaxation Allowance: Relaxation allowances are calculated so as to allow the worker to recover from fatigue. Relaxation allowance is a addition to the basic time intended to provide the worker with the opportunity to recover from the physiological and psychological effects of carrying out specified work under specified conditions and to allow attention to personal needs. The amount of allowance will depend on nature of the job.
Relaxation allowances are of two types: fixed allowances and variable allowances.
(i). Constituents of Fixed Allowances:

- Personal Needs Allowance: It is intended to compensate the operator for the time necessary to leave, the workplace to attend to personal needs like drinking water, smoking, washing hands. Women require longer personal allowance than men. A fair personal allowance is 5% for men, and 7% for women
- Allowances for Basic Fatigue: This allowance is given to compensate for energy expended during working. A common figure considered as allowance is 4% of the basic time.

(ii). Variable Allowance: Variable allowance is allowed to an operator who is working under poor environmental conditions that cannot be improved, added stress and strain in performing the job. The variable fatigue allowance is added to the fixed allowance to an operator who is engaged on medium and heavy work and working under abnormal conditions. The amount of variable fatigue allowance varies from organization to organization.

(B). Interference Allowance: It is an allowance of time included into the work content of the job to compensate the operator for the unavoidable loss of production due to simultaneous stoppage of two or more machines being operated by him. This allowance is applicable for machine or process controlled jobs. Interference allowance varies in proportion to number of machines assigned to the operator. The interference of the machine increases the work content.

(C).Contingency Allowance: A contingency allowance is a small allowance of time which may be included in a standard time to meet legitimate and expected items of work or delays. The precise measurement of which is uneconomical because of their infrequent or irregular occurrence. This allowance provides for small unavoidable delays as well as for occasional minor extra work: Some of the examples calling for contingency allowance are:

- Tool breakage involving removal of tool from the holder and all other activities to insert new tool into the tool holder.
- Power failures of small duration.
- Obtaining the necessary tools and gauges from central tool store. Contingency allowance should not exceed 5%.

(D). Policy Allowance: Policy allowances are not the genuine part of the time study and should be used with utmost care and only in clearly defined circumstances. The usual reason for making the policy allowance is to line up standard times with requirements of wage agreement between employers and trade unions. The policy allowance is an increment, other than bonus increment, applied to a standard time (or to some constituent part of it, e.g., work content) to provide a satisfactory level of earnings for a specified level of performance under exceptional circumstances. Policy allowances are sometimes made as imperfect functioning of a division or part of a plant.

Illustration - 17.1: Assuming that the total observed time for an operation of assembling an electric switch is 1.50 min. If the rating is 110%, find normal time. If an allowance of 10% is allowed for the operation, determine the standard time.

Solution:

Observed time (or) selected time = 1.50 min

Rating = 110%

Allowance = 10%

As we know that, normal time $= \dfrac{\text{(Rating \%) x Observed Time}}{100} = \dfrac{110 \times 1.50}{100}$

Normal Time= 1.65

Standard time = Normal time + Allowances

= 1.65 + 0.165 = 1.815 min.

Illustration 17.2 Calculate the standard production per shift of 8 hours duration. With the following data. Observed time per unit = 5 minutes, Rating factor = 120%, Total allowances = 33.33 % of normal time.

Solution:

Normal time per unit = Observed time/unit x Rating factor
= 5 x (120/100)
= 6 Minutes

Allowances = 33.33% of Normal time
= (33.33 x 6) / 100
= 2 Minutes

Standard Time/Unit = Normal Time/Unit + Allowances
= 6 + 2 = 8 minutes/unit

Standard production in shift of 8 hours = (8 x 60) / 8
= 60 units

Illustration 17.3 : Find out the standard time using the following data:
Average time for machine elements = 6 min
Average time for manual elements = 4 min
Performance rating = 110%
Allowances = 10%

Solution:

Normal time = Machinery time + Manual time × Rating
= 6 + 4 × 1.1
= 6 + 4.4
= 10.4 min

∴ Standard time = Normal time + Allowances
= 10.4 + (10.4 x 10 /100)
= 10.4 + (10.4 x 0.1)
= 10.4 + 1.04
= 11.44 minutes

17.5 SUMMARY:

Work measurement is a core industrial engineering technique used to determine the time required for a qualified worker to complete a task under defined conditions. It supports effective planning, scheduling, costing, and productivity improvement by establishing standard times and identifying delays, inefficiencies, and improper utilization of resources. When combined with method study, it provides a scientific basis for improving work systems, enhancing performance, and promoting continuous improvement.

The major objectives of work measurement include comparing alternative methods, planning manpower, supporting cost estimation, setting realistic delivery dates, designing incentive schemes, reducing costs, identifying substandard performance, and training employees. Work measurement is applied to both repetitive and non-repetitive work and uses several established techniques such as Time Study, Synthesis, Work Sampling, Predetermined Motion Time Systems (PMTS/MTM), and Analytical Estimating. Time Study and Work Sampling rely on direct observation, while the others are based on existing data and analytical methods.

Among these, Time Study is the most widely used technique. It systematically observes and records the time taken for each element of a task using a stopwatch and applies performance rating to determine normal time and standard time. It helps eliminate delays, balance workloads, set wage incentives, and improve productivity. The steps of time study include job selection, recording task details, breaking work into elements, timing each element, applying performance rating, adding allowances, and establishing the final standard time.

Standard time is computed by adding allowances—such as relaxation, interference, contingency, and policy allowances—to the normal time. These allowances compensate for fatigue, personal needs, unavoidable delays, and special organizational conditions. Together, these components ensure that standard time reflects realistic working conditions and supports efficient planning, control, and evaluation of work.

17.6 Technical Terms:

1. **Work Measurement**
   A technique used to determine the time required for a qualified worker to complete a job under specified conditions.
2. **Standard Time**
   The total time allowed to perform a task, including normal time plus all necessary allowances.
3. **Normal Time**
   The time taken to perform a task at a standard or "normal" pace, obtained after applying a performance rating.
4. **Performance Rating**
   The process of assessing a worker's speed relative to a defined normal speed to adjust observed time.
5. **Time Study**
   A stopwatch-based method for recording and analyzing the time taken for each element of a job to set standard time.
6. **Work Sampling**
   A technique involving random observations to determine the proportion of time spent on different activities.
7. **Predetermined Motion Time System (PMTS)**
   A method that uses pre-established times for basic human motions to calculate the time for a job.
8. **Allowances**
   Extra time added to normal time to account for fatigue, personal needs, unavoidable delays, and special conditions.
9. **Element**
   A small, measurable part of a job that is observed and timed separately during a time study.

1.0 Contingency Allowance
A small allowance added to standard time to cover minor, unavoidable delays or irregular activities that occur occasionally.

17.7 SELF-ASSESSMENT QUESTIONS

1) What is work measurement?
2) Describe the key steps involved in conducting a time study?
3) What are allowances in work measurement?
4) What are the major techniques of work measurement?

17.8 SUGGESTED READINGS:

1) S. A. Chunnawala, D. R. Patel, 'Production and Operations Management', 7th Edition, Himalaya Publishing House. New Delhi.
2) Aswathappa K., Sridhara Bhatt, 'Production and Operations Management', 7th Edition, Himalaya Publishing House.
3) S. N. Chary, 'Production and Operations Management', Tata McGraw Hill Publishing Company.
4) Kanishka Bedi, 'Production and Operations Management', Oxford University Press

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LESSON-18
QUALITY MANAGEMENT

LESSON OBJECTIVES

After completing this lesson, students will be able to:

- Define the core concepts of quality and quality management (QM), and explain their significance in a business context.
- Identify and differentiate between the primary dimensions and costs associated with quality.
- Summarize the evolution of quality management philosophies, from inspection to Total Quality Management (TQM).
- Analyze and apply the basic principles and tools of TQM, including continuous improvement and the Plan-Do-Check-Act (PDCA) cycle.
- Recognize the role of international standards like ISO 9001 in establishing a quality management system.

Structure of the Lesson

18.1 QUALITY AND QUALITY MANAGEMENT (QM)

Quality refers to the degree to which a product or service meets customer expectations and requirements. It is not just about defect-free products but also about delivering value.

From the customer's perspective Quality is defined as ‘meeting or exceeding expectations’.

From the producer's perspective, quality is defined as‘conformance to specifications’.

What is Quality? Quality is defined by many scholars as follows**.**

- Conformance to specifications (British Defence Industries Quality Assurance Panel)
- Conformance to requirements (Philip Crosby)
- Fitness for purpose or use (Juran)
- A predictable degree of uniformity and dependability, at low cost and suited to the market (Edward Deming)
- Synonymous with customer needs and expectations (R J Mortiboys)
- Meeting the (stated) requirements of the customer- now and in the future (MikeRobinson)
- The total composite product and service characteristics of marketing, engineering, manufacturing and maintenance through which the product and service in use will meet the expectations by the customer (Armand Feigenbaum)

The organisations made miracles in business with quality products for Example: Toyota automobiles, Sony electronic goods etc. German engineering products are known for quality with durability.

There are examples that shows poor quality products leads major disasters. 'Pixel 7' of google failed to meet to expectations of customers. For producing the goods as per the customer expectations in different dimensions is a Hercules Task. That is why, quality management systems to be adopted by the organisations.

Quality Management (QM)

Quality management is the discipline of ensuring that products, services, and processes consistently meet customer expectations while driving continuous improvement. It provides organizations with structured systems and practices to achieve efficiency, reduce waste, and deliver value sustainably.

Quality management is an act of overseeing all activities and tasks needed to maintain a desired level of excellence. The goal is to ensure that an organization's products, services, and processes are consistent and fit for purpose**.**

Principles of Quality Management

- Customer focus
- Leadership commitment
- Employee involvement
- Process approach
- Continuous improvement
- Evidence-based decision making

18.2 DIMENSIONS OF QUALITY

Quality has many dimensions. Meeting each parameter is very important for long term survival of the organisation. The dimensions are

- Performance (how well the product functions)
- Reliability (consistency of performance over time)

- Durability (lifespan of the product)
- Serviceability (ease of repair and maintenance)
- Aesthetics (look, feel, and appeal)
- Perceived quality (customer's impression and reputation)

18.3 THE COST OF QUALITY

Understanding that poor quality is expensive, but managing quality is an investment. The following are different types costs associated with quality management actions.

- **Costs of Conformance (Good Quality)**
  - **Prevention Costs:** Costs incurred to prevent defects (e.g., training, process planning, quality engineering).
  - **Appraisal Costs:** Costs incurred to assess quality (e.g., inspection, testing, quality audits).
- **Costs of Non-Conformance (Poor Quality)**
  - **Internal Failure Costs:** Costs from defects found before delivery (e.g., scrap, rework, re-testing).
  - **External Failure Costs:** Costs from defects found after delivery (e.g., warranty claims, customer complaints, lost goodwill

All organisations are generally focusing on conformance of quality so as to avoid component/equipment failure at customer's end. Hence, they are implementing different quality management models to avoid failures internally and externally.

18.3.1 The Evolution of Quality Philosophies (Quality Approaches)

- **Inspection:** Checking final products for defects.
- **Quality Control (QC):** Introducing statistical methods to monitor processes**.**
- **Quality Assurance (QA):** Shifting focus to the process to prevent defects.

18.3.2 The Core Contributions of the Quality Gurus

The three individuals listed revolutionized how businesses approach quality, shifting the focus from inspection after the fact to **prevention and systemic improvement**.

18.3.2.1 W. Edwards Deming

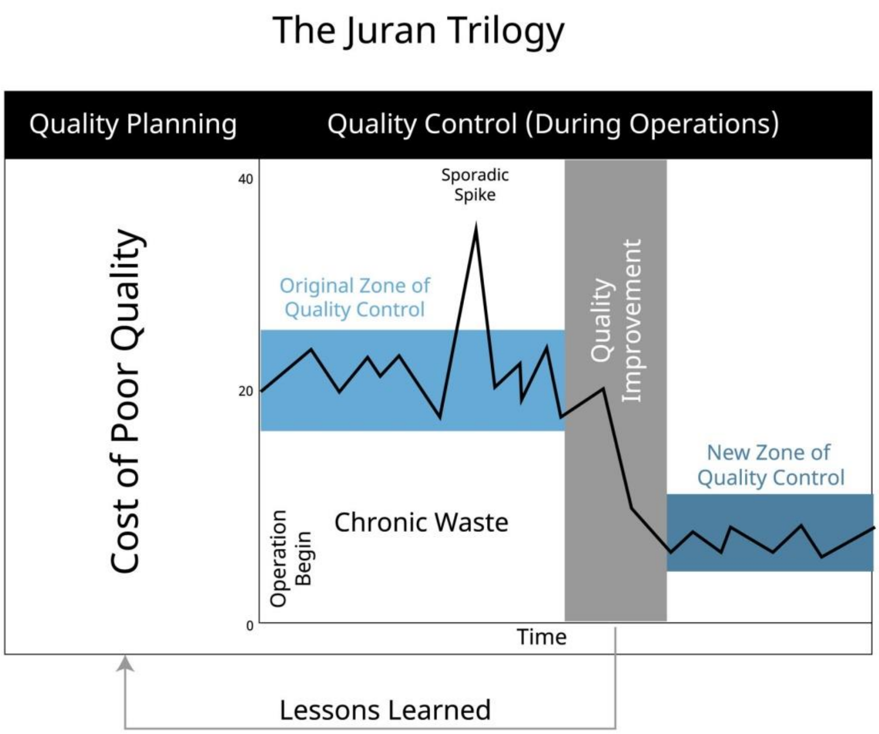
Deming is widely regarded as the father of the modern quality movement. His key contributions focused on understanding variation and the role of management in creating a quality-focused system:

- **Statistical Process Control (SPC):** Emphasized using statistical methods to distinguish between **common cause variation** (inherent in the process) and **special cause variation** (attributable to specific, external factors).
- **The Deming 14 Points for Management:** A philosophy and roadmap for management to transform business effectiveness, stressing the need to abolish quotas, institute training, drive out fear, and adopt a new philosophy.
- **PDCA Cycle:** Popularized the **Plan-Do-Check-Act** cycle (or Plan-Do-Study-Act, PDSA) as a model for continuous improvement.

18.3.2.2 Joseph Juran

Juran focused on the managerial and organizational aspects of quality, making quality management a core part of business strategy:

- **The Juran Trilogy:** This is his primary contribution, a three-pronged approach to managing quality:
  1. **Quality Planning:** Identifying customers and their needs, and designing processes to meet those needs.
  2. **Quality Control:** Evaluating actual performance, comparing it to goals, and acting on the difference (e.g., using control charts).
  3. **Quality Improvement:** Establishing an infrastructure for improvement and continuously raising the level of performance.



- **Fitness for Use:** Defined quality as "fitness for use," encompassing the product's performance, features, reliability, and serviceability.

18.3.2.3 Philip Crosby

Crosby is best known for his belief that quality is an investment, not an expense, and that it is achieved through prevention:

- **"Quality is Free":** This concept argues that the costs of poor quality (rework, scrap, warranty claims, lost customers) are far greater than the costs of preventing errors. Investment in quality pays for itself through reduced waste.

- **"Zero Defects" (ZD):** The concept that errors are not inevitable. ZD is a performance standard where the commitment is to meet the requirement every single time. It is a goal of prevention, not inspection.
- **Four Absolutes of Quality Management:**
  1. The definition of quality is **conformance to requirements**.
  2. The system for causing quality is **prevention**.
  3. The performance standard is **Zero Defects** (ZD).
  4. The measurement of quality is the **price of non-conformance** (PONC).

18.4 QUALITY ASSURANCE (QA)

Quality Assurance is a systematic process that ensures products and services meet defined standards of quality before reaching customers.As mentioned in approach of quality management, Inspection leads to conform that the product is accepted or rejected.

The main difference between Quality assurance and Quality Control (QC) is QA focuses on *process-oriented* (preventing defects) approach whereas QC focuss on *product-oriented* (detecting defects) approach. The **Purpose** of quality assurance is to prevent defects, build customer trust, and improve organizational efficiency.

Table 18.1QA vs QC Comparison

Aspect	**Quality Assurance (QA)**	**Quality Control (QC)**
Focus	Process-oriented	Product-oriented
Goal	Prevent defects	Detect defects
Approach	Proactive	Reactive
Responsibility	Organization-wide	Specific teams
Tools	Audits, process design	Testing, inspection

The main Objectives of Quality Assurance are

- Ensure compliance with standards and regulations
- Build confidence in product/service reliability
- Reduce risks and errors
- Enhance customer satisfaction
- Support continuous improvement

Principles of Quality Assurance are

- **Customer Focus**: Meeting or exceeding customer expectations
- **Process Orientation**: Designing robust processes to prevent defects
- **Documentation**: Clear procedures, policies, and records
- **Continuous Improvement**: Using feedback and audits to refine processes
- **Teamwork & Responsibility**: Everyone is accountable for quality

QA works on the following Standards or Framework

- **ISO 9001:2015** – International standard for quality management systems
- **CMMI (Capability Maturity Model Integration)** – Framework for process improvement in IT/software
- **Six Sigma** – Data-driven methodology to reduce variation and defects
- **TQM (Total Quality Management)** – Organization-wide culture of continuous improvement

The main function of QA are

- Developing quality policies and procedures
- Conducting audits and inspections
- Training employees on quality standards
- Reviewing supplier quality
- Monitoring performance metrics
- Implementing corrective and preventive actions

The Benefits of Quality Assurance are

- Higher customer satisfaction and loyalty
- Reduced costs from fewer defects and rework
- Improved efficiency and productivity
- Enhanced reputation and market competitiveness
- Compliance with regulatory requirements

Quality assurance works as mentioned in different companies

- **Pharmaceuticals**: QA ensures drug safety and compliance with FDA/WHO standards.
- **Software Development**: QA testing prevents bugs and improves user experience.
- **Automotive Industry**: QA systems reduce recalls and improve safety.

18.5 Seven Basic Quality Control (QC) Tools

1. Cause-and-Effect Diagram (Fishbone/Ishikawa Diagram)

- Identifies root causes of problems.
  - Categories often include: People, Methods, Machines, Materials, Environment, Measurement.
- Helps teams brainstorm and visualize contributing factors.

2. Check Sheet

- Structured form for collecting and analyzing data.
- Useful for recording frequency of events, defects, or issues.
- Provides a simple way to organize data for later analysis.

3. Control Chart (Shewhart Chart)

- Graphical tool to monitor process variation over time.
- Shows whether a process is stable (in control) or unstable (out of control).
- Helps distinguish between common cause and special cause variation.

4. Histogram

- Bar graph showing frequency distribution of data.
- Useful for understanding patterns, spread, and central tendency.
- Helps identify whether data follows a normal distribution or has unusual variation.

5. Pareto Chart

- Based on the 80/20 principle: 80% of problems often come from 20% of causes.
- Displays problems in descending order of frequency or impact.
- Helps prioritize issues for maximum improvement.

6. Scatter Diagram

- Plots relationship between two variables.
- Useful for identifying correlations (positive, negative, or none).
- Helps in root cause analysis and hypothesis testing.

7. Flowchart (or Stratification/Run Chart in some versions)

- Visual representation of a process.
- Helps identify bottlenecks, redundancies, or inefficiencies.
- Useful for process mapping and improvement initiatives.

Table 18.2 Summary Table of Traditional QC Tools

Tool	**Purpose**	**Example Use Case**
Fishbone Diagram	Identify root causes	Analyzing causes of machine breakdowns
Check Sheet	Collect data systematically	Tracking defect types in production
Control Chart	Monitor process stability	Measuring variation in assembly line
Histogram	Show data distribution	Analyzing customer complaint frequency
Pareto Chart	Prioritize problems	Identifying top causes of product defects
Scatter Diagram	Show variable relationships	Correlating temperature with defect rate
Flowchart	Map process steps	Visualizing order fulfillment process

18.6 TOTAL QUALITY MANAGEMENT (TQM)

TQM is a management philosophy that seeks to integrate all organizational functions (marketing, finance, design, engineering, production, customer service, etc.) to focus on meeting customer needs and organizational objectives.

TQM was developed in the mid-20th century, influenced by quality pioneers like W. Edwards Deming, Joseph Juran, and Kaoru Ishikawa. The **Core Idea** is Quality is everyone's responsibility, not just the quality department.

Total Quality Management (TQM) is a holistic management approach focused on continuous improvement, customer satisfaction, and employee involvement. It integrates quality into every aspect of an organization's operations to achieve long-term success.

18.6.1 KEY PRINCIPLES OF TQM

While implementing TQM, the key principles followed by organisations are

- **Customer Focus**: Meeting or exceeding customer expectations is the ultimate goal.
- **Continuous Improvement (Kaizen)**: Processes are constantly evaluated and improved.
- **Employee Involvement**: Every employee participates in problem-solving and decision-making.
- **Process-Centered Approach**: Focus on improving processes rather than blaming individuals.
- **Integrated System**: All departments work together toward common quality objectives.
- **Fact-Based Decision Making**: Use of data and statistical tools to guide improvements.
- **Strong Leadership**: Commitment from top management is essential.

18.6.2 TOOLS AND TECHNIQUES IN TQM USED

- **PDCA Cycle (Plan-Do-Check-Act)**: A systematic method for continuous improvement.
- **Benchmarking**: Comparing performance with industry leaders.
- **Quality Circles**: Small groups of employees solving quality-related problems.
- **Statistical Process Control (SPC)**: Monitoring processes using statistical methods.
- **Root Cause Analysis**: Identifying and eliminating causes of defects.
- And other tools based application.

18.6.3 BENEFITS OF TQM

- Higher customer satisfaction and loyalty
- Reduced costs due to fewer defects and rework
- Improved employee morale and teamwork
- Enhanced reputation and competitiveness
- Long-term sustainability and profitability

18.6.4 CHALLENGES IN IMPLEMENTING TQM

- Resistance to change from employees or management
- High initial investment in training and systems
- Requires cultural transformation across the organization
- Long-term commitment needed; results are not immediate

18.7 SIX SIGMA

Six Sigma is a data-driven methodology aimed at reducing defects and improving quality by minimizing process variation. The goal of Six sigma is to achieve fewer than 3.4 defects per million opportunities (DPMO). It was initially practiced and developed at Motorola in the 1980s, later popularized by General Electric.

18.7.1 CORE CONCEPTS

- **Sigma (σ)**: A statistical measure of variation. Higher sigma levels mean fewer defects.
- **Six Sigma Quality**: Represents near perfection in process performance.
- **Focus Areas**:
  - Customer satisfaction
  - Process improvement
  - Data-driven decision-making

18.7.2 Methodologies followed for successful implementation Six Sigma concept are

DMAIC (for existing processes)

1. **Define** – Identify problem, goals, and customer requirements.
2. **Measure** – Collect data and establish baseline performance.
3. **Analyze** – Identify root causes of defects.
4. **Improve** – Implement solutions to eliminate causes.
5. **Control** – Sustain improvements through monitoring.

DMADV (for new processes/products)

1. **Define** – Establish goals aligned with customer needs.
2. **Measure** – Identify critical-to-quality (CTQ) factors.
3. **Analyze** – Develop design alternatives.
4. **Design** – Create the best solution.
5. **Verify** – Test and validate the design.

18.7.3 ROLES IN SIX SIGMA

The following roles are created to make the process running with more involvement.

- **Champion**: Senior executive who sponsors projects.
  - **Master Black Belt**: Expert guiding strategy and training.
  - **Black Belt**: Leads projects and mentors Green Belts.
  - **Green Belt**: Works part-time on Six Sigma projects.

- **Yellow Belt**: Basic understanding, supports project teams.

18.7.4 TOOLS AND TECHNIQUES USED IN SIX SIGMA

- Statistical Process Control (SPC)
- Pareto Analysis
- Cause-and-Effect (Fishbone) Diagrams
- Regression Analysis
- Control Charts
- Failure Mode and Effects Analysis (FMEA)

18.7.5 BENEFITS OF SIX SIGMA

There is gradual improvement in terms of reduced defects and errors and increased efficiency and productivity. Cost is reduced with reduction in waste. The companies become more competitive with improved customer satisfaction and loyalty.

The challenges to be faced while implementation are a) Requires cultural change and leadership commitment b) High training and certification costs c) Resistance from employees due to unfamiliar with statistical methods. There is need of Long-term dedication and commitment needed from participants for sustainable results.

Case Examples

- **Motorola**: Originator of Six Sigma, saved billions in manufacturing costs.
- **General Electric (GE)**: Jack Welch made Six Sigma central to GE's strategy, achieving massive efficiency gains.
- **Healthcare**: Hospitals use Six Sigma to reduce medical errors and improve patient care.

18.8 QUALITY CIRCLES

Quality Circles are small groups of employees who voluntarily meet to identify, analyze, and solve work-related problems. It was introduced in Japan in the 1960s, inspired by Kaoru Ishikawa's philosophy of participative management. The purpose is to improve productivity, quality, and workplace morale through employee involvement.

The following are the characteristics of Quality Circles

- Voluntary participation
- Small group size (usually 5–10 members)
- Regular meetings (weekly or monthly)
- Focus on problem-solving and continuous improvement
- Democratic decision-making process
- Emphasis on teamwork and collaboration

The objectives of QCs are to

- Enhance product and service quality
- Reduce waste, defects, and costs
- Improve communication between employees and management
- Foster creativity and innovation
- Increase employee motivation and job satisfaction
- Promote a culture of continuous improvement

Structure of a Quality Circle

The Team members of each quality circle and their role in QC are as follows

- **Members**: Employees from the same work area or department act as idea creators or solution providers. And others play a leadrole.
- **Leader**: Usually chosen from within the group; facilitates discussions.
- **Coordinator/Facilitator**: Often a manager who supports and guides the circle.
- **Management**: Provides resources, encouragement, and recognition.

Process of Quality Circle Activities

1. **Problem Identification** – Select issues affecting quality, productivity, or safety.
2. **Problem Analysis** – Use tools like cause-and-effect diagrams, Pareto charts, and brainstorming.
3. **Solution Development** – Generate and evaluate possible solutions.
4. **Implementation** – Apply chosen solutions with management support.
5. **Review & Feedback** – Assess effectiveness and share results with the organization.

Case Examples

- **Toyota**: Used quality circles to drive continuous improvement in manufacturing.
- **Indian Railways**: Adopted quality circles to improve efficiency and reduce accidents.
- **Healthcare**: Hospitals use circles to improve patient care and reduce errors.

18.9 QUALITY STANDARDS AND SYSTEMS - ISO 9000

ISO 9000 is a family of international standards that provides a framework for effective quality management systems (QMS). It helps organizations ensure their products and services consistently meet customer and regulatory requirements while driving continual improvement.The Purpose of ISO 9000 is to help organizations document, implement, and maintain efficient quality systems that improve customer satisfaction and operational performance.ISO 9000 standards are industry-neutral and can be applied to organizations of any size, sector, or geography.

The ISO 9000 family includes several standards, each serving a specific role:

Table 18.3 ISO Family

Standard	**Focus**	**Key Use**
ISO 9000	Fundamentals & vocabulary	Provides definitions and concepts for QMS
ISO 9001	Requirements	Specifies criteria for certification; most widely used
ISO 9004	Performance improvement	Guidance for sustainable success through QMS
ISO 19011	Auditing	Guidelines for auditing management systems

18.9.1 ISO 9001 – THE CORE STANDARD

ISO 9001:2015 is the most widely adopted international standard for Quality Management Systems (QMS). It provides a structured framework for organizations to consistently deliver products and services that meet customer and regulatory requirements, while emphasizing risk-based thinking and continual improvement.

- **Requirements include**:
  - Establishing a quality policy and objectives
  - Documented processes and procedures
  - Risk-based thinking and preventive actions
  - Internal audits and management reviews
  - Corrective and continual improvement measures
- **Certification**: Organizations can be audited and certified by accredited bodies, demonstrating compliance with ISO 9001-2015.

A comparison table (Table 18.4)that helps leadership in organisations to select and utilize the tools against each concept to garner the benefits as mentioned.

Table 18.4 Comparison Table on Quality Concepts

Concept	**Focus Area**	**Key Tools/Methods**	**Benefits**
TQM	Organization-wide culture	PDCA, Kaizen, Juran Trilogy	Continuous improvement, customer focus
Six Sigma	Process defect reduction	DMAIC, statistical analysis	Efficiency, cost savings
ISO-9000	Standardized QMS	Documentation, audits	Global recognition, consistency
Quality Circles	Employee involvement	Group problem-solving	Morale, innovation
Cost of Quality	Financial impact of quality	Prevention, appraisal, failure costs	Balanced investment, reduced losses

18.10 SUMMARY

Quality Management is not just about meeting standards—it's about embedding a culture of continuous improvement, data-driven decision-making, and employee involvement to deliver superior value to customers. Investing in prevention and appraisal reduces failure costs significantly. Quality Assurance is about **building quality into processes** rather than just inspecting finished products. It creates a culture of prevention, compliance, and continuous improvement that strengthens customer trust and organizational success.

TQM is not a one-time initiative but a **continuous journey**. It requires leadership commitment, employee involvement, and a culture of improvement to deliver sustainable success.Six Sigma is not just a set of tools—it's a **strategic philosophy** that combines statistical rigor with organizational commitment to achieve near-perfect quality and customer satisfaction.

Quality Circles empower employees to take ownership of problems and solutions, fostering a culture of **participation, innovation, and continuous improvement**. They are a vital tool in building strong organizational quality systems. ISO 9001:2015 modernized quality management by embedding risk-based thinking, leadership accountability, and organizational context, making it more adaptable and relevant across industries worldwide.

18.11 KEY WORDS

TQM: TQM is a management approach focused on continuous improvement in quality of products, services, and processes with the involvement of all employees.

Six Sigma: Six Sigma is a data-driven quality improvement methodology aimed at reducing defects and process variation.

ISO 9001: ISO 9001 is an international standard for Quality Management Systems (QMS) issued by the International Organization for Standardization (ISO).

Quality Assurance: Quality Assurance is a systematic approach that ensures quality is built into the process rather than inspected after production.

PDCA Cycle (Deming Cycle): PDCA is a continuous improvement model used for process improvement.

Fishbone Diagram (Cause-and-Effect Diagram): Fishbone Diagram is a visual tool used to identify root causes of a problem.

Pareto Analysis: Pareto Analysis is a statistical technique based on the 80–20 principle, which states that 80% of problems are caused by 20% of factors.

Quality Circles: Quality Circles are small groups of employees who voluntarily meet regularly to identify, analyze, and solve work-related quality problems.

18.12 Self-Assessment Questions

1. What is quality and state the contributions of quality gurus.
2. Differentiate internal vs. external failure costs with examples.
3. Define quality management and its role in organizational success.
4. Explain how quality management meets customer expectations through process control.
5. Describe Total Quality Management (TQM) as a comprehensive approach
6. Define Six Sigma and its statistical basis
7. Summarize the ISO 9000 family and its purpose.
8. Describe implementation steps of quality circles and expected outcomes.

18.12.1 Multiple choice Questions

1. Who is known as the father of TQM (Total Quality Management)?
   a)Edward Deming
   b) Joseph Juran
   c) Philip Crosby
   d) Kaoru Ishikawa
2. Which ‘pillar of TQM’ recognizes that product quality is a result of process quality?
   a) Customer Focus
   b) Process Management
   c) Employee Empowerment
   d) Continuous Improvement
3. Which of the following does not belong to Juran’s Quality Trilogy?
   a) Quality Improvement
   b) Quality Assurance
   c) Quality Planning
   d) Quality Control

18.13 SUGGESTED READINGS

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LESSON-19
ACCEPTANCE SAMPLING AND STATISTICAL QUALITY CONTROL

LEARNING OBJECTIVES

By the end of this lesson, learners will be able to:

- Explain acceptance sampling and its importance
- Identify the steps in designing an acceptance sampling plan
- Discuss the strengths of statistical quality control in continuous improvement.
- Analyse case studies where acceptance sampling and SPC are applied.
- Explain the role of statistical quality control in maintaining and improving process stability
- Apply suitable control charts for assessment of quality in continuous production systems
- Recommend appropriate quality control strategies for different production scenarios.

STRUCTURE OF THE LESSON

19.1 STATISTICAL QUALITY CONTROL

Statistical Quality Control (SQC) is a **data-driven methodology** that uses statistical methods to **monitor, control, and improve** the quality of products and services. Its primary goal is to minimize variation and eliminate defects in the production process, ensuring that the output consistently meets specifications and customer requirements. It shifts the focus from **detecting** poor quality after production to **preventing** it during the process.

The Three Pillars of SQC

SQC is broadly divided into three main areas of application:

18.1.1 Acceptance Sampling

This technique is used to **inspect incoming or outgoing lots** (batches) of products to decide whether to **accept or reject** the entire lot based on the quality found in a **random sample**. It's used when 100% inspection is too costly or destructive.

18.1.2 Descriptive Statistics

This involves collecting, summarizing, and presenting data to describe the quality characteristics of a product or process. Tools include calculating:

- **Mean (bar{x}):** The average value.
- **Standard Deviation (sigma):** A measure of the spread or variability of the data.
- **Range (R):** The difference between the highest and lowest values.
- **Visualizations:** Histograms, scatter plots, etc.

18.1.3 Statistical Process Control (SPC)

SPC is the set of tools used to **monitor an ongoing process** to ensure it remains stable and in a state of **statistical control**. The core of SPC is distinguishing between two types of process variation:

- **Common Cause Variation (Random):** The natural, inherent, and expected variation in any process. It results in a stable process.
- **Special Cause Variation (Assignable):** Variation caused by external, non-routine factors (e.g., machine breakdown, untrained operator, faulty material). It results in an unstable, "out-of-control" process and requires investigation and correction.The main tool for SPC is the **Control Chart**.

Statistical Quality Control (SQC) is a **data-driven methodology** that uses statistical methods to **monitor, control, and improve** the quality of products and services.

19.2 ACCEPTANCE SAMPLING

Acceptance sampling is a **statistical quality control technique** used to determine whether or not to **accept or reject a production lot** (or batch) of material, products, or services based on the inspection of a **random sample** drawn from that lot.

It's a compromise between inspecting every single item (**100% inspection**) and performing **no inspection** at all. The decision to accept or reject the entire lot is based on whether the number of defective items found in the sample falls below a predefined acceptance number.

19.2.1 RATIONALE FOR ACCEPTANCE SAMPLING

Acceptance sampling is typically used in situations where:

- **100% inspection is impractical or too costly:** For very large lots, checking every item is often too time-consuming or expensive.
- **Testing is destructive:** If the inspection process destroys the item (e.g., testing the lifespan of a light bulb or the strength of a weld), you cannot test every unit.

- **Inspection errors are likely** during tedious 100% inspection.
- The lot is from a supplier with a **proven good quality history**.

19.2.2 Sampling by Attributes vs. Variables

- **Attributes Sampling:** The item is classified as either **conforming (good)** or **non-conforming (defective)** based on a "go/no-go" criterion. This is the most common type.
- **Variables Sampling:** The quality characteristic is a **measured numerical value** (e.g., diameter, weight, tensile strength). This typically requires smaller sample sizes but involves more complex calculations.

19.2.3 Risks in Acceptance Sampling (Type I & Type II Errors)

Since a decision about the entire lot is made based on a sample, there is always a risk of error:

- **Producer's Risk (alpha):** The risk of **rejecting a good-quality lot**. This is often associated with the **Acceptable Quality Level (AQL)**, which is the worst level of quality the consumer is willing to consistently accept.
- **Consumer's Risk (beta):** The risk of **accepting a poor-quality lot**. This is often associated with the **Lot Tolerance Percent Defective (LTPD)** or Rejectable Quality Level (RQL), which is a quality level considered unacceptable by the consumer.

19.2.4 Types of Sampling Plans

- Sampling plans are primarily categorized by the number of samples taken before a final decision is made:

Type of Plan	Description
Single Sampling	A decision is made after the **first and only sample**. If the number of defects (d) is less than or equal to the acceptance number (c), the lot is accepted; otherwise, it is rejected.
Double Sampling	A decision can be made after the first sample. If the result is **inconclusive** (defects fall between two numbers), a **second, larger sample is taken** to make the final decision.
Multiple Sampling	Similar to double sampling, but allows for **three or more successive samples** to reach a final decision.

19.2.5 Operating Characteristic (OC) Curve

The **OC Curve** is a graph that illustrates the discriminating power of a specific sampling plan. It plots the **Probability of Acceptance** (Pa) on the y-axis against the **Actual Lot Quality** (percent defective) on the x-axis. It helps in visualizing and selecting a plan that manages the producer's and consumer's risks.

The **Operating Characteristic (OC) curve** is a fundamental tool in **acceptance sampling** and statistical quality control. It is a graphical representation that describes the discriminatory power of a specific sampling plan.

In simple terms, it shows how effectively a chosen sampling plan (n, c) will accept lots of varying quality.

19.2.5.1 Structure of an OC Curve

The OC curve is a plot with two main axes:

1. **X-Axis (Horizontal):Lot Quality** (or Process Quality), usually measured as the **Proportion Defective (p)** or Percent Defective in the entire lot. This typically ranges from 0 (perfect quality) to 1 (100% defective).
2. **Y-Axis (Vertical):Probability of Acceptance (Pa)** of the lot. This ranges from 0 (certain rejection) to 1 (certain acceptance).

The curve itself is typically **S-shaped** and slopes downward from left to right. This makes intuitive sense: as the quality of the incoming lot gets worse (higher proportion defective), the probability of accepting that lot goes down.

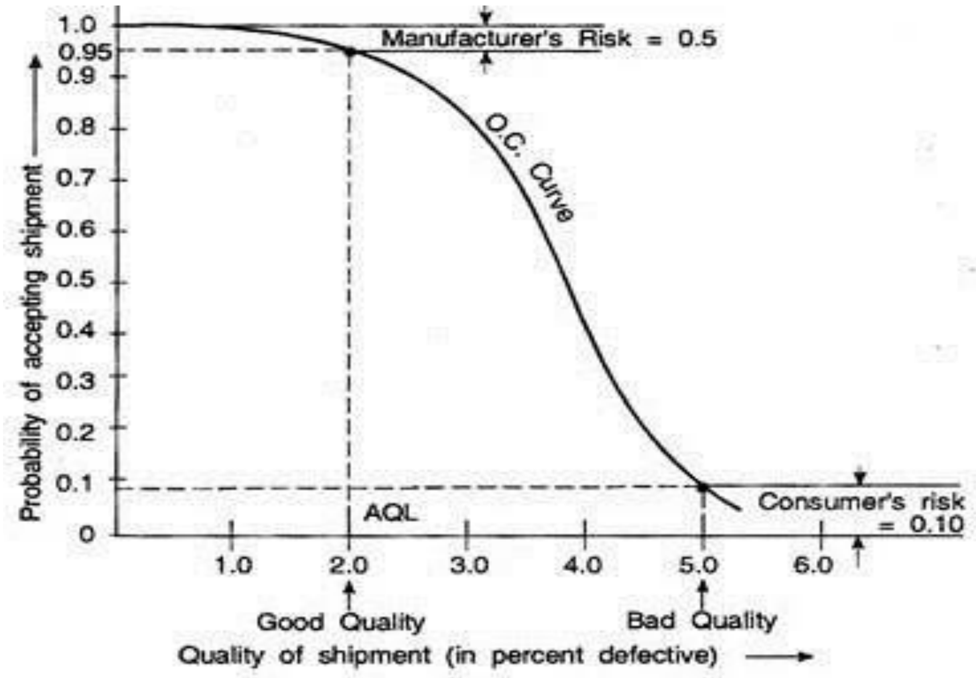


Fig 19.1 Operating Characteristic curve

19.2.5.2 Key Points on the OC Curve

The OC curve is used to visualize and balance the **Producer's Risk**(Manufacturer’s Risk) and the **Consumer's Risk**, which are the inherent risks in sampling:

Point	Definition	Associated Risk
Acceptable Quality Level (AQL)	The worst level of quality (highest proportion defective) that the consumer considers **acceptable** as a long-term process average.	**Producer's Risk (alpha)**
Producer's Risk (alpha)	The probability of **rejecting** a lot whose quality is **as good as the AQL** (or better). This is a Type I error. **It is calculated as alpha = 1 - Pa at the AQL.**	
Lot Tolerance Percent Defective (LTPD) or **Rejectable Quality Level (RQL)**	The worst level of quality (highest proportion defective) that the consumer is **willing to tolerate**. Lots worse than this should almost always be rejected.	**Consumer's Risk (beta)**
Consumer's Risk (beta)	The probability of **accepting** a lot whose quality is **as bad as the LTPD** (or worse). This is a Type II error. **It is calculated as beta = Paat the LTPD.**	

By using the OC curve, a quality manager can select a sampling plan (n, c) that strikes the desired balance between the cost of inspection (driven by n) and the risks of making an incorrect acceptance/rejection decision (alpha and beta).

Example Problem 19.1

Determining Acceptance/Rejection of a Lot.

A company uses a single sampling plan with the following specifications for an incoming lot of electronic components:

- **Lot Size (*N*):** 2,500 units
- **Sample Size (*n*):** 80 units
- **Acceptance Number (*c*):** 2 defects

A quality technician draws a random sample of 80 units and finds **3 defective components**.

Goal: Determine the action to be taken on the lot and explain the decision.

Solution and Decision

1. **Identify the Sampling Plan Parameters:**
    - Sample Size (n) = 80
    - Acceptance Number (c) = 2
2. **Count the Defects Found:**
    - Defects found in sample (d) = 3
3. **Compare Defects to Acceptance Number:**
    - $d>c$ (Since 3>2)

Conclusion

The lot must be **rejected**.

Explanation: The number of defective components found in the sample (d=3) exceeds the maximum allowable number of defects (c=2) defined by the sampling plan. According to the plan, finding more than 2 defects is a statistical indication that the quality of the entire lot is unacceptable, despite the lot size being 2,500 units. The company should either return the lot to the supplier or subject it to 100% inspection (screening).

Example Problem 19.2:

Calculating Operating Characteristic (OC) Curve Points

A specific single sampling plan for bolts has n=20 and c=1. We want to find the **Probability of Acceptance (Pa)** for a lot that is known to have a **3% fraction defective** (p=0.03).

Since the sample size (n=20) is much smaller than the Lot Size (N is assumed to be large, or effectively infinite), the **Poisson approximation** is the most common method for calculating Pa in acceptance sampling.

Note: *The probability is calculated for the case where the lot is accepted, meaning the number of defects found, x, is* $x \leq c$.

Solution Steps

Step 1. *Calculate the Expected Number of Defects (λ)*

The expected number of defects in the sample is **λ,** calculated as:

$\boldsymbol{\lambda = n \times p}$

$\lambda = 20 \times 0.03 = \mathbf{0.6}$

Step 2. *Determine the Acceptance Condition*

The lot is accepted if the number of defects found (x) is less than or equal to the acceptance number (c=1).

$Pa = P(x=0) + P(x=1)$

Step 3. *Use the Poisson Formula to Find* P(x)

The Poisson probability formula is: $\boldsymbol{P(x) = (e^{-\lambda} * \lambda^{x})/x!}$

- **Probability of 0 defects ($P(x=0)$):**

  $P(x=0) = e^{-0.6}(0.6)^0/0! = 10.5488 \times 1 \approx 0.5488$

- **Probability of 1 defect ($P(x=1)$):**

  $P(x=1) = e^{-0.6}(0.6)^1/1! = 10.5488 \times 0.6 \approx 0.3293$

Step 4. *Calculate the Probability of Acceptance (Pa)*

$\boldsymbol{Pa = P(x=0) + P(x=1)}$

$Pa = 0.5488 + 0.3293 = \mathbf{0.8781}$

Conclusion and Interpretation

For the sampling plan (n=20,c=1), there is an **87.81% probability** of accepting a lot that has an actual quality level of 3% defective (p=0.03).

This result is one point on the **Operating Characteristic (OC) curve** for this specific plan. If p=0.03 were the **Acceptable Quality Level (AQL)**, the producer's risk (α) would be 1−0.8781=0.1219 (or 12.19%).

19.3 STATISTICAL PROCESS CONTROL (SPC)

Statistical process control (SPC) is an effective method of monitoring a process through the use of control charts. Control charts enable the use of objective criteria for distinguishing background variation from events of significance based on statistical techniques.

19.3.1 CONTRIBUTION OF SHEWHART TO STATISTICAL QUALITY CONTROL (SQC)

Statistical Quality Control (SQC) is the application of statistical methods to monitor and control production processes. Walter A. Shewhart, a physicist and engineer at Bell Telephone Laboratories in the 1920s, introduced **control charts** to distinguish between common cause variation (natural process variation) and special cause variation (abnormal issues).

Before Shewhart, quality control meant **inspecting finished products** and discarding defective ones. Shewhart shifted focus to **controlling processes during production**, preventing defects rather than just detecting them.

His book(published in 1939) '*Statistical Method from the Viewpoint of Quality Control'* became a cornerstone of quality engineering.

Shewhart Control Charts

- **Purpose**: To determine whether a process is stable and predictable.
- **Types of Charts**:
  - **$\bar{X}$ and R Charts**: Monitor process mean and variability.
  - **p-Chart**: Tracks proportion defective.
  - **c-Chart**: Tracks count of defects.
- **Key Idea**:
  - If data points fall within control limits → process is "in control."
  - If points fall outside limits → indicates special cause variation requiring investigation.

19.3.2 Benefits of Statistical Quality Control

- Early detection of problems.
- Reduced costs from fewer defects.
- Improved customer satisfaction.
- Enhanced process efficiency and predictability.

Comparison: Pre-SQC vs Shewhart's SQC

Aspect	Pre-SQC (Inspection)	Shewhart's SQC
Focus	Finished products	Production process
Approach	Reactive (detect defects)	Proactive (prevent defects)
Tools	Visual/manual checks	Statistical charts
Outcome	High waste, rework	Stable, predictable processes

Walter A. Shewhart revolutionized quality management by introducing **statistical methods to control processes rather than just inspect products**. His control charts remain the backbone of modern quality assurance and continuous improvement systems.

19.4 CONTROL CHARTS

Control charts are the primary tool used in **Statistical Process Control (SPC)** to determine whether a manufacturing or business process is in a state of **statistical control**.

They graphically monitor a process over time to help distinguish between two types of process variation: **common causes** (random, expected variation) and **special causes** (assignable, non-routine variation).

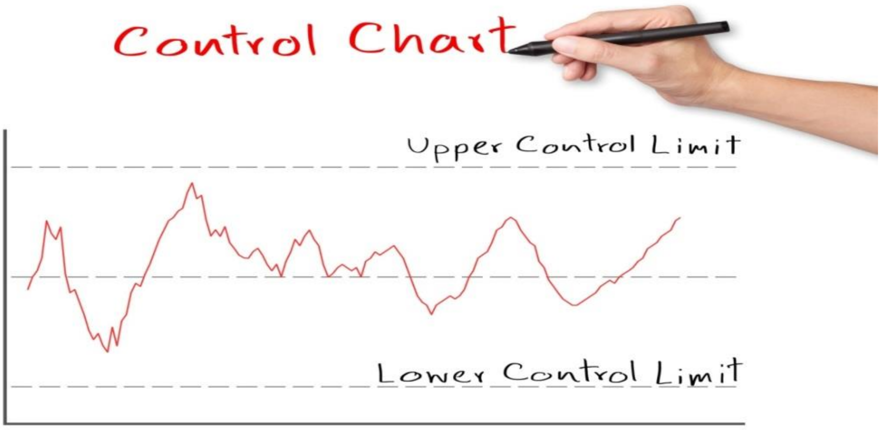
19.4.1 How Control Charts Work

A typical control chart has three main lines:

1. **Center Line (CL):** Represents the average (mean) performance of the process when it is operating normally.
2. **Upper Control Limit (UCL):** The maximum value considered acceptable for common cause variation.
3. **Lower Control Limit (LCL):** The minimum value considered acceptable for common cause variation.

The control limits are typically set at **3 standard deviations (sigma)** from the Center Line.

- **In Control:** If all sample points fall **between the LCL and UCL** and exhibit a random pattern, the process is considered **stable** or "in control." Only common cause variation is present.
- **Out of Control:** If a sample point falls **outside the control limits**, or if the points exhibit a **non-random pattern** (like a run or trend), a **special cause** is likely present.This signals that the process has shifted and needs immediate investigation and corrective action.



19.4.2 Types of Control Charts

Control charts are categorized based on the type of data they monitor:

- **Variables Control Charts (Data is measurable and continuous)**

These are used when quality is measured on a continuous scale (e.g., length, weight, temperature). They typically come in pairs to monitor two characteristics of the process distribution:

Chart Type	What it Monitors	Calculation Based On	Primary Purpose
(X-bar) Chart	The **process mean** (the central tendency).	The average of the sample means.	Detects shifts in the **level** of the process.
R Chart (Range Chart)	The **process variation** (the spread).	The range of values within each sample.	Detects changes in the **consistency** of the process.

- **Attributes Control Charts (Data is count-based or discrete)**

These are used when quality is categorized by counting defects or defective items.

Chart Type	What it Monitors	Calculation Based On	Primary Purpose
p Chart (Proportion Defective)	The **proportion of defective items** in a sample.	Binomial distribution.	Monitoring the overall fraction of non-conforming items (e.g., failed circuit boards).
c Chart (Count of Defects)	The **number of defects** per unit.	Poisson distribution.	Monitoring the number of non-conformities on a single item (e.g., scratches on a car).

Importance of control charts

The **control chart** is arguably the most important tool in Statistical Process Control (SPC) and quality management because it is the only tool that can statistically **distinguish between expected (common cause) variation and unexpected (special cause) variation** in a process.

By providing a real-time, objective visual of a process's stability, control charts enable managers to make **data-driven decisions** on when to intervene and when to leave a process alone, leading to significant reductions in cost, waste, and defects.

19.5 MEAN ($\bar{X}$) AND RANGE (R) CHARTS

- **Purpose**: Monitor process stability by tracking sample averages ($\bar{X}$) and ranges (R).
- **Used for**: Variables data (measurable characteristics like length, weight, time).

Example:

Suppose we measure the diameter of shafts in subgroups of 5 units.

Sample	Measurements (mm)	Mean ($\bar{X}$)	Range (R)
1	10.1, 10.2, 10.0, 10.3, 10.1	10.14	0.3
2	10.2, 10.1, 10.3, 10.2, 10.4	10.24	0.3
3	10.0, 10.1, 10.2, 10.0, 10.1	10.08	0.2

- **$\bar{X}$ Chart**: Plots subgroup means against control limits.
- **R Chart**: Plots subgroup ranges against control limits.
- Control limits are calculated using statistical constants (A_2, D_3, D_4) based on subgroup size.

Solved problems in mean($\bar{X}$) and range(R) chart

Here are two solved problems illustrating the application and interpretation of the $\bar{X}$ **(X-bar) and R (Range) charts** for variables data in Statistical Process Control (SPC).

We will use the following formulas, assuming n is constant and is ≤10:

Chart	Center Line (CL)	Control Limits (UCL/LCL)
R Chart	$\bar{R}=\sum Ri/n$	$UCLR=D_4\bar{R}$ and $LCLR=D3\bar{R}$
$\bar{X}$ **Chart**	$\bar{X}=\sum \bar{X}i/n$	$UCL\ \bar{X}/LCL\ \bar{X}=\bar{X}\pm A2\bar{R}$

Example Problem 19.3: Establishing Initial Control Limits

A machine fills bottles with liquid, and a quality control engineer wants to monitor the fill volume (in mL). Subgroups of ***n*=5** bottles are sampled every hour for 10 hours.

Subgroup (i)	$\bar{X}i$ (Average Volume)	Ri (Range of Volume)
1	500.2	1.8
2	500.5	2.1
3	499.8	1.5
4	500.1	2
5	500.3	1.9
6	499.7	1.7
7	500.4	1.6
8	500.6	2.2
9	500	1.4
10	500.4	1.8
Totals	$\sum \bar{X}i$=5002.0	$\sum Ri$=18.0

Factors for n=5 (from standard control chart tables): $A2$=0.577, $D4$=2.114, $D3$=0.

Solution Steps

Goal: Establish the control limits for both the R chart and the $\bar{X}$ chart.

Step A. *R Chart Calculations (Stability of Variation)*

1. **Calculate the Center Line ($\bar{R}$):**

   $\bar{R}=\sum Ri/n$ =18.0/10 =**1.8**

2. **Calculate the Control Limits:** (Using $D4$=2.114 and $D3$=0 for n=5)

   $UCLR=D4\bar{R}$=2.114×1.8=**3.8052**

   $LCLR=D3\bar{R}$=0×1.8=**0**

3. **Check for Control:** All Ri values (1.4 to 2.2) fall between $LCLR$=0 and $UCLR$ =3.8052. **The R chart is in control.** The process variation is stable.

Step B. $\bar{X}$ *Chart Calculations (Stability of Mean)*

1. **Calculate the Center Line ($\bar{X}$):**

   $\bar{X}=\sum \bar{X}i$/n =5002.0/10=**500.2**

2. **Calculate the Control Limits:** (Using $A2$=0.577 and $\bar{R}$=1.8)

   $UCL\bar{X}/LCL\bar{X}=\bar{X}\pm A2\bar{R}$

   $UCL\bar{X}/LCL\bar{X}$=500.2±(0.577×1.8)

   $UCL\bar{X}/LCL\bar{X}$=500.2±1.0386

   - **UCL** =500.2+1.0386=**501.2386**
   - **LCL** =500.2−1.0386=**499.1614**

3. **Check for Control:** All $\bar{X}i$ values (499.7 to 500.6) fall between $LCL\bar{X}$ =499.1614 and $UCL\bar{X}$=501.2386. **The $\bar{X}$ chart is in control.** The process average is stable.

Conclusion: Since both charts are in control, the filling process is statistically stable, and these limits can be used for future monitoring.

Example Problem 19.4: Interpreting an Out-of-Control Signal

Using the limits established in Problem 1 ($\bar{R}$=1.8, $UCLR$=3.8052, $UCL\bar{X}$=501.2386), the manufacturer collects two new subgroups (n=5 each):

Subgroup (i)	$\bar{X}i$	Ri
11	501	4.1
12	502.5	1.5

Solution Steps

Goal: Analyze the new data points and determine the appropriate action.

A. R Chart Analysis (Check Variation First!)

1. **Subgroup 11 Range (R11):** 4.1
   - Comparison: 4.1>$UCLR$(3.8052)
   - **Result: Subgroup 11 is out of control on the R chart.** The process variability has spiked.
2. **Subgroup 12 Range (R12):** 1.5
   - Comparison: 1.5<$UCLR$(3.8052) and 1.5>$LCLR$(0).
   - **Result:** Subgroup 12 is in control on the R chart.

19.6 P-Chart (Proportion Defective Chart)

- **Purpose**: Monitors proportion of defective items in samples when sample size varies.
- **Used for**: Attributes data (fraction defective).

Example:
Inspection of samples of 100 items per day:

Day	**Defectives**	**Sample Size**	**Proportion Defective (p)**
1	5	100	0.05
2	8	100	0.08
3	4	100	0.04
4	6	100	0.06
5	7	100	0.07

- **Average proportion ($\bar{p}$)** = (0.05+0.08+0.04+0.06+0.07)/5 = 0.06
- **Control Limits**:
  - UCL = $\bar{p} + 3\sqrt{[\bar{p}(1-\bar{p})/n]} = 0.06 + 3\sqrt{[(0.06\times0.94)/100]} \approx 0.06 + 0.07 = 0.13$
  - LCL = $\bar{p} - 3\sqrt{[\bar{p}(1-\bar{p})/n]} = 0.06 - 0.07 \approx -0.01 \rightarrow$ set to 0

Example Problem 19.5: Establishing Initial Control Limits

A manufacturer of electronic cables inspects batches of 200 cables for physical defects (cuts, incorrect pin alignment). Over 10 shifts, the following data was collected.

Shift (*i*)	Number of Cables Inspected (*ni*)	Number of Defective Cables (*npi*)	Proportion Defective (*pi*)
1	200	8	0.04
2	200	12	0.06
3	200	9	0.045
4	200	10	0.05
5	200	15	0.075
6	200	7	0.035
7	200	14	0.07
8	200	11	0.055
9	200	13	0.065
10	200	6	0.03

Solution Steps

Goal: Establish the P-chart's Center Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL).

1. Calculate the Center Line ($\bar{p}$)

The Center Line is the average proportion defective, calculated as the total number of defects divided by the total number of units inspected.

Total Defective: 8+12+9+10+15+7+14+11+13+6=105

Total Inspected: 10×200=2,000

$\bar{p}=\sum ni / \sum npi=$ 105/2000 = **0.0525**

Center Line (CL) = 0.0525

2. Calculate the Control Limits

Since the sample size (n) is constant (n=200), the control limits are also constant. We use the 3-sigma limits formula:

$UCL/LCL= \bar{p} \pm 3\sqrt{[\bar{p}(1-\bar{p})/n}$

$UCL/LCL=0.0525\pm3*\sqrt{(0.0525(1-0.0525)/200)}$

$UCL/LCL=0.0525\pm3*\sqrt{(0.0525(0.9475)/200)}$

$UCL/LCL=0.0525\pm3*\sqrt{0.0002486}$

UCL/LCL=0.0525±3(0.01577)

UCL/LCL=0.0525±0.0473

- **UCL** =0.0525+0.0473=**0.0998**
- **LCL** =0.0525−0.0473=**0.0052**

3. Interpretation

All the calculated proportions (pi) in the table (ranging from 0.030 to 0.075) fall between the LCL (0.0052) and the UCL (0.0998). Therefore, the process is considered to be **in statistical control** during the period the data was collected, and these limits can be used to monitor future production.

Example Problem 19.6: Handling Variable Sample Sizes

A call center tracks the number of calls that resulted in a customer complaint (defective) over four consecutive days, where the total number of calls handled (ni) varies.

Day (i)	Calls Handled (ni)	Number of Complaints (npi)	Proportion Complaining (pi)
1	350	14	0.04
2	400	12	0.03
3	320	16	0.05
4	450	36	0.08

Solution Steps

Goal: Determine the control limits and check if the process is in control.

Step 1. *Calculate the Center Line* (p̄)

Total Complaints: 14+12+16+36=78

Total Handled: 350+400+320+450=1520

$\bar{p}$=152078≈**0.0513**

Center Line (CL) = 0.0513

Step 2. *Calculate Control Limits for Each Day*

Since ni varies, the UCL and LCL must be calculated for each day:

UCL/LCL=0.0513±3√(0.0513(1−0.0513)/ni)

Day	ni	3√($\bar{p}$(1−$\bar{p}$))/ni	LCL	UCL	pi	In Control?
1	350	3*√(0.0513)(0.9487)/350 ≈0.0349	0.0164	0.0862	**0.04**	Yes
2	400	3*√(0.0513)(0.9487)/400 ≈0.0326	0.0187	0.0839	**0.03**	Yes
3	320	3*√(0.0513)(0.9487)/320 ≈0.0366	0.0147	0.0879	**0.05**	Yes

4	450	3*√(0.0513)(0.9487)/450 ≈0.0308	0.0205	0.0821	**0.08**	Yes

***Step 3**. Interpretation*

On all four days, the proportion of complaints (*pi*) falls between the dynamically calculated LCL and UCL for that specific sample size. The process is currently **in statistical control**.

19.7 c-Chart (Count of Defects Chart)

- **Purpose**: Monitors the number of defects per unit when sample size is constant.
- **Used for**: Attributes data (defects like scratches, cracks, errors).

Example:

Inspection of 10 printed circuit boards per day:

Day	Defects (c)
1	3
2	4
3	2
4	5
5	3

- **Average defects ($\bar{c}$)** = (3+4+2+5+3)/5 = 3.4
- **Control Limits**:
  - UCL = $\bar{c} + 3\sqrt{\bar{c}} = 3.4 + 3\sqrt{3.4} \approx 9.9$
  - LCL = $\bar{c} - 3\sqrt{\bar{c}} = 3.4 - 3\sqrt{3.4} \approx -3.1$ → set to 0
- Plot daily defect counts against these limits.

Solved problems in c-chart

Example Problem19.7: Establishing Initial Control Limits

A glass manufacturer inspects samples of a standard-sized glass sheet for surface blemishes (bubbles, scratches). Data was collected from 10 successive sheets:

Sheet Number (*i*)	Number of Blemishes (*ci*)
1	8
2	12
3	9
4	10
5	15
6	7
7	14
8	11
9	13
10	6

Solution Steps

Goal: Establish the C-chart's Center Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL).

***Step 1**. Calculate the Center Line ($\bar{c}$)*

The Center Line is the average number of defects per unit, calculated as the total number of defects divided by the total number of units inspected.

Total Defects: $\sum c_i = 8+12+9+10+15+7+14+11+13+6 = 105$ *Total Units:* $n=10$

$\bar{c} = \sum c_i / n = 105/10 =$ **10.5**

Center Line (CL) = 10.5

***Step 2**. Calculate the Control Limits*

The C-chart uses 3-sigma limits based on the Poisson distribution:

$UCL/LCL = \bar{c} \pm 3\sqrt{\bar{c}}$

$UCL/LCL = 10.5 \pm 3 * \sqrt{10.5}$

$UCL/LCL = 10.5 \pm 3 * (3.2404)$

$UCL/LCL = 10.5 \pm 9.72$

- **UCL** =10.5+9.72=**20.22**
- **LCL** =10.5−9.72=**0.78**

***Step 3**. Interpretation*

All c_i values in the table (ranging from 6 to 15) fall between the LCL (0.78) and the UCL (20.22). Therefore, the process is considered to be **in statistical control** based on this initial data.

Example Problem 19.8: Detecting an Out-of-Control Point

Using the established control limits from Problem 1 (CL=10.5, UCL=20.22, LCL=0.78), the manufacturer collects data for the next five sheets:

Sheet Number (i)	Number of Blemishes (c_i)
11	16
12	22
13	11
14	5
15	10

Solution Steps

Goal: Determine if the process is out of control during the subsequent shifts.

1. Check Sheet 11 ($c_{11}=16$)

Since $0.78<16<20.22$, **Sheet 11 is in control.**

2. Check Sheet 12 (c12=22)

Since 22>20.22 (UCL), **Sheet 12 is out of control.** This is a **special cause signal**.

3. Check Sheets 13, 14, 15

- c13=11: In control.
- c14=5: In control.
- c15=10: In control.

Action Required

The spike on Sheet 12 (c=22) indicates a **special cause of variation** occurred. The quality team must immediately investigate what happened during the production of this sheet. Possibilities include a sudden contamination in the glass mixture, a temporary scratch on a forming roller, or a sudden change in temperature/pressure.

In total, the table below explains the charts in a nutshell.

Chart Type	**Data Type**	**Example**	**Control Limits**
$\bar{X}$ Chart	Variable (mean)	Shaft diameters	$\bar{X} \pm A2 \cdot \bar{R}$
R Chart	Variable (range)	Range of diameters	$D3 \cdot \bar{R}$ to $D4 \cdot \bar{R}$
c-Chart	Attribute (defects count)	Defects per PCB	$\bar{c} \pm 3\sqrt{\bar{c}}$
p-Chart	Attribute (proportion defective)	Fraction defective in samples	$\bar{p} \pm 3\sqrt{[\bar{p}(1-\bar{p})/n]}$

19.8 SUMMARY

Acceptance sampling is a decision-making tool that helps organizations manage inspection costs and risks. Statistical Quality Control (SQC) is a data-driven methodology that uses statistical principles and techniques to monitor, control, and improve the quality of products and services. Control charts are the process's vital signs. The P-chart (or Proportion Chart) is a vital tool in Statistical Process Control (SPC) used to monitor the proportion of nonconforming (defective) units in a sample over time. It is a systematic approach focused on prevention rather than detection, aiming to minimize variation and eliminate defects in the production process to ensure the output consistently meets customer specifications.

19.9 KEY TERMS

SQC: SQC is the application of statistical techniques to measure, monitor, and control quality in production and service processes.

SPC – Statistical Process Control: SPC is a technique used to monitor and control a process during production using statistical tools.

Acceptance Sampling: Acceptance Sampling is a statistical inspection method in which a sample is taken from a lot to decide whether to accept or reject the entire lot

OC Curve – Operating Characteristic Curve: An OC Curve is a graph showing the probability of accepting a lot against the percentage of defective items.

Variables: Variables are quality characteristics that can be measured numerically.

Attributes: Attributes are quality characteristics that are counted, not measured.

Control Charts: Control charts are graphical tools used to determine whether a process is in statistical control.

19.10 SELF-ASSESSMENT QUESTIONS

1. Explain the difference between acceptance sampling and statistical quality control in terms of timing and focus.
2. Why might a company choose acceptance sampling instead of 100% inspection?
3. Describe the role of control charts in statistical quality control.
4. What is the contribution of Shewhart?
5. A company manufactures 5,000 ball bearings daily. Instead of inspecting all, they use acceptance sampling: they randomly select 200 bearings, with an acceptance number of 5. a) If 7 defective bearings are found, what decision should be made?
   b) How could SPC be used alongside acceptance sampling to improve long-term quality?

19.10.1 Multiple-Choice Questions (MCQs)

1. **Which of the following best describes acceptance sampling?**
   1. Inspecting every item in a batch
   2. **Inspecting a sample to decide whether to accept or reject a batch**
   3. Monitoring the production process continuously
   4. Eliminating all defects before shipping
2. **Statistical Quality Control (SQC) primarily focuses on:**
   1. Reducing the cost of inspection
   2. **Monitoring and improving the production process**
   3. Rejecting defective batches
   4. Increasing production speed
3. **In acceptance sampling, the "acceptance number" refers to:**
   1. The total number of items in the batch
   2. **The maximum number of defects allowed in the sample**
   3. The number of samples inspected
   4. The probability of rejecting a good batch

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LESSON-20

MAINTENANCE MANAGEMENT

LEARNING OBJECTIVES

By the end of this lesson, learners will be able to:

1. Define the primary **functions and objectives** of maintenance management.
2. Differentiate between the various **types of plant maintenance** strategies.
3. Analyse the **cost trade-off** between preventive maintenance and breakdown costs.
4. Identify the three phases of the **Bathtub Curve** regarding machine failures.
5. Understand the criteria for **machine replacement decisions**.

STRUCTURE OF LESSON

20.1 INTRODUCTION TO MAINTENANCE MANAGEMENT

Maintenance management is the systematic process of planning, organizing, and controlling maintenance activities to keep equipment, assets, and facilities reliable, safe, and cost-effective.

Maintenance management is strategically managing resources, workforce, and budgets to maximize overall organizational efficiency. Effective maintenance planning and control contribute to higher productivity, better customer satisfaction, and sustainable operations.

Maintenance management involves installation, prevention of equipment failures, and restoring equipment condition after failure. It is a critical function in manufacturing, service industries, and facility management because it directly impacts productivity, safety, and profitability. It's main objectives include maximizing plant availability by minimizing breakdowns and downtime, maintaining product quality by keeping machines in proper working order, and preserving asset value by reducing wear and tear. It also aims to optimize costs by balancing maintenance expenses with equipment availability and performance.

In short, **maintenance management ensures that assets are reliable, safe, and cost-efficient**, forming a vital backbone for modern enterprises

20.1.1 Primary Functions

Maintenance is not just about "fixing things." It involves a cycle of specific activities:

- **Inspection:** Monitoring the condition of equipment.
- **Repair & Overhaul:** Restoring equipment to operational standards.
- **Lubrication & Cleaning:** Basic care to reduce friction and wear.
- **Record Keeping:** Tracking history of failures, costs, and spare parts.
- **Inventory Management:** Ensuring critical spare parts are available without overstocking.

20.2 OBJECTIVES OF MAINTENANCE MANAGEMENT

The ultimate goal is to maximize equipment availability at the lowest cost. The objectives of maintenance management are as follows

- **Ensure reliability and efficiency** of equipment and assets.
- **Minimize downtime** by preventing unexpected breakdowns.
- **Optimize costs** through planned maintenance rather than expensive emergency repairs.
- **Extend asset life** by applying preventive and predictive strategies.
- **Support safety standards** and compliance with regulations.
- **Quality Assurance:** Well-maintained machines produce fewer defects.

20.3 TYPES OF PLANT MAINTENANCE

The plants, equipment, machine tools and other types of utility services are to maintained well to produce the planned quantities. But the situations vary from time to time to prioritise the maintenance activities; some equipment may failure all of a sudden. Some equipment may give hints in advance. Some failures may create abnormal loss to production and machinery. Some failures may lead to accidents. Hence a systematic planning is required to avoid unwanted failures. Different types of maintenance followed by organisations are as follows.

20.3.1 Breakdown (Corrective) Maintenance

Breakdown (Corrective) Maintenance is a **reactive maintenance strategy** where actions are taken *only after* equipment fails or breaks down, aiming to restore functionality quickly, often using simple fixes for non-critical or easily replaceable items like light bulbs or fuses, contrasting with planned maintenance. It's also called **reactive** or **run-to-failure maintenance**, used when preventing failure is costlier or less critical than the repair itself, minimising immediate disruption for non-essential assets.

Key Characteristics:

- **Philosophy:** "Run it until it breaks."
- **Triggered by Failure**: Maintenance starts only when a malfunction occurs, not before.
- **Reactive & Unplanned**: It's a "fix it when it breaks" approach, unlike preventive or predictive methods.
- **Goal**: Restore immediate operation and minimize downtime for the failed asset.
- **Suitable For**: Non-critical equipment, cheap/disposable parts (batteries, bulbs), or assets with short lifecycles. Low-priority items (e.g., changing a lightbulb) where failure does not stop production.
- **Disadvantage:** High unexpected downtime and secondary damage.

20.3.2 Preventive Maintenance (PM)

Preventive Maintenance (PM) is a proactive maintenance strategy aimed at reducing the likelihood of equipment failure by performing regular, scheduled servicing and inspections. Instead of waiting for machines to break down, preventive maintenance ensures that assets are maintained at predetermined intervals to keep them in good working condition.

Features of Preventive maintenance

- **Philosophy:** Time-based or Usage-based intervention. A stitch in time saves nine.
- **Scheduled Interventions:** Maintenance tasks are carried out at fixed time intervals or usage milestones (e.g., every 500 operating hours).
- **Routine Checks:** Includes cleaning, lubrication, adjustments, and replacement of worn parts.
- **Standardized Procedures:** Follows manufacturer guidelines or industry best practices.
- **Documentation:** Maintenance records are kept to track asset history and performance.
- **Action:** Replacing parts or servicing machines on a fixed schedule (e.g., every 100 hours or every month) regardless of condition

Benefits

- Minimizes downtime by preventing unexpected breakdowns.
- Extends asset life through timely servicing.
- Improves safety by ensuring equipment operates within safe limits.
- Cost savings compared to emergency repairs.
- Reduces catastrophic failures.

Limitations

- May lead to unnecessary maintenance if equipment is serviced before actual need.
- Requires planning and scheduling systems to manage tasks efficiently.
- Involves higher upfront costs for manpower and spare parts compared to reactive maintenance.

20.3.3 Predictive Maintenance (PdM)

Predictive Maintenance (PdM) is an advanced maintenance approach designed to prevent unexpected equipment failures by continuously monitoring asset health and predicting potential issues before they happen. Unlike reactive maintenance (fixing after breakdown) and preventive maintenance (scheduled servicing), predictive maintenance relies on real-time data and analytics to determine the optimal time for intervention.

Key Concepts

- **Philosophy:** Condition-based intervention
- **Condition Monitoring:** Sensors track parameters such as vibration, temperature, pressure, and noise to assess equipment health.Using sensors (vibration analysis, thermal imaging, oil analysis) to predict when a failure *will* occur and servicing it just before.
- **Data Analytics & AI:** Machine learning and deep learning algorithms detect anomalies and forecast failures.
- **Real-time Insights:** Provides actionable information to maintenance teams, ensuring repairs are done only when necessary.
- **Integration with IoT:** Connected devices and cloud platforms enhance predictive accuracy and scalability.

Benefits

- **Reduced Downtime:** Anticipates failures, minimizing costly interruptions.
- **Cost Efficiency:** Avoids unnecessary scheduled maintenance and emergency repairs.
- **Extended Asset Life:** Timely interventions prevent severe damage.
- **Safety & Reliability:** Ensures equipment operates within safe limits.
- Maximizes part life compared to Preventive Maintenance.

Challenges

- Requires accurate data collection and reliable sensors.
- High initial investment in technology and training.
- Needs strong integration with enterprise systems (like ERP or CMMS).

20.3.4 Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance (RCM) is a structured approach to maintenance that focuses on ensuring assets continue to perform their intended functions reliably, cost-effectively, and safely.A strategic mix of the above methods based on the criticality of the equipment.

Reliability Centered Maintenance (RCM) is a systematic process used by organizations to determine the most effective maintenance strategies for physical assets such as machines, tools, and infrastructure. The central idea is to maintain equipment in a way that maximizes **reliability, availability, and safety**, while minimizing unnecessary costs.

Core Principles

- **Function-focused:** RCM begins by identifying the primary functions of an asset and the performance standards it must meet.
- **Failure analysis:** It examines how and why assets fail, and the consequences of those failures.
- **Tailored strategies:** Maintenance tasks are chosen based on the criticality of the asset and the impact of failure, rather than applying a one-size-fits-all approach.
- **Cost-effectiveness:** The goal is to balance reliability with maintenance costs, avoiding both excessive preventive work and costly breakdowns.

Key Features

- **Customized approach:** Each asset has a unique maintenance plan based on its usage, environment, and failure modes.
- **Integration of methods:** Combines preventive, predictive, and condition-based maintenance depending on the asset's needs.
- **Safety and compliance:** Ensures that maintenance strategies align with safety regulations and operational standards.
- **Decision framework:** Provides a structured methodology for deciding whether to repair, replace, or redesign equipment.

Benefits

- Maximizes **equipment availability** and reliability.
- Reduces unnecessary maintenance costs.
- Extends asset life and improves safety.
- Provides a clear, logical framework for maintenance planning.

Modern Developments

Traditionally, maintenance management was paper-based and reactive. Today, it has evolved into **computerized maintenance management systems (CMMS)**, which automate scheduling, track asset performance, and integrate with enterprise systems. This digital transformation enables organizations to improve uptime, reduce costs, and make data-driven decisions. **Total Productive Maintenance (TPM)** is being practice by organisation to enhance the overall effectiveness of the plants.

20.3.5 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a system for maintaining and improving the integrity of production and quality systems through the **machines, equipment, processes, and employees** that sustain them.

- **Total:** Involvement of all employees (from top management to shop floor).
- **Productive:** Actions are performed while maintaining high productivity.
- **Maintenance:** Keeping equipment in top working condition.

The ultimate goal of TPM is **zero losses** across four key areas:

- **Zero Breakdowns** (maximizing uptime)
- **Zero Defects** (maximizing quality)
- **Zero Accidents** (maximizing safety)
- **Zero Waste** (maximizing efficiency)

2. The Guiding Metric: Overall Equipment Effectiveness (OEE)

OEE is the gold standard metric for measuring the effectiveness of production equipment. TPM focuses on eliminating the six major equipment losses (the "Six Big Losses") that reduce the OEE score.

OEE = Availability + Performance + Quality

- **Availability:** Accounts for downtime losses (breakdowns, setups).

Availability = Run Time/Planned Production Time

- **Performance:** Accounts for speed losses (idling, minor stoppages, reduced speed).
- **Quality:** Accounts for quality losses (rejects, rework).

World-Class OEE: A score of **85%** is generally considered world-class for discrete manufacturing.

The Eight Pillars of TPM

TPM is built on eight foundational pillars (or activities) that work together to create a pervasive culture of continuous improvement. The details of pillars are in table 20.2.

Table 20.2 Details of eight pillars TPM

Pillar	Focus	Operator/Maintenance Role
1. Autonomous Maintenance (Jishu Hozen)	Empowers operators to take ownership of their machines.	**Operators** perform routine cleaning, inspection, and lubrication (CIL).
2. Focused Improvement (Kobetsu Kaizen)	Uses cross-functional teams to eliminate chronic losses (the "Six Big Losses").	**Teams** use tools like 5 Whys and Pareto charts for root cause analysis.

3. Planned Maintenance	Schedules maintenance activities based on data (PM/PdM) to prevent breakdowns.	**Maintenance Teams** focus on predictive techniques and scheduled overhauls.
4. Quality Maintenance (Hinshitsu Hozen)	Focuses on defect prevention by controlling machine conditions that affect quality.	**Operators/Quality** monitor process parameters to eliminate root causes of defects.
5. Early Equipment Management	Uses lessons learned from existing equipment maintenance to design simpler, more reliable new equipment.	**Engineers/Designers** incorporate maintenance-friendly features into new assets.
6. Training and Education	Provides structured training to operators, maintenance staff, and managers to fill knowledge gaps.	**All Staff** are trained on skills relevant to their role in the TPM program.
7. Safety, Health, and Environment (SHE)	Aims for a working environment with **zero accidents** and **zero pollution**.	**All Staff** ensure a safe and organized workplace (often integrated with 5S).
8. TPM in Administration (Office TPM)	Applies TPM principles (eliminating waste) to administrative functions like scheduling, logistics, and procurement.	**Office Staff** streamline paperwork and processes to support production goals.

In total all the types of maintenances are described in table 20.2 in a nut shell

Table 20.2 Key focus of different types of maintenance

Type	Full Name	Description	Key Focus
TPM	**Total Productive Maintenance**	A holistic system involving **all employees** (from operators to management) to maximize equipment effectiveness and eliminate all losses.	**Operator Ownership** (Autonomous Maintenance) and **OEE**.
RCM	**Reliability-Centered Maintenance**	A systematic process used to determine the *minimum* required maintenance program for equipment to ensure its functions are preserved.	**Function Preservation** and efficient use of resources.
PdM	**Predictive Maintenance**	Uses **sensors** and condition monitoring tools (e.g., vibration analysis, thermal imaging) to predict *when* a failure will occur, allowing maintenance to be scheduled just before that point.	**Condition-Based** (maintenance performed only when needed).

PM	**Preventive Maintenance**	Maintenance performed on a **fixed schedule** (time or usage-based) to prevent breakdowns, regardless of the asset's actual condition.	**Time/Usage-Based** (scheduled inspections, oil changes, etc.).
CBM	**Condition-Based Maintenance**	An umbrella term for maintenance triggered by the actual **condition** of an asset, which includes PdM.	**Actual Condition** (similar to PdM).
CM	**Corrective Maintenance**	Maintenance performed *after* equipment has failed (also called **Breakdown Maintenance**).	**Reactive** (often expensive and disruptive).

20.4 Cost Balance in Maintenance

Maintenance work should achieve a balance between equipment availability and running costs. Excessive maintenance may increase costs and reduce asset life, whereas insufficient maintenance can cause frequent breakdowns and higher unplanned repair expenses. Effective maintenance management optimizes labor, materials, and downtime costs for financial and operational efficiency.

20.5 EQUIPMENT LIFE CYCLE

The equipment lifecycle begins from the time when equipment is requested *through* the end of its useful life or when it is disposed.

The equipment lifecycle typically consist of three phases: Acquisition, Use and Disposal

- **Acquisition**

Equipment is acquired through direct purchase, fabrication, transfer-in from other institutions, loaned equipment, and capital lease. When the equipment purchase goes through a process, all vouchers that charge capital equipment accounts require the Asset Form to be filled out. This form requests additional information on the purchase enabling the organisation to track such asset purchases.

- **Institutional Use**

Capital equipment is intended for production use and not for private purposes. Use may be additionally restricted by the terms of the award for which the capital equipment was acquired.

- **Disposal**

The source of funding for equipment determines how it can be disposed. For example, sponsor funded purchases and donations may have specific disposal restrictions. The key to determining disposal restrictions is to read the sponsor agreement or donation documentation.

20.5.1 Total life cycle costs

The life cycle costs are divided into three groups. i.e. Capital costs, operational Costs including Maintenance and production losses. The life cycle costs and influencing parameters on costs are specified are as follows.

Capital costs: Capital costs include the expenses towards the following activities.

- Design
- Development
- Plant/equipment purchase
- Installation
- Commissioning
- Training of plant staff
- Manuals and documentation
- Tools and facilities for maintenance
- Initial spares holding

Operational costs: It includes labour expenses towards operation and engineering, consumables cost etc.

- Labor- Plant operation and –Engineering
- Energy eg.Oil --Gas --- Electricity
- Utilities like Steam,Water and coolants

Maintenance Costs: It includes labour costs for maintenance personnel, Cost of Materials used, holding cost of spares, costs associated with repairs done in workshops, Annual contract costs when it is outsourced etc.

- Labor
- Material
- Spare parts holding costs
- Modification costs
- Contract service costs

Production and Quality losses due to maintenance: Life cycle costs also consider the losses associated with non availability of pant and plant malfunction in delivering quality outputs.

- Due to plant non availability
- Due to plant malfunction

Disposal costs: The equipment may have salvage value. Sometimes disposing the plant may cost the company.

The above all factors in the build-up of **total life cycle cost.**

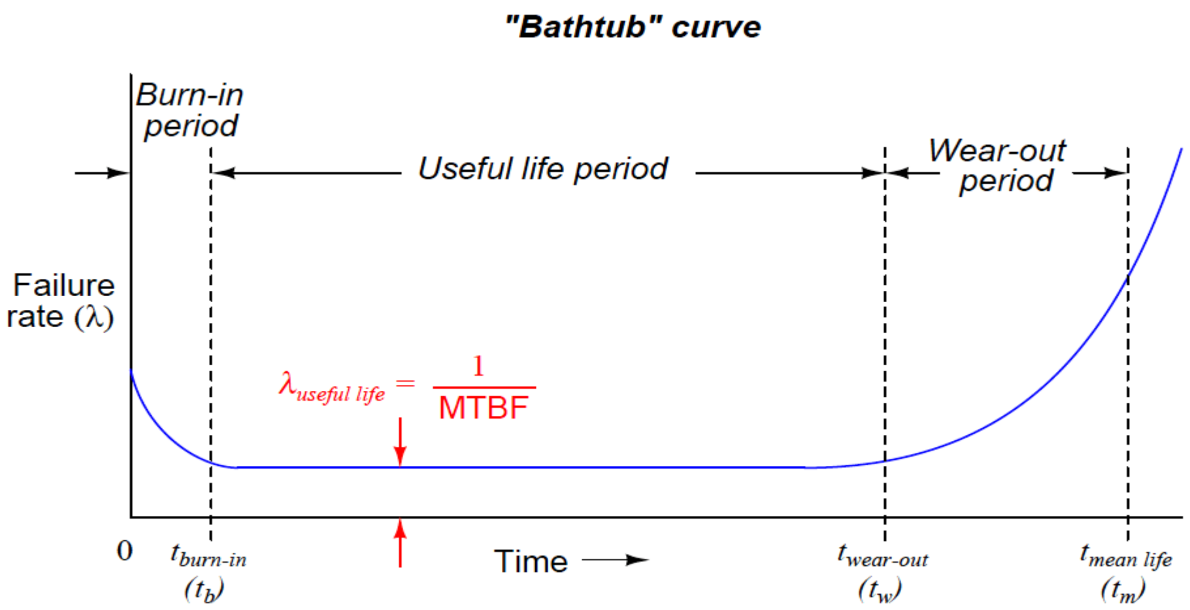
20.6 TYPES OF EQUIPMENT FAILURES

Failures can be classified by cause and timing:
Random Failures: Unpredictable, caused by external factors like operator error or power surges.
Wear-Out Failures: Due to aging and material fatigue, predictable near end of life.
Early Life Failures: Occur soon after installation from defects or incorrect use.
Hidden Failures: Failures are not apparent to operators, such as safety device malfunctions.
Functional Failures: Gradual performance degradation or operational drift.
Human-Caused Failures: Resulting from errors in operation, maintenance, or installation.

20.6.1 Failure Types by Lifecycle (The Bathtub Curve)

Bathtub curve is usually considered to be one of most useful and essential graphical representations of reliability of assets. Bathtub Curve is generally **graph** that is used to demonstrate overall life cycle of assets and failure rate of overall population of assets over time. Assets are usually equipment, components, or parts of equipment, etc.

With help of such graph, one can determine and predict when failure usually happens and then identify root causes. The failure rate of most non-electronic equipment follows a pattern known as the **Bathtub Curve** when plotted against time or usage.



This curve divides an asset's life into three distinct periods, each with its own characteristic failure rate and causes.

1. Burn in Period--Infant Mortality (Early Failures**)**
2. Useful Life (Random Failures)
3. Wear-Out (Old Age)

The details are in table.

Failure Phase	Failure Rate Trend	Key Causes	Maintenance Strategy
Infant Mortality (Early Life)	High, rapidly **decreasing**	Manufacturing defects, installation errors, improper calibration, design flaws.	**Commissioning & Testing:** Strict quality control, "burn-in" periods, warranty management.
Useful Life (Normal Life)	Low and relatively **constant**	Random external events, operator error, accidental overloads, undetected contamination, poor maintenance routines.	**Preventive & Predictive:** Condition monitoring (PdM) and scheduled maintenance (PM) to catch hidden defects.
Wear-Out (Late Life)	High, rapidly **increasing**	Natural degradation of materials, corrosion, fatigue, erosion, and component aging.	**Replacement & Overhaul:** Planning for component replacement, major overhaul, or complete asset retirement.

20.6.3 Root Cause of Failure

In addition to the lifecycle patterns, operational failures are often attributed to specific physical, human, or environmental factors

20.6.3.1 Physical/Mechanical Causes

- **Improper Lubrication:** Using the wrong lubricant, under-greasing, or over-greasing, leading to excessive friction and heat.
- **Mechanical Wear:** Abrasive (caused by dirt/particles) or adhesive (metal rubbing metal) wear on contact surfaces.
- **Corrosion:** Chemical degradation of materials due to moisture, acid, or environmental factors.
- **Fatigue:** Stress failure in metal components caused by constant flexing or cyclic loading (even within design limits).
- **Contamination:** Ingress of dirt, water, or process fluids into critical components (e.g., oil or cooling systems).

20.6.3.2 Human/Procedural Causes

- **Operator Error:** Using the equipment outside its design parameters, improper startup/shutdown, or forgetting a critical step (a major cause of "random" failures).
- **Lack of PM:** Missing scheduled inspections, ignoring minor leaks, or skipping routine checks.
- **Over-Maintenance:** Excessive dismantling and reassembly can introduce dirt, damage components, or lead to misalignment, paradoxically *causing* failure.
- **Incorrect Installation/Repair:** Misalignment of shafts, improper tensioning of belts, or poor fitting of replacement parts.

20.7 Machine Replacement Problems

The managers are to determine the mathematical point where replacement is cheaper than maintenance. Deciding when to replace machinery involves evaluating the cost of continued maintenance and downtime against the investment in new equipment. Factors include failure frequency, repair costs, efficiency loss, and technological obsolescence. Optimal replacement balances lifecycle costs with operational reliability and productivity.

20.7.1 When to Replace?

Machines should be replaced when the cost of keeping the old machine (maintenance + operating cost) exceeds the average annual cost of a new machine.

Two Types of Problems

Replacement due to Deterioration: The machine works, but maintenance costs are rising, and efficiency is falling (e.g., an old car).

Replacement due to Obsolescence: The machine works fine, but a new technology is available that is significantly faster or cheaper to run (e.g., replacing a Typewriter with a Computer).

20.7.2 The Average Annual Cost Calculation

To solve replacement problems, we calculate the Average Annual Cost **A(n)** for keeping a machine for n years:

$$A(n) = (C - S + \sum Mt) / n$$

Where:

- C = Capital Cost (Purchase Price)
- S = Scrap Value
- $\sum Mt$ = Sum of maintenance/operating costs up to year n
- n = Number of years

Decision Rule:

Calculate A(n) for year 1, year 2, year 3, etc. Replace the machine at the end of the year where A(n) is at its **minimum**.

Here is a step-by-step solution to a **Machine Replacement Problem**. This example illustrates how to calculate the "Economic Life" of an asset—the ideal time to replace it to minimize costs.

20.7.3 Problem Statement

A manufacturing plant purchases a new CNC machine for **Rs. 6,000**.The **Scrap Value** (resale value) is negligible (assumed to be **Rs. 0**).The **Maintenance and Operating Costs**are low initially but increase as the machine ages, as shown in the table below.**Determine the optimal year to replace the machine.**

Year (n)	Maintenance Cost for the Year (Mt)
1	Rs. 1,000
2	Rs. 1,200
3	Rs. 1,600
4	Rs. 2,400
5	Rs. 3,500

Solution: The Logic & Formula

We need to find the year where the **Average Annual Cost** is at its lowest.

$$A(n) = (C - S + \sum Mt) / n$$

Where:

- C = Rs.6,000 (Capital Cost)
- S = Rs.0 (Scrap Value)
- **∑Mt**= Cumulative Maintenance Cost (Sum of all maintenance costs up to year n)
- n = Number of years the machine is kept

Step-by-Step Calculation Table

We will calculate the Average Annual Cost**A(n)**for each year.

End of Year (n)	Maint. Cost (Mt)	Cumulative Maint. (∑Mt)	Capital (Depreciated) Cost (C−S)	Total Cost (C−S+∑Mt)	Average Annual Cost- A(n)
1	1,000	1,000	6,000	7,000	7000/1 =Rs.**7,000**
2	1,200	2,200	6,000	8,200	8200/2 =Rs. **4,100**
3	1,600	3,800	6,000	9,800	9800/3 =Rs. **3,266**
4	2,400	6,200	6,000	12,200	12200/4 =Rs. **3,050**
5	3,500	9,700	6,000	15,700	15700/5 =Rs. **3,140**

Analysis of Results

- **Year 1-3:** The average cost is dropping rapidly because the high initial capital cost ($6,000) is being spread over more years.
- **Year 4:** The average cost hits a minimum of **Rs. 3,050**.
- **Year 5:** The average cost starts to rise again (**Rs. 3,140**) because the maintenance cost for that specific year (**Rs. 3,500**) is now higher than the running average.

Final Decision

The optimal replacement time is at the end of **Year 4**.

If you keep the machine for a 5th year, your average cost of ownership begins to increase, meaning it is now cheaper to buy a new machine than to keep maintaining the old one.

20.7.4 Machine Replacement with Time Value of Money

Goal: To make decisions based on real-world economics (Interest & Inflation).

In the previous simple example, we assumed Rs.1 spent five years from now is the same as Rs.1 spent today. In reality, money has a "time value."

- **Money today is worth more:** You can invest Rs.1 today and earn interest.
- **Future costs are "discounted":** A maintenance bill of Rs.1,000 due in 5 years is less painful than a Rs.1,000 bill due today, because you could set aside a smaller amount (say, Rs.700) today and let it grow to Rs.1,000 by year 5.

1. The Discount Factor

To adjust the costs, we use the **Present Value (PV)** formula:

$$PV = F / (1+r)^n$$

Where:

- F = Future Cost (Maintenance cost in year n)
- r = Interest Rate (e.g., 0.10 for 10%)
- n = Year number

2. Effect on the Decision

When you account for interest ($r > 0$):

1. The "weight" of future rising maintenance costs is reduced (discounted).
2. This typically **shifts the optimal replacement year later**.
3. It encourages keeping the machine longer because the high maintenance costs in later years are "cheaper" in today's dollars.

3. New Decision Criterion: Equivalent Annual Cost (EAC)

Instead of a simple average, we calculate the **Equivalent Annual Cost**. This spreads the total discounted cost of the machine equally over its life, acting like a loan payment.

20.8 SUMMARY

Maintenance management is the systematic process of planning, organizing, and controlling the upkeep of physical assets to ensure they remain effective, safe, and cost-efficient throughout their lifecycle. A good maintenance plan combines various strategies based on asset criticality and failure patterns. Different types of maintenance include preventive, predictive will help the plant work efficiently. Total productive maintenance will reduce the failure rate and downtime.

Life cycle costs (LCC) is a concept which aims to optimise the total costs of asset ownership, by identifying and quantifying all the significant net expenditures arising during the ownership of an asset. By examining trade-offs between the different cost areas, LCC attempts to ensure the optimum selection, use and replacement of physical assets.

20.9 Key Words

Preventive Maintenance: Preventive Maintenance is planned maintenance carried out at regular intervals to prevent equipment failure.
Predictive Maintenance: Predictive Maintenance is a condition-based maintenance approach that predicts when equipment failure might occur using monitoring techniques.
Corrective Maintenance: Corrective Maintenance refers to maintenance performed after a fault is detected to restore equipment to normal operation.
Proactive Maintenance: Proactive Maintenance focuses on eliminating the root causes of equipment failure rather than fixing the symptoms.
Breakdown Maintenance: Breakdown Maintenance is maintenance performed only after equipment fails completely.
TPM- Total Productive Maintenance: TPM is a company-wide maintenance strategy aimed at maximizing equipment effectiveness through employee involvement.
OEE – Overall Equipment Effectiveness: OEE is a performance metric used to measure how effectively equipment is utilized.

20.10 SELF-ASSESSMENT QUESTIONS

1. Discuss various models of maintenance alternatives
2. What is the difference between Preventive and Predictive maintenance?
3. Explain the primary objective of maintenance management in terms of asset reliability and cost control.
4. A factory experiences frequent breakdowns, costing huge. Recommend a maintenance strategy shift and justify using cost balance principles.
5. Analyze the bathtub curve for equipment failures. Identify the three phases and explain how each influences maintenance scheduling.
6. Evaluate which breakdown maintenance is suitable for a high-volume production line. Provide two reasons supporting your evaluation.
7. Explain the concept of life cycle costs.
8. Discuss the TPM.
9. A company operates identical delivery trucks and wants to set a fixed replacement policy to minimize average annual costs.

Given Data:

- **Initial Cost (*C*):** Rs.20,000
- **Salvage Value (*St*):** Rs.15,000 at the end of year 1, decreasing by $3,000 each year
- **Annual Operating and Maintenance Costs (*Mt*):** as given intable.

Year	Mt (Rs.)	St (Rs.)
1	3000	15000
2	4000	12000
3	6000	9000
4	9000	6000
5	13000	3000

Solution Steps

Goal: Determine the optimal year (*t*) for replacement that minimizes the **Average Annual Total Cost (AATC)**.

The Average Annual Total Cost (AATC) for replacement at year *t* is calculated as:

AATC(t)= Initial Cost − Salvage Value $_t$+Cumulative Operating Cost $_t$

AATC(t)= $(C - St + \sum Mi) / t$

Year (t)	Cumulative Mt ($\sum Mi$)	Total Net Cost ($C - St + \sum Mi$)	AATC(t)
			(Total Net Cost / t)
1	3,000	20,000−15,000+3,000 = 8,000	8,000/1=8,000
2	3,000+4,000=7,000	20,000−12,000+7,000 = 15,000	15,000/2=7,500
3	7,000+6,000=13,000	20,000−9,000+13,000 = 24,000	24,000/3=8,000
4	13,000+9,000=22,000	20,000−6,000+22,000 = 36,000	36,000/4=9,000
5	22,000+13,000=35,000	20,000−3,000+35,000 = 52,000	52,000/5=10,400

Conclusion

The minimum average annual total cost is **$7,500.00**, which occurs if the truck is replaced at the **end of Year 2**. The company should adopt a policy of replacing these trucks every two years.

20.10.1 Choice based questions

1. Which type of maintenance relies on sensors and real-time monitoring to detect failure before it happens?
   - A) Corrective Maintenance
   - B) Preventive Maintenance
   - C) Predictive Maintenance
   - D) Breakdown Maintenance

2. In the "Bathtub Curve," what is the primary cause of failures during the "Infant Mortality" phase?
   - A) Wear and tear
   - B) Manufacturing defects or installation errors
   - C) Old age
   - D) Random accidents

3. What is the main objective of calculating the "Maintenance Cost Balance"?
   - A) To eliminate all breakdowns completely.
   - B) To find the lowest sum of Preventive Maintenance costs and Breakdown costs.
   - C) To spend the entire budget on spare parts.
   - D) To ensure the maintenance team is always busy.

4. When solving a Machine Replacement problem without interest, you should replace the machine when:
   - A) The maintenance cost exceeds the scrap value.
   - B) The machine stops working entirely.
   - C) The Average Annual Cost reaches its minimum point.
   - D) The machine is 10 years old.

Answer Key

1. **C) Predictive Maintenance** (It predicts failure using condition monitoring).
2. **B) Manufacturing defects...** (Early failures happen due to quality issues).
3. **B) To find the lowest sum...** (Optimization of total cost).
4. **C) The Average Annual Cost...** (The economic sweet spot).

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LESSON-21
PROJECT MANAGEMENT

OBJECTIVES:

- By the time you complete the lesson you gain knowledge on basics of project management
- Framework of project management
- Roles and duties of a project manager

STRUCTURE:

21.1 INTRODUCTION

A project is composed of jobs, activities, functions known as tasks that are interrelated on another in some way and all of these should be completed in order to complete the project. Projects are undertaken to create a unique product, feature, service, or any specific result. Management of projects is a temporary endeavour with a clear beginning and end date.

Each project has three specific objectives. They are:

i. The project should be completed with a minimum of elapsed time.
ii. It should use available manpower and other resources as sparingly as possiblewithout delay
iii. It should be completed with a minimum of capital investment without delay.

Project management is defined as the process of applying knowledge, skills, tools and techniques to meet specific objectives of the project. Project management has specific objectives and goals unlike operations. Project management includes planning, executing, monitoring and closure of the projects.

Project Management (PM) is a disciplined process of leading teams to achieve specific goals within defined constraints (scope, time, budget) through key phases, namely, Initiation, Planning, Execution, Monitoring/Controlling, and Closing**.**

Project Management Definition: The discipline of applying knowledge, skills, tools, and techniques to project activities to meet project requirements and deliver defined outcomes.
Project Management Core Idea: To successfully bring a unique endeavour (project) from an idea to completion, managing challenges like scope creep, budget overruns, and missed deadlines.
Project Management Framework offers a structured approach, which include:
Project Lifecycle: The Stages a project goes through (Initiation, Planning, Execution, Monitoring and Control, Closure).
Processes and Tasks: Standardized steps for each stage (e.g., defining scope, risk assessment, resource allocation).
Tools and Templates: Standardized documents (WBS, Gantt charts, risk registers) and software to support processes.
Methodologies: Underlying approaches through which defined work gets done.

21.2 FOCUS OF PROJECT MANAGEMENT

Project management focuses on how to plan, initiate, monitor, execute and close projects successfully by ensuring that they are delivered on time and within budget with required quality standards as planned. Key to the Successful project management is to balance the constraints of scope, time and cost. For the successful completion of the project the two resources required are material and manpower.

Changing the scope of the project (such as adding features to a product) could require more time and money. Managing these constraints while still delivering the desired outcome is a major challenge for project managers. Tools like Gantt charts, risk assessments, and performance metrics are commonly used to keep projects aligned with their goals.

21.3 PHASES / FRAMEWORK

A project management framework consists of the processes, tasks, and tools used to take a project from start to finish. It encompasses all the key components required for planning, managing, and governing projects. Project Management Framework is how consistently the project is done.

21.3.1 FRAMEWORKS - KEY ELEMENTS:

Element -1: The 4 Ps, namely, People, Product, Process, and Project.
Element-2: The 5 Cs, namely, Complexity, Criticality, Compliance, Culture and Compassion.
Element-3: The Control Cycles, namely, the mechanisms to track performance against plans.

21.3.2 Frameworks Matter for the following:

i. **Consistency**: Standardizes how projects are run across an organization.
ii. **Visibility**: Helps managers see project status at any time.
iii. **Efficiency**: Reduces wasted effort by providing proven methods.
iv. **Risk Management**: Proactively identifies and addresses potential issues.

21.4 ROLES AND RESPONSIBILITIES OF PROJECT MANAGER

A Project Manager (PM) orchestrates the project, defining goals, securing resources, managing stakeholders, mitigating risks, and ensuring quality, acting as the central hub for communication and accountability to drive successful project completion. The role of project manager is multifaceted. The term "project manager" is so broad that it can encompass various tasks and mean different things to different people.

a. These highly organized and detail-oriented individuals have a comprehensive understanding of project lifecycles, helping teams navigate a roadmap to produce deliverables on time. Their strong critical thinking skills help them tackle complex projects and solve problems as they arise.

b. Project managers are also people managers. After all, they are responsible for leading the team and communicating clearly and regularly with all relevant parties — not an easy feat. They must encourage their team members, engage regularly with their stakeholders, and inspire their clients.

c. Project managers are critical to the success of any venture.

The key duties of a project manager include:

- Planning the project
- Leading the team
- Executing the project
- Managing schedules
- Overseeing the budget
- Preparing documents
- Maintaining and troubleshooting deliverables

A. Planning

A project manager is responsible for formulating a project plan to meet the objectives of project while adhering to an approved budget and timeline. This blueprint will guide the project from ideation to fruition. It will include the project's scope, the resources necessary, the anticipated time and financial requirements, the communication strategy, a plan for execution and documentation, and a proposal for follow-up and maintenance. If the project has not yet gained approval, this plan will serve as a critical part of the pitch to key decision makers.

B. Leadership

A key role of any project manager is to assemble and lead the project team. He should have excellent communication, people, and leadership skills, as well as a keen eye for others' strengths and weaknesses. Once the team has been created, the project manager assigns tasks, sets deadlines, provides necessary resources, and meets regularly with the members. An ability to speak openly and frequently with all stakeholders is critical.

C. Execution

The project manager participates in each and every stage of execution of the project in addition to supervise the successful execution of each stage of the project. Again, this requires frequent, open communication with the project team members and stakeholders, ensuring effective project management practices are applied throughout.

D. Time management

Staying on schedule is crucial to completing any project, and time management is one of the key responsibilities of a project manager. Project managers are responsible for resolving derailments and communicating effectively with team members and other stakeholders to ensure the project gets back on track. Project managers should be experts at risk management and contingency planning to continue moving forward even when roadblocks occur.

E. Budget management

Project managers devise a budget for a project and stick to it as closely as possible. If certain parts of the project end up costing more (or, in a perfect world, less) than anticipated, project managers need to moderate the expenditure, and reallocate funds when necessary.

A project manager ensures that a project successfully moves from planning to completion. He oversee every aspect of the project, ensuring the budget constraints without compromising on quality standards. He must manage the timelines and resources to prevent delays and unexpected changes to the scope of the project.

F. Documentation

A project manager must develop effective ways to measure and analyse the progress of the project. Common strategies for documenting a project include data collection and verbal and written status reports is also the job of a project manager.

G. Maintenance

The work doesn't end once a project has been completed. There needs to be a plan for ongoing maintenance and troubleshooting. The project manager devises methods for properly supporting the final deliverable going forward, even if they are not directly overseeing its day-to-day operations.

21.4.1 Day-to-day duties of project manager:

Each project is unique and, as a result, no two days are alike. A project manager's job is to keep the project moving forward and clear a path for their team members to succeed.
A project manager does on a day-to-day basis the following:

- Answering emails related to the execution or maintenance of a project
- Scheduling meetings with team members, such as daily stand-ups
- Check with the client or other stakeholders to update them on the progress of project

- Creating project reports and other documents to assess project risks, budget, schedule, and scope
- Reviewing workload charts and timesheets and reallocating resources as needed
- Working with project management software and tools including Gantt charts, Kanban boards, dashboards, calendars, and more.

21.4.2 Qualities of a good project manager

A good project manager delivers a final product that is on time, on budget, and meets or exceeds the expectations of the stakeholders or clients. Tying projects back to business goals is becoming increasingly necessary for project managers. It's essential to communicate with stakeholders at the beginning to ensure the project is strategically impacting the business's needs.
Qualities that make a successful project manager are:

- Organizational prowess
- Acute attention to detail
- Ability to see the big picture
- Resourcefulness
- Risk management capabilities
- Critical thinking and problem-solving skills
- Excellent communication skills
- Can-do attitude
- Ability to inspire and motivate
- Openness to self-assessment and reevaluation.

21.5 SUMMARY

Project management lesson has made an elaborate discussion on different aspects of managing projects from the planning stage through various facets of the execution- resource planning, to human and machine resources. It has discussed about duties and responsibilities of the project managers in addition to framework of the projects.

21.6 KEYWORDS

Project Management (PM): is a disciplined process of leading teams to achieve specific goals within defined constraints (scope, time, budget) through key phases, namely, Initiation, Planning, Execution, Monitoring/Controlling, and Closing**.**

Project Lifecycle: The Stages a project goes through (Initiation, Planning, Execution, Monitoring and Control, Closure).

Planning: A project manager is responsible for formulating a project plan to meet the objectives of project while adhering to an approved budget and timeline

Time management: Staying on schedule is crucial to completing any project, and time management is one of the key responsibilities of a project manager. Project managers are responsible for resolving derailments and communicating effectively with team members and other stakeholders to ensure the project gets back on track. Project managers should be experts at risk management and contingency planning to continue moving forward even when roadblocks occur.

Budget management: Project managers devise a budget for a project and stick to it as closely as possible. If certain parts of the project end up costing more (or, in a perfect world, less) than anticipated, project managers need to moderate the expenditure, and reallocate funds when necessary.

21.7 SELF-ASSESSMENT EXERCISES

1) What is Project management?
2) What are different frameworks of project?
3) List and discuss the duties and responsibilities of a project manager?
4) What are the qualities of a good project manager?

21.8 FURTHER READINGS

1) R. Panneerselvam, Production & operations management, Prentice Hall lndia,2017.
2) Mahadevan B., Operations Management Theory and Practice, Pearson Publication, 3rd Edition,
3) Project Planning and control with PERT and CPM, Punmia, B C and Khandelwal, KK,Laxmi Publications (p) ltd, New Delhi, 2010.

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LESSON-22

PERT AND CPM

OBJECTIVES:

- On successful completion of the lesson you understand various details about the project management and network analysis.
- Know the construction of network using interrelationships.
- Calculate and identify Critical path using single time estimate(CPM)
- Calculate and identify Critical path using three time estimates(PERT)

STRUCTURE:

22.1 INTRODUCTION TO NETWORK TECHNIQUES

Network Analysis includes normally two techniques, CPM and PERT were developed almost simultaneously, one in the industrial activity and the other in military operations. CPM (Critical Path Method) was the discovery of M. R. Walker of E. I. Du Pont de Nemours & Co. and J.E. Kelly of Remington Rand, circa 1957, Chemical factory. The computation was designed for the UNIVAC-I computer. The first test was made in 1958, when CPM was applied to the construction of a new chemical plant. In March 1959, the method was applied to maintenance shut-down at the Du Pont works in Louisville, Kentucky. Unproductive time was reduced from 125 to 93 hours. Objective was to minimise the down time (out of commission) of equipment in a chemical plant- Batch production- down time in between one batch to another. Dismantling the equipment, clean, dry, and Reassemble the equipment before next batch of production. Activities are repeated in nature. Precise time estimates are possible for each activity. The required computing was done by Remington Rand Corporation

Initial objective in using the network planning techniques was minimization of time. Later network was used to determine and minimize project cost and allocation and leveling of resources like money, machinery and manpower a more difficult objective.

A means of automatically optimizing these conflicting objectives is yet to be devised. To submit a network analysis in support of Govt. contracts in many major building and construction companies like Oil Companies, Railways and Civil Service departments in countries like UK and USA is a must. A means of automatically optimizing these conflicting objectives is yet to be devised.

Contrary, PERT (Project Evaluation and Review Technique) was devised in 1958 for the POLARIS missile program by the Program Evaluation Branch of the Special Projects office of the U.S. Navy, helped by the Lockheed Missile Systems division and the Consultant firm of Booz-Allen & Hamilton. The calculations were so arranged so that they could be carried out on the IBM Naval Ordinance Research Computer (NORC) at Dahlgren, Virginia.

The methods are essentially network-oriented techniques using the same principle. PERT and CPM are basically time-oriented methods in the sense that they both lead to determination of a time schedule for the project. The significant difference between two approaches is that the time estimates for the different activities in CPM were assumed to be deterministic while in PERT these are described probabilistically. These techniques are referred as project scheduling techniques.

Need for CPM/PERT: Growing awareness in industry/ Business for better planning. Look ahead and anticipate snags before they arise. In CPM activities are shown as a network of precedence relationships using activity-on- node network construction, Single estimate of activity time and deterministic activity times.

Used in Production management - for the jobs of repetitive in nature where the activity time estimates can be predicted with considerable certainty due to the existence of past experience.

In PERT activities are shown as a network of precedence relationships using activity-on-arrow network construction

- Multiple time estimates
- Probabilistic activity times

Project management, for non-repetitive jobs (research and development work), where the time and cost estimates tend to be quite uncertain. This technique uses probabilistic time estimates.

22.1.1 Benefits of PERT/CPM

- Useful at many stages of project management
- Mathematically simple

- Give critical path and slack time
- Provide project documentation
- Useful in monitoring costs

22.1.2 Limitations of PERT/CPM

- Clearly defined, independent and stable activities
- Specified precedence relationships
- Over emphasis on critical paths

22.2 Applications of CPM / PERT

These methods have been applied to a wide variety of problems in industries and have found acceptance even in government organizations. These include:

i. Construction of a dam or a canal system in a region
ii. Construction of a building or highway
iii. Maintenance or overhaul of airplanes or oil refinery
iv. Space flight
v. Cost control of a project using PERT / COST
vi. Designing a prototype of a machine
vii. Development of supersonic planes

22.2.1 Basic Steps in PERT / CPM

Project scheduling by PERT/CPM consist of four main steps.

1. Planning
The planning phase is started by splitting the total project in to small projects. These smaller projects in turn are divided into activities and are analyzed by the department or section. The relationship of each activity with respect to other activities are defined and established and the corresponding responsibilities and the authority are also stated. Thus the possibility of overlooking any task necessary for the completion of the project is reduced substantially.

2. Scheduling
The ultimate objective of the scheduling phase is to prepare a time chart showing the start and finish times for each activity as well as its relationship to other activities of the project. Moreover the schedule must pinpoint the critical path activities which require special attention if the project is to be completed in time. For non-critical activities, the schedule must show the amount of slack or float times which can be used advantageously when such activities are delayed or when limited resources are to be utilized effectively.

3. Allocation of resources
Allocation of resources is performed to achieve the desired objective. A resource is a physical variable such as labour, finance, equipment and space which will impose a limitation on time for the project.When resources are limited and conflicting, demands are made for the same type of resources a systematic method for allocation of resources become essential. Resource allocation usually incurs a compromise and the choice of this compromise depends on the judgment of managers.

4. Controlling

The final phase in project management is controlling. Critical path methods facilitate the application of the principle of management by expectation to identify areas that are critical to the completion of the project. By having progress reports from time to time and updating the network continuously, a better financial as well as technical control over the project is exercised. Arrow diagrams and time charts are used for making periodic progress reports. If required, a new course of action is determined for the remaining portion of the project.

22.3 THE FRAMEWORK FOR PERT AND CPM

Essentially, there are six steps which are common to both the techniques. The procedure is listed below:

I. Define the Project and all of its significant activities or tasks. The Project (made up of several tasks) should have only a single start activity and a single finish activity.
II. Develop the relationships among the activities. Decide which activities must precede and which must follow others.
III. Draw the "Network" connecting all the activities. Each Activity should have unique event numbers. Dummy arrows are used where required to avoid giving the same numbering to two activities.
IV. Assign time and/or cost estimates to each activity
V. Compute the longest time path through the network. This is called the critical path.
VI. Use the Network to help plan, schedule, and monitor and control the project.

The Key Concept used by CPM/PERT is that a small set of activities, which make up the longest path through the activity network control the entire project. If these "critical" activities could be identified and assigned to responsible persons, management resources could be optimally used by concentrating on the few activities which determine the fate of the entire project.

Non-critical activities can be replanned, rescheduled and resources for them can be reallocated flexibly, without affecting the whole project.

Five useful questions to ask when preparing an activity network are:

- Is this a Start Activity?
- Is this a Finish Activity?
- What Activity Precedes this?
- What Activity Follows this?
- What Activity is Concurrent with this?

22.4 NETWORK DIAGRAM REPRESENTATION

In a network representation of a project certain definitions are used: They are:

22.4.1 Activity

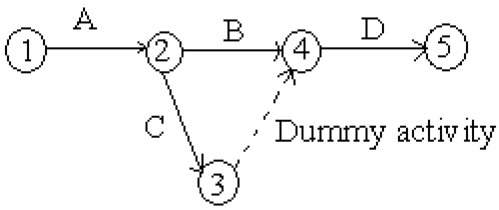
Any individual operation which utilizes resources and has an end and a beginning is called activity. An arrow is commonly used to represent an activity with its head indicating the direction of progress in the project. These are classified into four categories.

1. **Predecessor activity** – Activities that must be completed immediately prior to the start of another activity are called predecessor activities.
2. **Successor activity** – Activities that cannot be started until one or more of other activities are completed but immediately succeed them are called successor activities.
3. **Concurrent activity** – Activities which can be accomplished concurrently are known as concurrent activities. It may be noted that an activity can be a predecessor or a successor to an event or it may be concurrent with one or more of other activities.
4. **Dummy activity** – An activity which does not consume any kind of resource but merely depicts the technological dependence is called a dummy activity.

The dummy activity is inserted in the network to clarify the activity pattern in the following two situations

- To make activities with common starting and finishing points distinguishable
- To identify and maintain the proper precedence relationship between activities that is not connected by events.

For example, consider a situation where A and B are concurrent activities. C is dependent on A and D is dependent on A and B both. Such a situation can be handled by using a dummy activity as shown in the figure.

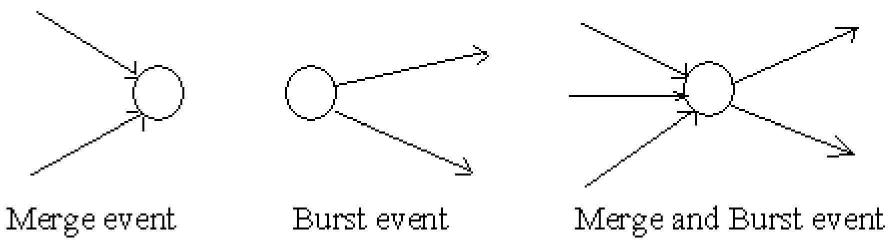


5. Event

An event represents a point in time signifying the completion of some activities and the beginning of new ones. This is usually represented by a circle in a network which is also called a node or connector.

The events are classified in to three categories

i. **Merge event** – When more than one activity comes and joins an event such an event is known as merge event.
ii. **Burst event** – When more than one activity leaves an event such an event is known as burst event.
iii. **Merge and Burst event** – An activity may be merge and burst event at the same time as with respect to some activities it can be a merge event and with respect to some other activities it may be a burst event.



6. Sequencing

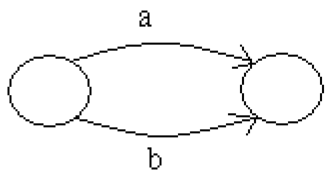
The first prerequisite in the development of network is to maintain the precedence relationships. In order to make a network, the following points should be taken into considerations

- What job or jobs precede it?
- What job or jobs could run concurrently?
- What job or jobs follow it?
- What controls the start and finish of a job?

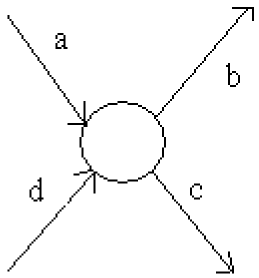
Since all further calculations are based on the network, it is necessary that a network be drawn with full care.

22.5 RULES FOR DRAWING NETWORK DIAGRAM

Rule 1: **Each activity is represented by one and only one arrow in the network**



Rule 2: **No two activities can be identified by the same end events**



Rule 3: In order to ensure the correct precedence relationship in the arrow diagram, following questions must be checked whenever any activity is added to the network

- What activity must be completed immediately before this activity can start?
- What activities must follow this activity?
- What activities must occur simultaneously with this activity?

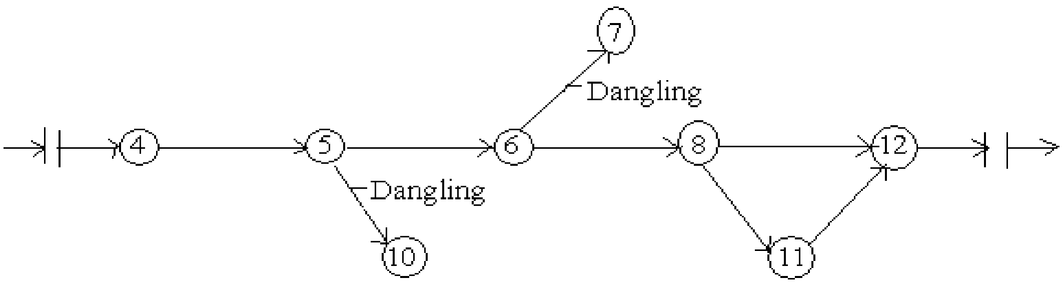
In case of large network, it is essential that certain good habits be practiced to draw an easy to follow network

- Try to avoid arrows which cross each other
- Use straight arrows
- Do not attempt to represent duration of activity by its arrow length
- Use arrows from left to right. Avoid mixing two directions, vertical and standing arrows may be used if necessary.
- Use dummies freely in rough draft but final network should not have any redundant dummies.
- The network has only one entry point called start event and one point of emergence called the end event.

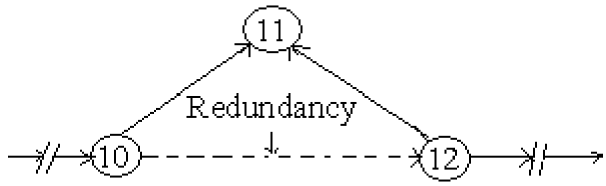
22.6 COMMON ERRORS IN DRAWING NETWORKS

The three types of errors are most commonly observed in drawing network diagrams

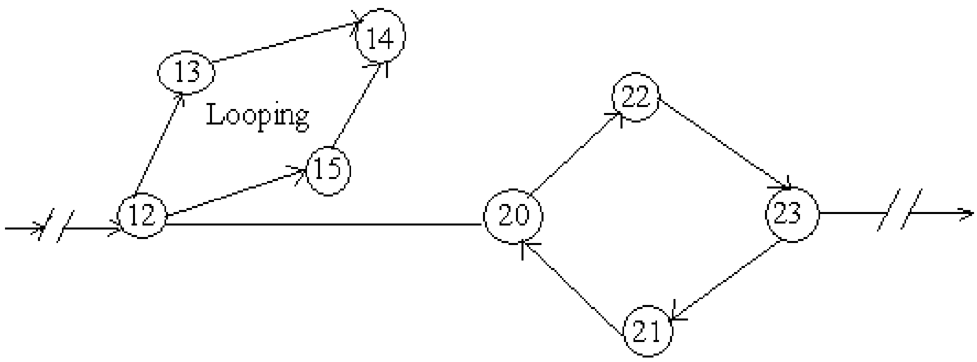
a) **Dangling:** To disconnect an activity before the completion of all activities in a network diagram is known as dangling. As shown in the figure activities (5 – 10) and (6 – 7) are not the last activities in the network. So the diagram is wrong and indicates the error of dangling



b) **Looping or Cycling:** Looping error is also known as cycling error in a network diagram. Drawing an endless loop in a network is known as error of looping as shown in the following figure.



c) **Redundancy:** Unnecessarily inserting the dummy activity in network logic is known as the error of redundancy as shown in the following diagram.



22.7 ADVANTAGES AND DISADVANTAGES

PERT/CPM has the following advantages

a) A PERT/CPM chart explicitly defines and makes visible dependencies (precedence relationships) between the elements,

b) PERT/CPM facilitates identification of the critical path and makes this visible,

c) PERT/CPM facilitates identification of early start, late start, and slack for each activity,

d) PERT/CPM provides for potentially reduced project duration due to better understanding of dependencies leading to improved overlapping of activities and tasks where feasible.

PERT/CPM has the following disadvantages:

i. There can be potentially hundreds or thousands of activities and individual dependency relationships,

ii. The network charts tend to be large and unwieldy requiring several pages to print and requiring special size paper,

iii. The lack of a timeframe on most PERT/CPM charts makes it harder to show status although colours can help (e.g., specific colour for completed nodes),

iv. When the PERT/CPM charts become unwieldy, they are no longer used to manage the project.

22.8 CRITICAL PATH IN NETWORK ANALYSIS

Basic Scheduling Computations:

The notations used are:

(i, j) = Activity with tail event i and head event j
E_i = Earliest occurrence time of event
L_j = Latest allowable occurrence time of event j
D_{ij} = Estimated completion time of activity (i, j)
$(Es)_{ij}$ = Earliest start time of activity (i, j)
$(Ef)_{ij}$ = Earliest finish time of activity (i, j)
$(Ls)_{ij}$ = Latest start time of activity (i, j)
$(Lf)_{ij}$ = Latest finish time of activity (i, j)

The procedure is as follows

1) Determination of Earliest time (E_j): Forward Pass computation

Step 1: The computation begins from the start node and move towards the end node. For easiness, the forward pass computation starts by assuming the earliest occurrence time of zero for the initial project event.

Step 2: Earliest start time of activity (i,j) is the earliest event time of tail end event $(Es)_{ij}=E_i$

Earliest finish time of activity (i,j) = {Earliest start time + the activity time} i.e., $(Ef)_{ij} = (Es)_{ij} + D_{ij} = E_i + D_{ij}$

Earliest event time for event j is the maximum of the earliest finish times of all activities ending into that event, i.e., E_j = Max [$(Ef)_{ij}$ for all immediate predecessor of (i, j)]

i.e., E_j =max [$E_i + D_{ij}$]

2) Backward Pass computation (for latest allowable time)

Step 1: For ending event assume E = L. Remember that all E's have been computed by forward pass computations.

Step 2: Latest finish time for activity (i, j) is equal to the latest event time of event j,

i.e., $(Lf)_{ij} = L_j$

Step 3: Latest starting time of activity (i, j) = the latest completion time of (i, j) – the activity time i.e., $(Ls)_{ij} =(Lf)_{ij} - D_{ij}$ or $(Ls)_{ij} = L_j - D_{ij}$

Step 4: Latest event time for event 'i' is the minimum of the latest start time of all activities originating from that event i.e. L_i = min [$(Ls)_{ij}$ for all immediate successor of (i, j)] = min [$(Lf)_{ij} - D_{ij}$] = min [$L_j - D_{ij}$]

A. Determination of floats and slack times

There are three kinds of floats:

Total float: The amount of time by which the completion of an activity could be delayed beyond the earliest expected completion time without affecting the overall project duration time. Mathematically,

$(Tf)_{ij}$ = (Latest start – Earliest start) for activity (i – j) $(Tf)_{ij} = (Ls)_{ij} - (Es)_{ij}$ or $(Tf)_{ij} = (L_j - D_{ij}) - E_i$

Free float: The time by which the completion of an activity can be delayed beyond the earliest finish time without affecting the earliest start of a subsequent activity. Mathematically,

$(Ff)_{ij}$ = (Earliest time for event j – Earliest time for event i) – Activity time for (i,j)

$(Ff)_{ij} = (E_j - E_i) - D_{ij}$

Independent float: The amount of time by which the start of an activity can be delayed without effecting the earliest start time of any immediately following activities, assuming that the preceding activity has finished at its latest finish time. Mathematically,

$(If)_{ij} = (E_j - L_i) - D_{ij}$

The negative independent float is always taken as zero.

Event slack: It is defined as the difference between the latest event and earliest event times. Mathematically, Head event slack = $L_j - E_j$, Tail event slack = $L_i - E_i$

22.9 Determination of critical path

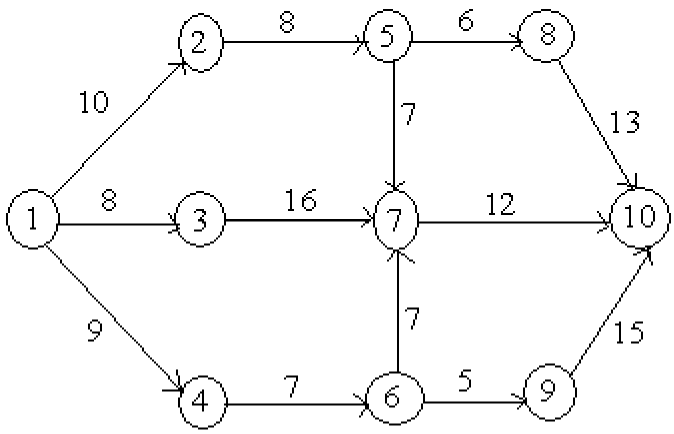
Critical event: The events with zero slack times are called critical events. In other words the event i is said to be critical if $E_i = L_i$

Critical activity: The activities with zero total float are known as critical activities. In other words an activity is said to be critical if a delay in its start will cause a further delay in the completion date of the entire project.

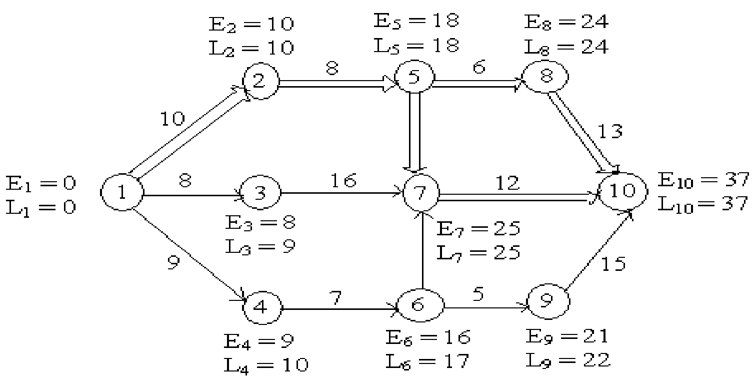
Critical path: The sequence of critical activities in a network is called critical path. The critical path is the longest path in the network from the starting event to ending event and defines the minimum time required to complete the project.

22.10 SOLVED EXAMPLES ON CPM:

Example 1: Determine the early start and late start in respect of all node points and identify critical path for the following network.



Solution: Calculation of E_i and L_i for each node is shown in the network



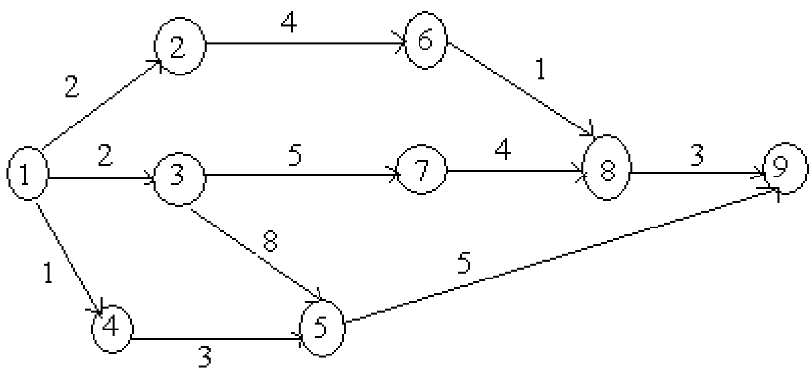
Network Analysis Table

Activity (i, j)	Normal Time (D_{ij})	Earliest Time		Latest Time		Float Time (L_i - D_{ij}) - E_i
		Start (E_i)	Finish ($E_i + D_{ij}$)	Start ($L_i - D_{ij}$)	Finish (L_i)	
(1, 2)	10	0	10	0	10	0
(1, 3)	8	0	8	1	9	1
(1, 4)	9	0	9	1	10	1
(2, 5)	8	10	18	10	18	0
(4, 6)	7	9	16	10	17	1
(3, 7)	16	8	24	9	25	1
(5, 7)	7	18	25	18	25	0
(6, 7)	7	16	23	18	25	2
(5, 8)	6	18	24	18	24	0
(6, 9)	5	16	21	17	22	1
(7, 10)	12	25	37	25	37	0
(8, 10)	13	24	37	24	37	0
(9, 10)	15	21	36	22	37	1

From the table, the critical nodes are (1, 2), (2, 5), (5, 7), (5, 8), (7, 10) and (8, 10)
From the table, there are two possible critical paths.

i. 1 → 2 → 5 → 8 → 10
ii. 1 → 2 → 5 → 7 → 10.

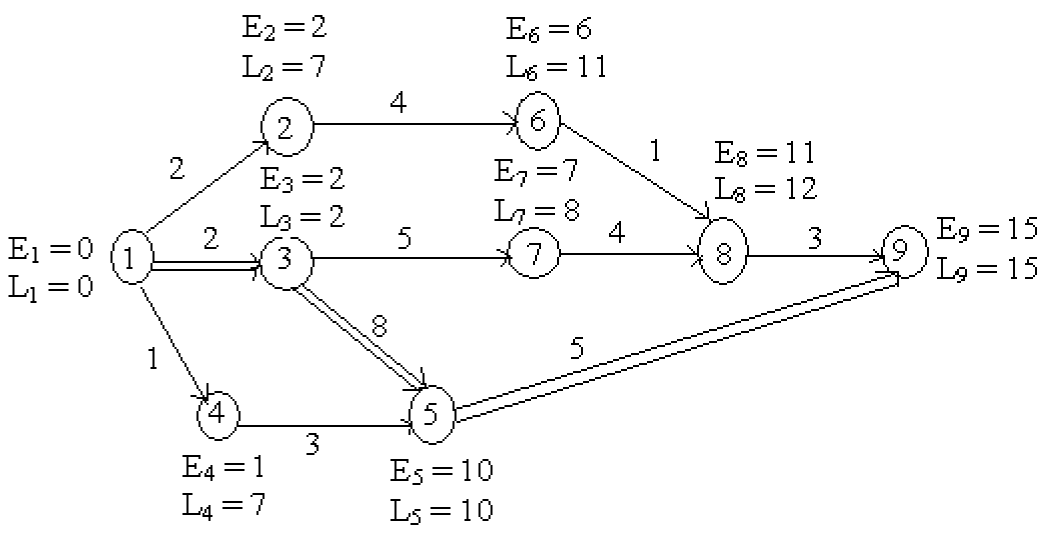
Example 2: Find the critical path and calculate the slack time for the following network



Solution: The earliest time and the latest time are obtained below

Activity(i, j)	Normal Time (D_{ij})	Earliest Time		Latest Time		Float Time (L_i - D_{ij}) - E_i
		Start (E_i)	Finish ($E_i + D_{ij}$)	Start ($L_i - D_{ij}$)	Finish (L_i)	
(1, 2)	2	0	2	5	7	5
(1, 3)	2	0	2	0	2	0
(1, 4)	1	0	1	6	7	6
(2, 6)	4	2	6	7	11	5
(3, 7)	5	2	7	3	8	1
(3, 5)	8	2	10	2	10	0
(4, 5)	3	1	4	7	10	6
(5, 9)	5	10	15	10	15	0
(6, 8)	1	6	7	11	12	5
(7, 8)	4	7	11	8	12	1
(8, 9)	3	11	14	12	15	1

From the above table, the critical nodes are the activities (1, 3), (3, 5) and (5, 9)



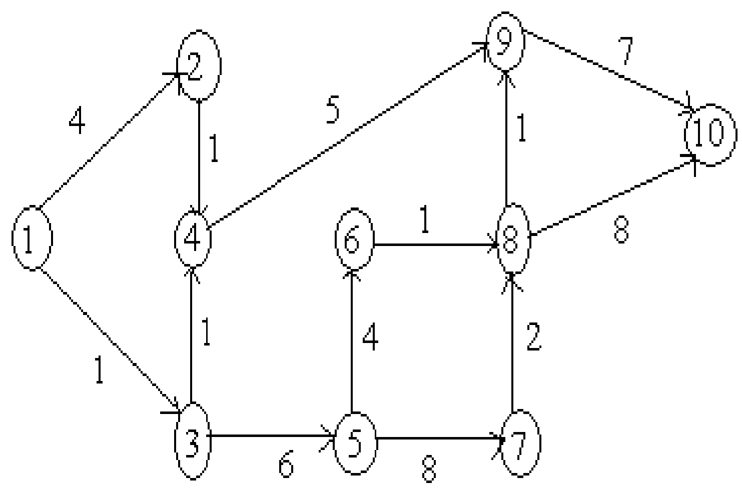
The critical path is 1 → 3 → 5 → 9

Example 3: A project has the following times schedule

Activity	Times in weeks	Activity	Times in weeks
(1 – 2)	4	(5 – 7)	8
(1 – 3)	1	(6 – 8)	1
(2 – 4)	1	(7 – 8)	2
(3 – 4)	1	(8 – 9)	1
(3 – 5)	6	(8 – 10)	8
(4 – 9)	5	(9 – 10)	7
(5 – 6)	4		

Construct the network and compute: i) T_E and T_L for each event, ii) Float for each activity and iii) Critical path and its duration

Solution: The network is

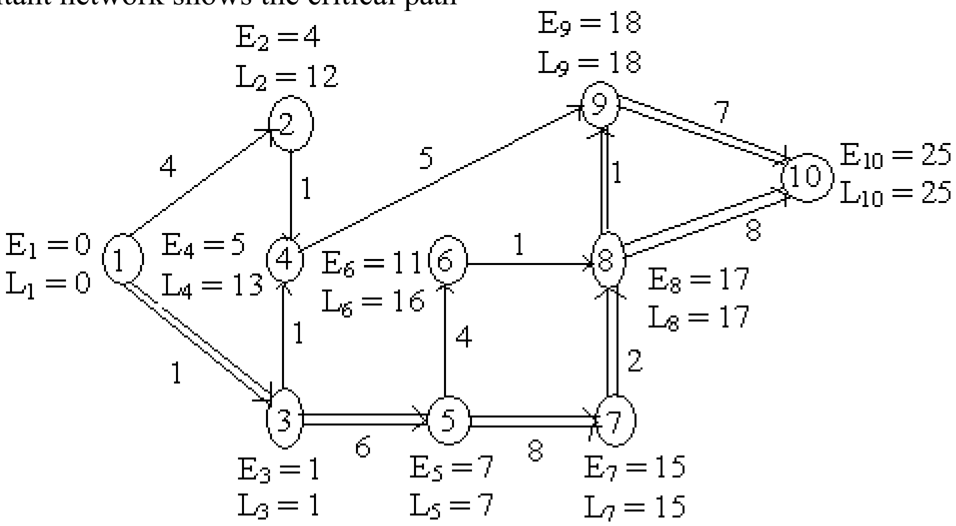


Event No.:	1	2	3	4	5	6	7	8	9	10
T_E:	0	4	1	5	7	11	15	17	18	25
T_L:	0	12	1	13	7	16	15	17	18	25

Float = T_L (Head event) – T_E (Tail event) – Duration

Activity	Duration	T_E (Tail event)	T_L (Head event)	Float
(1 – 2)	4	0	12	8
(1 – 3)	1	0	1	0
(2 – 4)	1	4	13	8
(3 – 4)	1	1	13	11
(3 – 5)	6	1	7	0
(4 – 9)	5	5	18	8
(5 – 6)	4	7	16	5
(5 – 7)	8	7	15	0
(6 – 8)	1	11	17	5
(7 – 8)	2	15	17	0
(8 – 9)	1	17	18	0
(8 – 10)	8	17	25	0
(9 – 10)	7	18	25	0

The resultant network shows the critical path



The two critical paths are

i. 1 → 3 → 5 →7 → 8 → 9 →10
ii. 1 → 3 → 5 → 7 → 8 →10

22.11 PROJECT EVALUATION AND REVIEW TECHNIQUE (PERT)

The main objective in the analysis through PERT is to find out the completion for a particular event within specified date. The PERT approach takes into account the uncertainties. The three time values are associated with each activity

i. **Optimistic time:** It is the shortest possible time in which the activity can be finished. It assumes that everything goes very well. This is denoted by t_0.
ii. **Most likely time:** It is the estimate of the normal time the activity would take. This assumes normal delays. If a graph is plotted in the time of completion and the frequency of completion in that time period, then most likely time will represent the highest frequency of occurrence. This is denoted by t_m.
iii. **Pessimistic time:** It represents the longest time the activity could take if everything goes wrong. As in optimistic estimate, this value may be such that only one in hundred or one in twenty will take time longer than this value. This is denoted by t_p.

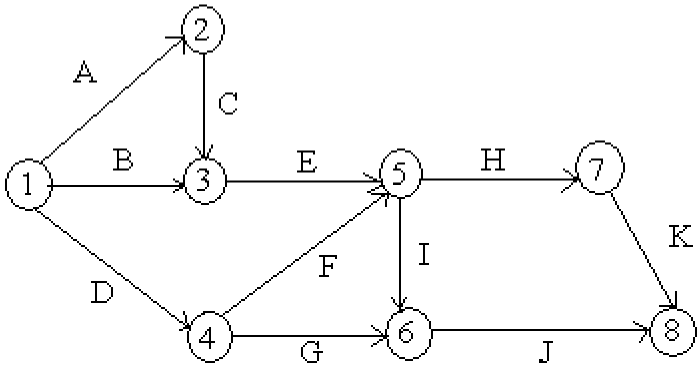
In PERT calculation, all values are used to obtain the percent expected value.

A. **Expected time:** It is the average time an activity will take if it were to be repeated on large number of times and is based on the assumption that the activity time follows Beta distribution, this is given by

$$t_e = \{(t_0 + 4\ t_m + t_p)/6\}$$

B. The variance for the activity is given by $\sigma^2 = [(t_p - t_o) / 6]^2$

Example 4: For the project



Task:	A	B	C	D	E	F	G	H	I	J	K
Least time:	4	5	8	2	4	6	8	5	3	5	6
Greatest time:	8	10	12	7	10	15	16	9	7	11	13
Most likely time:	5	7	11	3	7	9	12	6	5	8	9

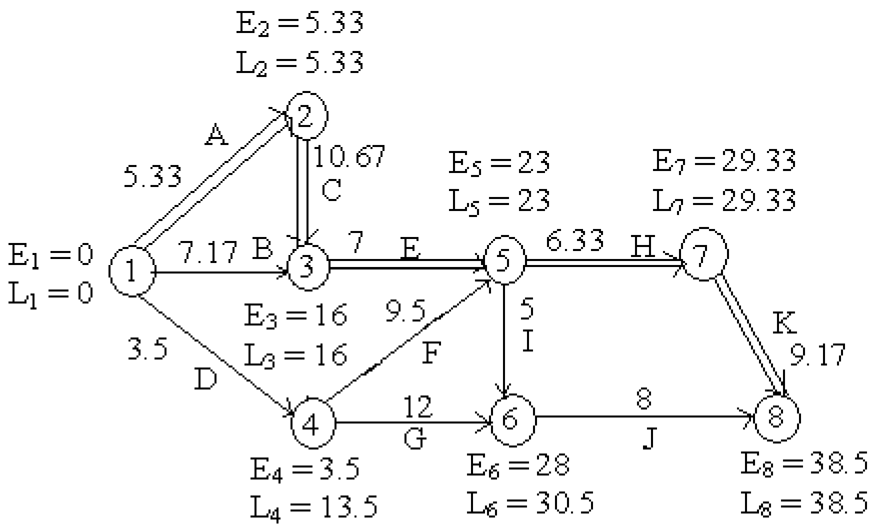
Find the earliest and latest expected time to each event and also critical path in the network.

Solution

Task	Least time(t_0)	Greatest time (t_p)	Most likely time (t_m)	Expected time $(to + t_p + 4t_m)/6$
A	4	8	5	5.33
B	5	10	7	7.17
C	8	12	11	10.67
D	2	7	3	3.5
E	4	10	7	7
F	6	15	9	9.5
G	8	16	12	12
H	5	9	6	6.33
I	3	7	5	5
J	5	11	8	8
K	6	13	9	9.17

Task	Expected time (t_e)	Start		Finish		Total float
		Earliest	Latest	Earliest	Latest	
A	5.33	0	0	5.33	5.33	0
B	7.17	0	8.83	7.17	16	8.83
C	10.67	5.33	5.33	16	16	0
D	3.5	0	10	3.5	13.5	10
E	7	16	16	23	23	0
F	9.5	3.5	13.5	13	23	10
G	12	3.5	18.5	15.5	30.5	15
H	6.33	23	23	29.33	29.33	0
I	5	23	25.5	28	30.5	2.5
J	8	28	30.5	36	38.5	2.5
K	9.17	29.33	29.33	31.5	38.5	0

The network is



The critical path is A →C →E → H → K

Example 5: A project has the following characteristics

Activity	Most optimistic Time (a)	Most pessimistic Time (b)	Most likely Time (m)
(1 – 2)	1	5	1.5
(2 – 3)	1	3	2
(2 – 4)	1	5	3

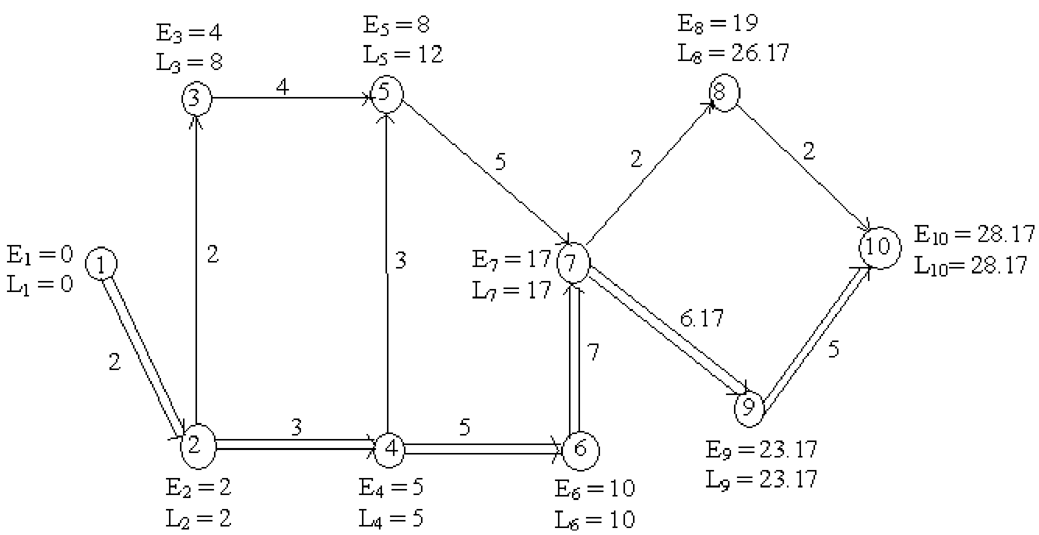
(3 – 5)	3	5	4
(4 – 5)	2	4	3
(4 – 6)	3	7	5
(5 – 7)	4	6	5
(6 – 7)	6	8	7
(7 – 8)	2	6	4
(7 – 9)	5	8	6
(8 – 10)	1	3	2
(9 – 10)	3	7	5

Construct a PERT network. Find the critical path and variance for each event.

Solution:

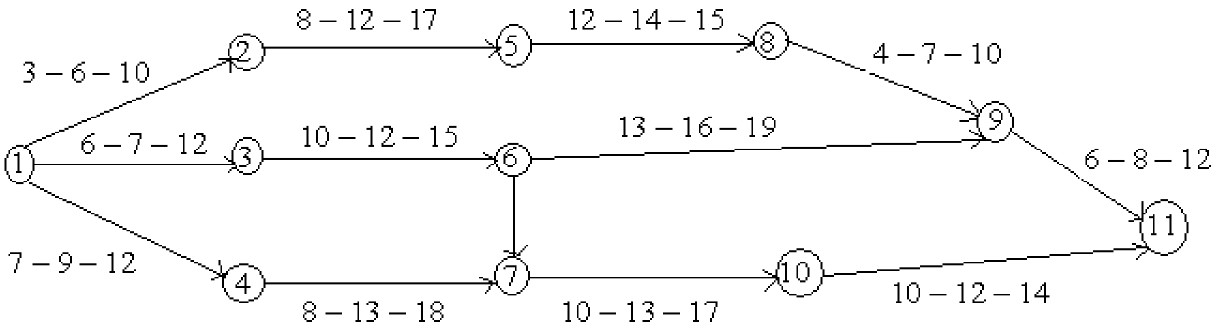
Activity	(a)	(b)	(m)	(4m)	t_e = (a + b + 4m)/6	σ = $[(b - a)/6]^2$
(1 – 2)	1	5	1.5	6	2	4/9
(2 – 3)	1	3	2	8	2	1/9
(2 – 4)	1	5	3	12	3	4/9
(3 – 5)	3	5	4	16	4	1/9
(4 – 5)	2	4	3	12	3	1/9
(4 – 6)	3	7	5	20	5	4/9
(5 – 7)	4	6	5	20	5	1/9
(6 – 7)	6	8	7	28	7	1/9
(7 – 8)	2	6	4	16	4	4/9
(7 – 9)	5	8	6	24	6.17	1/4
(8 – 10)	1	3	2	8	2	1/9
(9 – 10)	3	7	5	20	5	4/9

The network is constructed as shown below



The critical path = 1 → 2 → 4 → 6 → 7 →9 →10

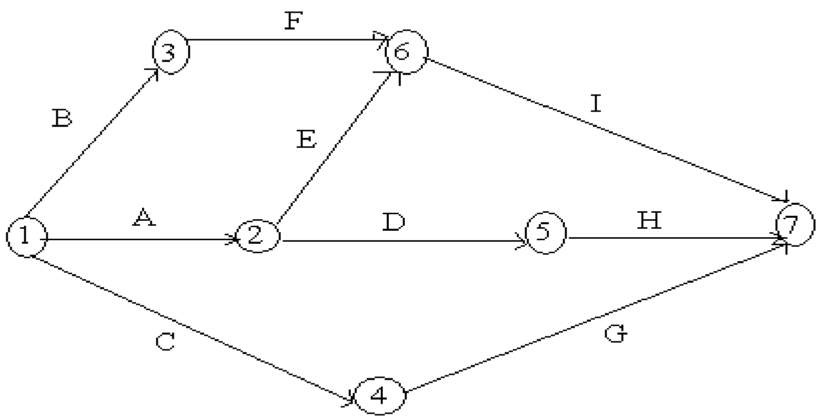
Example 6: Calculate the variance and the expected time for each activity



Solution:

Activity	(t_o)	(t_m)	(t_p)	t_e $(t_o + t_p + 4t_m)/6$	v $[(t_p – t_o) / 6]^2$
(1 – 2)	3	6	10	6.2	1.36
(1 – 3)	6	7	12	7.7	1.00
(1 – 4)	7	9	12	9.2	0.69
(2 – 3)	0	0	0	0.0	0.00
(2 – 5)	8	12	17	12.2	2.25
(3 – 6)	10	12	15	12.2	0.69
(4 – 7)	8	13	19	13.2	3.36
(5 – 8)	12	14	15	13.9	0.25
(6 – 7)	8	9	10	9.0	0.11
(6 – 9)	13	16	19	16.0	1.00
(8 – 9)	4	7	10	7.0	1.00
(7 – 10)	10	13	17	13.2	1.36
(9 – 11)	6	8	12	8.4	1.00
(10 – 11)	10	12	14	12.0	0.66

Example 7: A project is represented by the network as shown below and has the following data



Task:	A	B	C	D	E	F	G	H	I
Least time:	5	18	26	16	15	6	7	7	3
Greatest time:	10	22	40	20	25	12	12	9	5
Most likely time:	15	20	33	18	20	9	10	8	4

Determine: i) Expected task time and their variance and ii) Earliest and latest time

Solution:

Activity	Least time (t_0)	Greatest time (t_p)	Most likely time (t_m)	Expected time $(to + t_p + 4t_m)/6$	Variance (σ^2)
(1-2)	5	10	8	7.8	0.69
(1-3)	18	22	20	20.0	0.44
(1-4)	26	40	33	33.0	5.43
(2-5)	16	20	18	18.0	0.44
(2-6)	15	25	20	20.0	2.78
(3-6)	6	12	9	9.0	1.00
(4-7)	7	12	10	9.8	0.69
(5-7)	7	9	8	8.0	0.11
(6-7)	3	5	4	4.0	0.11

Earliest time:

$E_1 = 0$
$E_2 = 0 + 7.8 = 7.8$
$E_3 = 0 + 20 = 20$
$E_4 = 0 + 33 = 33$
$E_5 = 7.8 + 18 = 25.8$
$E_6 = \max [7.8 + 20, 20 + 9] = 29$
$E_7 = \max [33 + 9.8, 25.8 + 8, 29 + 4] = 42.8$

Latest time:

$L_7 = 42.8$
$L_6 = 42.8 - 4 = 38.8$
$L_5 = 42.8 - 8 = 34.3$
$L_4 = 42.8 - 9.8 = 33$
$L_3 = 38.8 - 9 = 29.8$
$L_2 = \min [34.8 - 18, 38.8 - 20] = 16.8$
$L_1 = \min [16.8 - 7.8, 29.8 - 20, 33 - 33] = 0$

22.14 SUMMARY

Two very important network analysis techniques used in project management called as CPM and PET are discussed in detail. Required tetminology, namely, EST, LFT are explained. Identification of critical path with deterministic times and uncertain time estimated are discussed. Detailed explanation of using the techniques are discussed using different examples.

22.15 KEYWORDS

Predecessor activity: Activities that must be completed immediately prior to the start of another activity are called predecessor activities.

Successor activity: Activities that cannot be started until one or more of other activities are completed but immediately succeed them are called successor activities.
Concurrent activity: Activities which can be accomplished concurrently are known as concurrent activities. It may be noted that an activity can be a predecessor or a successor to an event or it may be concurrent with one or more of other activities.
Dummy activity: An activity which does not consume any kind of resource but merely depicts the technological dependence is called a dummy activity.
Total float: The amount of time by which the completion of an activity could be delayed beyond the earliest expected completion time without affecting the overall project duration
Optimistic time: It is the shortest possible time in which the activity can be finished. It assumes that everything goes very well. This is denoted by t_0.
Most likely time: It is the estimate of the normal time the activity would take. This assumes normal delays. If a graph is plotted in the time of completion and the frequency of completion in that time period, then most likely time will represent the highest frequency of occurrence. This is denoted by t_m.
Pessimistic time: It represents the longest time the activity could take if everything goes wrong. As in optimistic estimate, this value may be such that only one in hundred or one in twenty will take time longer than this value. This is denoted by t_p.
Expected time: It is the average time an activity will take if it were to be repeated on large number of times and is based on the assumption that the activity time follows Beta distribution, this is given by $\mathbf{t_e = \{(t_0 + 4\, t_m + t_p)/6\}}$
Variance: Variance for the activity is given by $\boldsymbol{\sigma^2 = [(t_p - t_o) / 6]^2}$

22.16 SELF-ASSESSMENT EXERCISES

1. What is CPM?
2. What is PERT?
3. What are the advantages of using PERT/CPM?
4. List out the applications of PERT/CPM
5. Explain the following terms: a) Earliest time, b) Latest time, c) Total activity slack, d) Event slack, e) Critical path
6. Explain the following terms: a) Optimistic time, b) Most likely time, c) Pessimistic time, d) Expected time and e) Variance.
7. Explain the importance of CPM in network analysis.
8. What are the rules for drawing network diagram? Also mention the common errors that occur in drawing networks.
9. What is the difference between PERT and CPM/
10. What are the uses of PERT and CPM?
11. Explain the basic steps in PERT/CPM techniques.
12. Write the framework of PERT/CPM.
13. For the following data, draw network. Find the critical path, slack time after calculating the earliest expected time and the latest allowable time

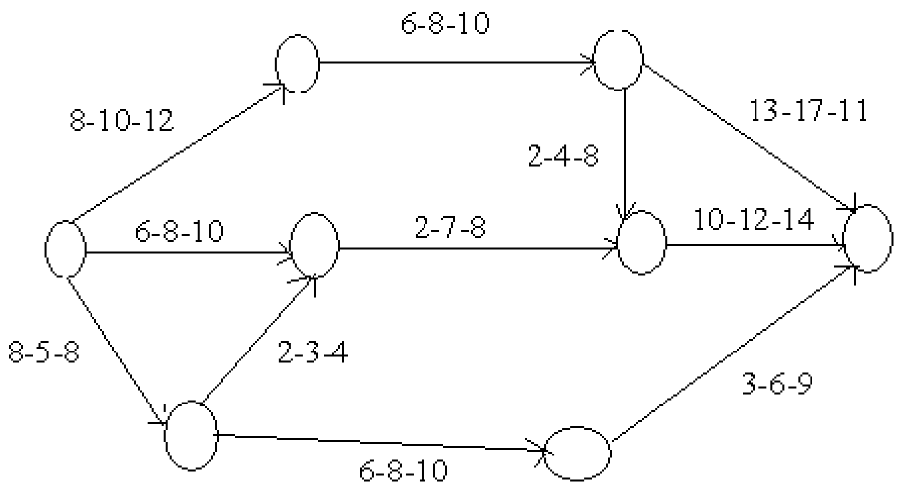
Activity	Duration	Activity	Duration
(1 – 2)	5	(5 – 9)	3
(1 – 3)	8	(6 – 10)	5
(2 – 4)	6	(7 – 10)	4
(2 – 5)	4	(8 – 11)	9
(2 – 6)	4	(9 – 12)	2
(3– 7)	5	(10 – 12)	4
(3 – 8)	3	(11 – 13)	1
(4 – 9)	1	(12 – 13)	7

[Ans. Critical path: 1 → 3 → 7 → 10 → 12 →13]

14. A project schedule has the following characteristics. Construct a PERT network and find out i) The earliest possible time, ii) Latest allowable time and iii) Slack values. Also find the Critical path.

Activity	Most optimistic time	Most likely time	Most pessimistic time
(1 – 2)	1	2	3
(2 – 3)	1	2	3
(2 – 4)	1	3	5
(3 – 5)	3	4	5
(4 – 5)	2	5	4
(4 – 6)	3	5	7
(5 – 7)	4	5	6
(6 – 7)	6	7	8
(7 – 8)	2	4	6
(7 – 9)	4	6	8
(8 – 10)	1	2	3
(9 – 10)	3	5	7

15. Calculate the variance and the expected time for each activity



22.15 FURTHER READINGS:

1) R. Panneerselvam, Production & operations management, Prentice Hall lndia,2017.
2) Mahadevan B., Operations Management Theory and Practice, Pearson Publication, 3rd Edition,
3) Project Planning and control with PERT and CPM, Punmia, B C and Khandelwal, KK,Laxmi Publications (p) ltd, New Delhi, 2010.

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