204 – Production & Operations Management

Course Objectives:

1. To introduce the fundamental concepts and relevance of production management, including productivity, production systems, and work study techniques.
2. To explain plant location and layout planning, process design, maintenance strategies, and replacement policies for efficient operations.
3. To develop an understanding of production planning and control (PPC), including scheduling techniques, quality control tools, and modern quality standards.
4. To equip students with inventory and materials management strategies, including EOQ, MRP, JIT, and waste management practices.
5. To provide knowledge of project management techniques, including PERT, CPM, and cost-time trade-off analysis using network models.

Course Outcomes:

After the completion of the course, students will be able to:

1. Describe the functions and importance of production management, and apply work study methods to improve productivity.
2. Design effective plant layouts and implement appropriate maintenance and replacement strategies to enhance operational efficiency.
3. Develop and manage production schedules and apply quality control techniques, including control charts, Six Sigma, and ISO standards.
4. Apply inventory control techniques and materials management tools, such as EOQ, ABC analysis, and MRP, to optimise resource use.
5. Use project management tools like PERT and CPM to plan, schedule, and evaluate projects, including crashing and cost optimisation.

UNIT – I

Production Management: Role and Relevance of Production Management – Concepts of Productivity – Production Systems – Work Study: Method study and Work Measurement.

UNIT – II

Plant Location: Plant Layout Types – Process Design- Classification and Merits. Plant Maintenance Methods – Breakdown, Preventive and Predictive Maintenance. Replacement Policies – Unit and Group Replacement Policies.

UNIT – III

Production Planning and Control: Processes in PPC, Job Shop and Flow Shop Scheduling, Job Sequence Rules (Simple Problems) - Johnson's Rules – Line Balancing

– Quality Control: Control Charts (X-R chart, NP Chart and C-chart) - ISO 9000 series – Six Sigma Approach.

UNIT – IV

Materials Management: Concepts – Classification of Inventory – Inventory Control Methods, Stores Management and Deterministic Inventory Models– ABC analysis- Inventory Levels – EOQ – MRP – Just in Time – Simple Problem on EOQ – Waste Management.

UNIT – V

Project Management: Concepts of Project Management, CPM, PERT and Project Network– Crashing and Cost Analysis – Applications of Network Techniques.

References:

1. Muheleman and Sudhir B **-** *Production/Operations Management*, Pearson Education
2. S. N. Chary **-** *Production and Operations Management*, Tata McGraw-Hill.
3. R. Panneer Selvam **-** *Production and Operations Management*, Prentice Hall of India.
4. Adam Ebert - *Production & Operations Management,* Prentice Hall of India.
5. K. Aswathappa, K. Sriddhan Bhat **-** *Production and Operations Management,* Himalaya.
6. P K Gupta, D S Hira **-** *Operations Research,* S. Chand Publishing**.**

PRODUCTION MANAGEMENT

UNIT – I

INTRODUCTION

Production implies the creation of goods and services to satisfy human needs. It involves conversion of inputs (resources) into outputs (products). It is a process by which, raw materials and other inputs are converted into finished products. Earlier the word “manufacturing” was used synonymously with the word “production”, but nowadays, we use the term “manufacturing” to refer to the process of producing only tangible goods whereas the word “production” (or operation) is used to refer to the process of creating both goods (which are tangibles) as well as services (which are intangibles).

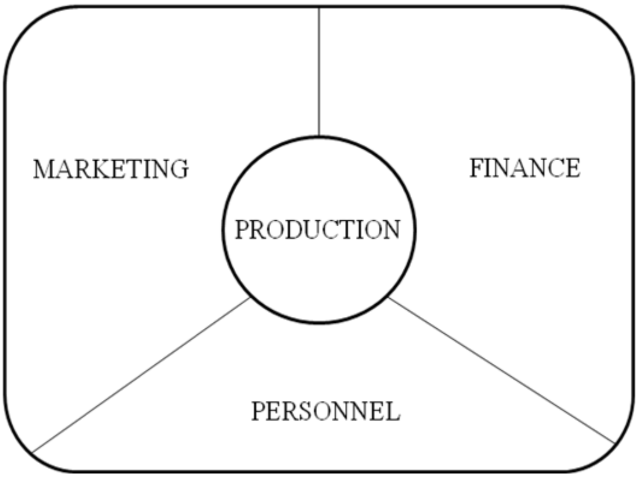
Any process which involves the conversion of raw materials and bought-out components into finished products for sale is known as production. Such conversion of inputs adds to the value or utility of the products produced by the conversion or transformation process. The utility or added value is the difference between the value of outputs and the value of inputs. The value addition to inputs is brought about by alteration, transportation, storage or preservation and quality assurance.

The managing of any organization that produces products demanded by customers presents a greater challenge today than ever before. An organization consists mainly of four functional subsystems, viz. Marketing, Production, Finance and Personnel. Production is the basic activity of all industrial units. All other activities revolve around this activity. The end-product of the production activity is the creation of goods and services for the satisfaction of human wants. The production activity is nothing but the step-by-step conversion of one form of materials into another, either chemically or mechanically. This is done in factories which house manufacturing processes. The basic inputs of the production processes are men, machines, plant, services and methods. The products of the mine, farm, sea and forest are used as raw materials on which the processing is done to create or enhance the form utility. It should be noted that the finished product of one manufacturing unit does not always furnish a ready-made product for the ultimate consumption. In a chain of manufacturing activities, the finished product of the processor sometimes becomes the raw materials (or component) for the other manufacturing firms falling next in the sequence.

Production management does not involve a mechanical assemblage of relevant factors. In contrast to mere transformation of raw materials into finished products, it aims at transmuting and permuting resources of higher productivity so that the greatest outputs are obtained from the least inputs. With its end in views, production management embraces the productive process too and involves planning, directing and controlling operations till their successful completion. Quality, quantity, cost and times of production have an important bearing on productivity of the manufacturing enterprise. Accordingly, it is the task of production management to see that effective utilization of resources is made, time is shortened, wastes and scrapings are avoided, and harmonious working is made to prevail in the plant.

For effective managerial performance, the work of production department is required to be organized on sound lines. All the principles and practices of organizing are to be applied in building a sound structure for improving the result of production management. Successful production management is not practicable without the existence of an appropriate organization structure. Consequently, managerial efforts are to be directed in designing an organization structure that conforms to the needs of the product, size of the enterprise and availability of production facilities. Organizing for production may be conceived in broader sense to include some aspects of works engineering or works organization like plant layout and factory building.

The problems of production management differ from case to case and are mainly related to the system of production. There are several systems of production which determine the magnitude of production work and the problems to be tackled in manufacturing operations. Hence, a familiarity with the different systems of production is required for understanding the intricacies of production management. Of course, the system of production is dictated in a particular case by the volume of sales and the nature of product. The quantity to be produced is nothing but an answer to the question of 'what can be sold”. In the ultimate analysis, therefore, sales are the regulator of a system of production.



The ***Marketing function*** of an organization aims to promote its products among customers, which helps it to obtain substantial sales order.

The ***Finance function*** provides authorization and control to all other subsystems to utilize money more effectively through a well-designed mechanism.

The ***Personnel function*** is a supporting function which plans and provides manpower to all other subsystems of the organization and to itself by formulating proper recruitment and training programmers.

Product: Product is anything that is capable of satisfying a person's needs.

Production: It is the process by which raw materials and other inputs are converted into finished products with the help of certain process.

Production Management: The set of interrelated management activities which are involved in manufacturing certain products is called as production management.

If the same concept is extended to services management, then the corresponding set of management activities is called as ***operations management.***

Definitions:

"Production/Operation management is the process which combines and transforms various resources used in the Production/Operations subsystem of the organization into value added products/services in a controlled manner as per the policies of the organization"

- Unknown

"Production management deals with decision making related to production process so that the resulting goods or services are produced according to specifications in amounts and by the schedules demanded, and at a minimum cost."

- Elwood S Buffa

"Production management is concerned with those processes which convert the inputs into outputs. The inputs are various resources like raw materials, men, machines, methods, etc. and the outputs are goods and services".

- H.A. Harding

Thus production management is concerned with the decision making regarding the production of goods and services at a minimum cost according to the demands of the customers through the management process of planning, organizing and controlling. In order to attain these objectives, effective planning and control of production activities is very essential. Otherwise, the customers shall remain unsatisfied and ultimately certain activities will have to be closed.

SCOPE OF PRODUCTION MANAGEMENT

- Production management mainly associated with the factory management as the problems of production crept with the development of factory system.
- Before the evolution of factory system, manufacturing activities are carried on by single person that pose no problem or very insignificant problem of production and therefore question of production management did not arise.
- But with for inception of factory system, the situation changed and so many problems of production were begun to creep up and necessity arose to tackle with the problems of quality control, layout facilities, meeting the schedules and organization of production activities.
- Thus the scope of production management began to develop. **In early stage, the stress was on controlling the labour costs because labour cost was the major element of the total cost of production.**
- They had developed devices like designing and packing of products, indirect labour cost control, production and inventory control and quality control.

Since the level of production has increased tremendously, so many other production problems have been added to its scope. On the present era of intense competition, the scope of production management is very wide. The various activities that form scope of production function can be studied in two broad areas:-

i. Designing or formulating of production system and
ii. Analyzing and controlling of production operation after production system has been activated.

Activities Relating to Production System Designing:

This activity concerns the production engineering and includes problems regarding design of tools and jigs, the design, development and installation of equipment and the selection of the optimum size of the firm.

The selection of an optimum plant location very much depends upon the decision taken regarding production engineering. The next decision regarding production system design concerns the use of those techniques which are concerned with work environment and work measurement and includes problems like motion study process analysis, layout of the plant, materials handling and time study.

Activities Relating to Analysis and Control of Activities:

The next problem after the designing of the production system is the analysis and control of the production system. It includes all decisions regarding production administration and therefore all functions of the management so far as they are applicable to the production system from the subject matter of the production management. These activities are:-

a) Production Planning
b) Production Control
c) Quality Control

OBJECTIVES OF PRODUCTION MANAGEMENT

The objective of the production management is 'to produce goods services of Right Quality & Right Quantity at the Right Time & Right Manufacturing Cost'.

1. **Right Quality:** The quality of product is established based upon the customers' needs. The right quality is not necessarily best quality. It is determined by the cost of the product and the technical characteristics as suited to the specific requirements.

2. **Right Quantity:** The manufacturing organization should produce the products in right number. If they are produced in excess of demand the capital will block up in the form of inventory and if the quantity is produced in short of demand, leads to shortage of products.

3. **Right Time:** Timelines of delivery is one of the important parameter to judge the effectiveness of production department. So, the production department has to make the optimal utilization of input resources to achieve its objective.

4. **Right Manufacturing Cost:** Manufacturing costs are established before the product is actually manufactured. Hence, all attempts should be made to produce the products at cost, so as to reduce the variation between actual and the standard cost.

DIFFERENCE BETWEEN GOODS & SERVICES

- Services are usually intangible whereas goods are tangible
- Services are often produced and consumed simultaneously, services cannot be stored whereas goods can be produced and inventoried before consumption of use.
- Services are often unique, for example insurance policies, medical treatment procedures, haircut styles etc.,
- Some aspects of quality of goods are measurable whereas many aspects of quantity of services are difficult to measure
- Selling and production are distinct in case of goods whereas in case of services selling is often a part of the services
- Goods can be transported whereas service cannot be transported but the service provider can be transported
- Location of facility to manufacture goods affects costs whereas location of service facility affects customer contact
- Manufacturing of goods can be easily automated whereas service is often difficult to automate

FUNCTIONS AND RESPONSIBILITIES OF PRODUCTION MANAGER OR PRODUCTION MANAGEMENT

A production manager is responsible for the following functions:

- **Production Planning:** Production Planning is the main concern of the production manager. It facilitates the supply of goods at a proper time to execute the order received by the company. It also helps control over the production process. The function of production planning involves the decision when, what, how and why to produce goods.

- **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.

- **Quality Control:** The production manager is also responsible for the 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.

- **Method Analysis:** There may be so many alternatives for manufacturing a product. As because all alternatives for manufacturing a product. As because all alternatives do not work equally, some may be more economical that 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.

- **Inventory Control:** Production manager is supposed to have control over the cost of production by reducing the wastage of man and materials. 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 levels (minimum, maximum and danger levels of the stock of materials) so that the problems of over and under stock of materials may not arise.

- **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 is turn reduces wastage of man and material and helps in reducing the cost of production.
- **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 work by a worker.

- **Other Functions:** Apart from the above functions, the production manager 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.

Role and Relevance of Production Management

Introduction

Production Management deals with the **planning, organizing, directing, and controlling** of production activities. Its main objective is to produce goods and services of the **right quality, in the right quantity, at the right time, and at minimum cost**.

It plays a vital role in the success and growth of a manufacturing organization.

ROLE OF PRODUCTION MANAGEMENT

Production Management plays a vital role in ensuring that production activities are carried out smoothly and efficiently. It is concerned with converting raw materials into finished goods that meet customer requirements. The role of production management includes the following:

▪ **Designing the Production System:**
Production management is responsible for designing a suitable production system based on the nature of the product and market demand. It involves selecting the appropriate type of production process such as job, batch, mass, or continuous production. It also includes deciding the plant layout and selecting proper machines and technology. A well-designed production system ensures smooth workflow, better coordination, and minimum wastage of time and resources.

▪ **Production Planning:**
Production management decides in advance what to produce, how much to produce, and when to produce. Proper planning ensures that resources like labour, materials, and machines are available at the right time. It helps the organization meet customer demand without overproduction or shortages and ensures a continuous flow of work.

▪ **Production Control:**
After planning, production management ensures that actual production activities are carried out according to the plan. It monitors the production process, identifies deviations, and takes corrective actions when necessary. This helps in completing production on time, maintaining quality, and avoiding unnecessary delays and costs.

▪ **Efficient Utilization of Resources:**
Production management ensures the optimum use of all resources such as men, machines, materials, money, and methods. Proper utilization reduces wastage, increases efficiency, and lowers production costs. It ensures that machines are not idle and workers perform tasks according to their skills.

▪ **Quality Maintenance:**
Maintaining product quality is a key role of production management. It sets quality standards and ensures that goods are produced according to specifications. By reducing defects and rework, production management helps in improving customer satisfaction and building the reputation of the company.

▪ **Cost Reduction:**
Production management plays a major role in reducing production costs through better planning, waste control, and efficient operations. Lower costs increase profitability and help the firm remain competitive in the market.

▪ **Coordination with Other Departments:**
Production management works in coordination with marketing, finance, purchase, and human resources departments. It ensures that production plans are aligned with sales forecasts, financial budgets, and manpower availability. This coordination helps the organization function effectively as a whole.

▪ **Ensuring Timely Delivery:**
Production management ensures that goods are produced and delivered to customers on time. Proper scheduling and monitoring of production activities help in meeting delivery commitments, which improves customer trust and satisfaction.

In short, the role of production management is to design efficient systems, plan and control production, utilize resources effectively, maintain quality, reduce costs, and ensure timely delivery. Through these roles, it contributes directly to the productivity, profitability, and overall success of the organization.

RELEVANCE OF PRODUCTION MANAGEMENT

Production Management is highly relevant in today's business environment because it directly affects cost, quality, productivity, and customer satisfaction. Its importance can be understood from the following points:

▪ **Improves Productivity:**
Production management focuses on using resources like labour, machines, and materials efficiently. By adopting better methods and technologies, it increases output from the same level of inputs. Higher productivity leads to better performance and higher profits for the organization.

▪ **Reduces Production Cost:**
One of the main objectives of production management is cost control. By minimizing wastage of materials, reducing idle time of workers and machines, and improving processes, it lowers the cost per unit of production. Lower costs help the firm earn more profit and compete effectively in the market.

▪ **Ensures Optimum Utilization of Resources:**
Resources such as men, materials, machines, and money are limited and costly. Production management ensures that these resources are neither underutilized nor over utilized. Proper utilization leads to maximum efficiency and avoids unnecessary losses.

▪ **Maintains Quality Standards:**
In today's competitive market, customers demand high-quality products. Production management ensures that goods are produced according to required standards and specifications. Maintaining quality builds customer trust and enhances the company's reputation.

▪ **Ensures Timely Delivery:**
Customers expect products to be delivered on time. Production management plans and controls production activities in such a way that goods are completed and supplied as per schedule. Timely delivery improves customer satisfaction and strengthens business relationships.

▪ **Supports Business Growth:**
Efficient production leads to higher output, better quality, and lower costs. This increases sales and profits, which supports the expansion and growth of the business. Thus, production management contributes directly to organizational development.

▪ **Helps in Facing Competition:**
In the modern competitive environment, firms must produce better products at lower prices. Effective production management helps achieve this by improving efficiency, reducing waste, and adopting modern technology, giving the firm a competitive advantage.

▪ **Adapts to Technological Changes:**
Production management encourages the adoption of new machinery, automation, and improved production techniques. This helps the organization stay updated with technological advancements and improve efficiency and product quality.

▪ **Stability in Production Operations:**
Proper planning and control reduce confusion, delays, and breakdowns in the production process. This ensures smooth and continuous operations, which is essential for maintaining a steady supply of goods.

In conclusion, the relevance of production management lies in its ability to improve productivity, reduce costs, maintain quality, ensure timely delivery, and help organizations remain competitive and profitable. It is therefore considered the backbone of any manufacturing enterprise.

CONCEPTS OF PRODUCTIVITY

Productivity is a term that has a number of different meanings although it is most commonly associated with effectiveness of labour or employees in an industry. In a broad sense productivity is the relationship between the output of an organization and the inputs required to produce these outputs.

The dictionary meaning of the word "Productivity" is "the quality or state of being productive". It is the productive efficiency that improves the economic condition of any enterprise, any industry as a whole resulting in economic prosperity of the country and thereby improving the standard of living of its people.

Productivity is a relationship between the output (product/services) and the input (resources consumed in providing them) of a business system.

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

For the survival of any organization, this productivity ratio must be at least 1. If it is more than one, the organization is in a comfortable position. So, the objective of the organization should be to identify ways and means to improve productivity to the highest possible level. There are several strategies for improving the productivity which are:

1. Increased output for the same input

2. Decreased input for the same output
3. Proportionate increase in the output is more than the proportionate increase in the input
4. Proportionate decrease in the input is more than the proportionate decrease in the output
5. Simultaneous increase in the output with decrease in the input.

1. Increased output for the same input. In this strategy, the output is increased while keeping the input constant.

2. Decreased input for the same output. In this strategy, the input is decreased to produce the same output.

3. Proportionate increase in the output is more than the proportionate increase in the input. Consider the example of introducing a new product into the existing product mix of an organization. If the new product is taken up for production, then the following will result.

a) There will be a increase in the revenue of the organization by way of selling the new product in addition to the existing product mix.
b) There will be an increase in the material cost, and operation and maintenance cost of machineries because of producing the new product.

If we closely examine these two increases, we find that the proportionate increase in the revenue will be more than the proportionate increase in the input cost. Hence, there will be a net increase in the productivity ration.

4. Proportionate decrease in the input is more than the proportionate decrease in the output. Let us consider the reverse case of the previous example, i.e. dropping an uneconomical product from the existing product mix. This will result in the following:

a) There will be a decrease in the revenue of the organization because of dropping a product from the existing product mix.
b) There will be a decrease in the material cost, and operation and maintenance cost of machineries because of dropping an existing product from the product mix.

If we closely examine these two decreases, we find that the proportionate decrease in the input cost will be more than the proportionate decrease in the revenue. Hence, there will be a net increase in the productivity ratio.

5. Increase in the output with decrease in the input. Let us assume that advanced automated technologies like, Robot, Automated Guided Vehicle System (AGVS), etc., are available in the market which can be employed in the organization of our interest. The outcomes of these modern tools can be summarized as following.

a) There will be a drastic reduction in the operation cost. Initially, the cost on equipment would be very high.
b) These advanced facilities would help in producing more number of goods because they don't experience fatigue. The increased production will therefore yield more revenue.

In this example, there is an increase in the revenue while there is a decrease in the input in the long run. Hence, the productivity ratio will increase at a faster rate.

PRODUCTIVITY MEASUREMENT

Since productivity is measured as a ration of output to input, we have various measures of productivity dependi9ng on whether a single input is used or multiple inputs are used. When just one resource (such as labour, or capital or material) is used, the productivity is referred to as single-factor productivity.

When input consists of several factors such as land, capital, labour, material, machinery, energy etc., productivity is referred to as multifactor productivity or total factor productivity or total productivity.

Labour productivity = Units produced (i.e., Output)

Hours worked

$$\text{Capital productivity} = \frac{\text{Output}}{\text{Capital input}}$$

$$\text{Material productivity} = \frac{\text{Output}}{\text{Materials input}}$$

$$\text{Machine productivity} = \frac{\text{Output}}{\text{Machine – hours input}}$$

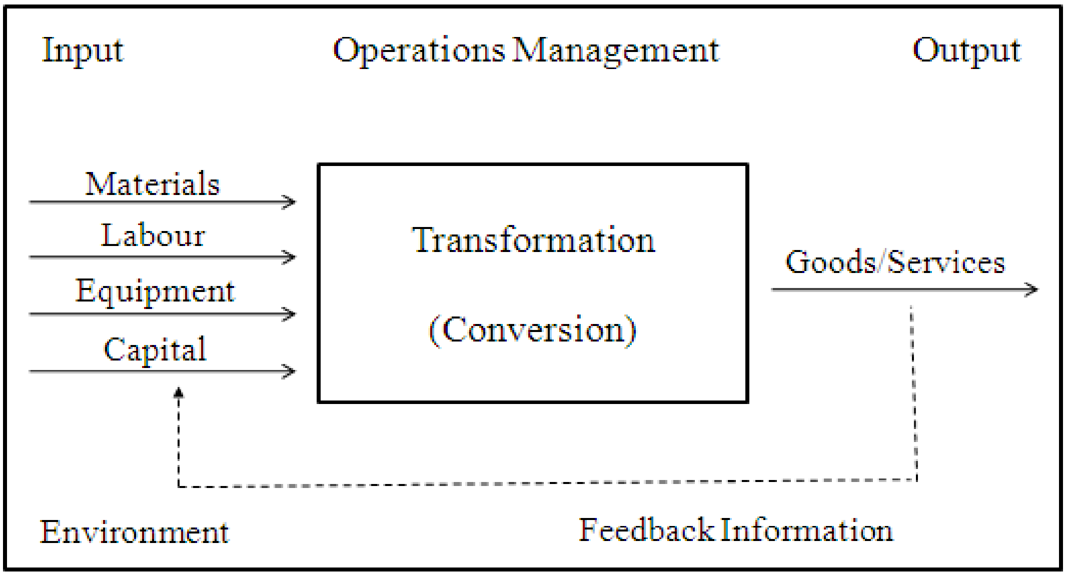
$$\text{Total productivity} = \frac{\text{Output}}{\text{Labour + Material + Energy + Capital}}$$

Since units of inputs vary for different factors of input, it is meaningful to express productivity as the ratio of value of output (goods & services) produced to the value of resources utilized to produce those outputs. Although we are concerned with all factors of inputs affecting productivity, greater emphasis is placed on the effectiveness of labour, the efficient utilization of machinery, equipment and facilities and the economical use of materials, reducing the wastage to the minimum.

SYSTEMS CONCEPT OF PRODUCTION

System is a collection of interrelated entities. The inputs to the system are materials, labour, equipments and capital. These inputs are combined and converted into goods and/or services by a suitable process technology. The types of inputs used vary from one industry to another. In product manufacturing, the major inputs are capital, machines, equipments and tools, and labour is required to operate and maintain the equipments. The material input is the basis for the conversion process.

Production means creation of utility and the framework within which the creation of utility can occur is termed as 'production system'. System is a collection of interrelated entities. At one end of system are inputs and at the other end output. Input and output are linked by certain processed or operation or activities imparting value to the inputs. These processes, operations or activities may be called production systems.



System aspect of production/operations function

In the process of conversion, definitely, there will be some deviations in the product's attributes like quality, size, shape and number of units produced. Just to cope up with the predetermined plans and policies, it is highly essential to communicate these deviations to the input stage in the form of feedback for making necessary corrections.

Based on the feedback, the system once again tries to produce the product/service with modified parameters, in order to meet the specifications. The feedback mechanism is a continuous exercise to monitor the status of the system.

DIFFERENT TYPES OF PRODUCTION SYSTEMS

The production system of a company mainly uses facilities, equipments, and operating methods (called the production system) to produce goods that satisfy customers' demand. The above requirements of a production system depend on the type of product that the company offers and the strategy that it employs to serve its customers.

1. Continuous Production System:

Continuous Production situations are those where facilities are standardized as to routing and flow since the raw material or inputs are standardized. Therefore, a standard set of processes and sequences of processes are adopted. *Examples of industries using such technology are petroleum, chemicals, steel and sugar industry.*

a. **Mass Production:** This system of production is used by concerns where manufacturing is carried on continuously in anticipation of demand though demand of the product may not be uniform throughout the year. Standardization is the keynote of mass production.In order to maintain a continuous flow of production the layout of the plant and machinery is arranged in conformity with the sequence of operations needed for manufacturing a particular product. This system may also be called "**Flow Production System**" because flow of production is maintained.

b. **Process Production:** This system is an extended form of mass production where production is carried on continuously through a uniform predetermined sequence of operations. Generally under this system finished product of one process is used in the next process as a raw material till the last process. Process production calls for the setting up of automatic machines and equipment as far as possible. *For example, crude oil is processed into kerosene, gasoline and other products.*

2. Intermittent Production System:

Intermittent production system situations are those where the facilities must be flexible enough to handle a wide variety of products and sizes or where the basic nature of activity imposes change of important characteristics the input. It is done more often on the basis of customer orders.

The chief characteristics of intermittent industries are that components are made for inventory but they are combined differently for different customers.

a) Job Production: In this system, goods are produced according to the orders of the customers. Continuous demand of such items is not assured and therefore production is done only when the orders for the manufacturing of items are produced from the customers. Job production calls for an adjustment of tools and equipment in working out each individual job.

b) 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, medium 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.*

Classification of Production System

Basis	**Classifications**	**Examples**
Type of Output	Products	Consumer goods like furniture, TV, Radio, etc. Producer goods like, lathe, milling machine etc.
	Services	Transportation, health, entertainment, banking services, education system, etc.
Type of Flow	Projects	Construction of bridge, dam, road, etc
	Job Shop	Hospital, auto repair, machine shop, furniture company, etc.
	Flow Shop	High volume TV factory, auto factory, etc.
	Continuous Process	Postal services, telephone company, power corporation, oil refinery, chemical plant
Type of Specification Under Service Type	Customized	Medical care, legal services
	Standardized	Insurance, wholesale stores

- **Flow Shop:** This is conversion process in which successive units of output undergo the same sequence of operations, using specialized equipments usually positioned along a production line. Extreme form of flow shop is sometimes treated as a continuous process in which there is a constant flow of materials, as in oil refining, chemical processing and others in which there is no way to identify successive units of output.

- **Job Shop:** This is a conversion process in which units of different types of products follow different sequences through different shops. This type of system has more flexibility. But this system results into more set-up time, more in-process inventory, complex scheduling, varying quality, and so forth.

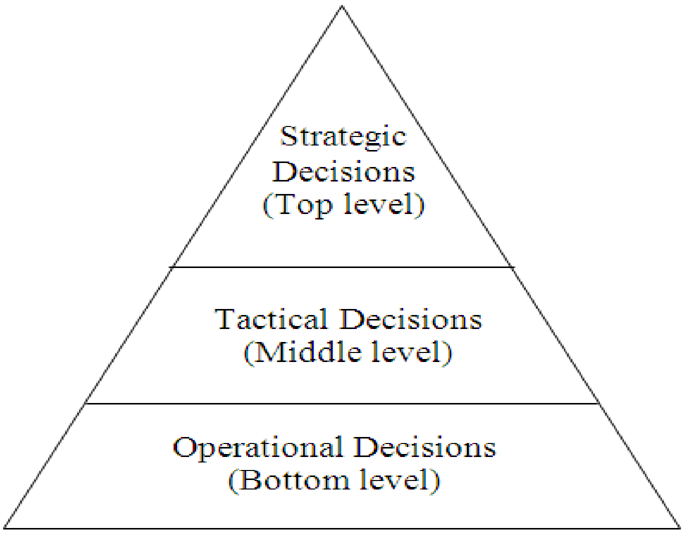
- **Batch Manufacturing:** A batch manufacturing facility produces some intermediate varieties of products with intermediate volumes. The volume of any single product may not be sufficient to justify the use of a dedicated set of equipments for its production. Under this condition, a few or several products will have to share the production resources to balance their utilization. Production equipment in batch manufacturing must be capable of performing a variety of tasks, but the range of possible operations is much narrower than in a job shop.

- **The Project:** A project refers to the process of creating a complex one-of-a-kind product or service with a set of well-defined tasks in terms of resources required and time phasing.

PRODUCTION DECISION LEVELS

In the process of managing various subsystems of the organization, executives at different levels of the organization need to take several management decisions. The management decisions are classified into *strategic decisions, tactical decisions and operational decisions.*

1. ***Strategic Decisions:*** These decisions are taken by the top level management. These are long-term and broad in nature and usually have a time period of five years or more. Long term strategic decision are concerned with production and process design, facility location and layout, capacity, expansion of existing facilities, etc. these decisions impact the long term profitability of an organization.



Production Decision Levels

2. ***Tactical Decisions:*** These decisions are taken at the middle management level. These are medium-term in nature and have a time frame of one or two years. These decisions are concerned with identifying the manpower requirement, determining the appropriate inventory level for various materials, determine the reordering level and order quantity, identifying vendors, and so on. Operations managers need to ensure that these decisions are aligned with the strategic decisions of the organization.

3. ***Operational Decisions:*** These decisions are taken at the bottom level of management. These are short-term in nature and generally have a time frame of less than a week. These are specific in nature, and they address problems and requirements at the operational level, such as scheduling weekly production and assigning jobs/responsibilities to workers.

Matrix of Functional Subsystems and Management Activities

Management Activity Level	Functional Subsystems			
	Marketing	Production	Finance	Personnel
Strategic	Consideration of new markets and new marketing strategies.	Alternative manufacturing approaches had alternative approaches to automation.	Long-run strategy to ensure adequate financing	Strategies for recruitment, salary, training, and benefits.
Tactical	Comparison of overall Performance marketing plan.	Summary reports which compare overall planned or standard performance	Information on budgeted versus actual cost of financial resources	Variance analysis on hiring and firing
Operational	Hiring and firing of sales force, the day-to-day scheduling of sales and promotion efforts and periodic analysis of sales volumes by region, product, customer, etc.	Reports comparing actual performance to production schedule and highlighting areas where bottlenecks occur.	Daily error and exception reports, records of processing delays, reports of unprocessed transactions, etc.	Decision on hiring, training, termination, changing pay rates and issuing benefits.

WORK STUDY

Industry everywhere has been striving hard to discover new work methods and techniques which could help produce goods of required quality at reasonable costs. The search has resulted in finding techniques such as work simplification, job design, value analysis and the like. All these are collectively called methods engineering or industrial engineering. The other names used are work design, work study, methods analysis and operation analysis. Methods engineering is closely affiliated with the functions of work measurement (or time study) and the method study.

In today's competitive business environment, it is necessary that the employees work harder, be more productive so that, the production costs can be kept to meet global competition. Operations managers have to continuously strive for low production costs, high product quality and improve every facet of manufacturing. In this direction, improving labour productivity and reducing costs by improving work methods and simplifying the work needs special attention by operations managers. To facilitate this, work study technique has been developed over a period of time.

Definition:

Work study is defined as that body of knowledge concerned with the analysis of the work methods and the equipment used in performing a job, the design of an optimum work method and the standardization of proposed work methods. Work study has contributed immeasurably to the search for better methods, and the effective utilization of this management tool has helped in the accomplishment of higher productivity. Work study is a management tool to achieve higher productivity in any organization, whether manufacturing tangible products or offering services to its customers.

Work study deals with the techniques of method study and work measurement, which are employed to ensure the best possible of human, machine and material resources in carrying out a specified activity.

***Objective**:* Work study is concerned with finding better ways of doing work and avoiding waste in all its forms. As such the objective of work study is to assist management to obtain the optimum use of the human, machine and material resources available to the organization for the accomplishment of the work upon which it is engaged.

The objective of work study effective use of three aspects:

- The most effective use of plant and equipment
- The most effective use of human effort
- The evaluation of human work.

Work Study has divided into two broad areas:

Method Study is concerned with finding the facts about a situation and after a critical examination of these facts, developing a new and better method of doing that work. It is defined as the existing and proposed ways of doing work and the development and application of easier and more productive methods.

Time Study is concerned with the establishment of time standards for a qualified worker to perform a specified job at a defined level of performance.

Method study must precede time study before any attempt is made to measure and set standards for the various jobs concerned.

METHOD STUDY

It is the systematic recording, analysis and critical examination of existing and proposed ways of doing work and the development and application of easier and new production methods.

Areas of application of method study. It can be applied to any field of work, but the most important areas where it plays a major role in improving productivity are as follows:

- Improved layout of office, working areas of factories
- Improved design of plant and equipment
- Improved use of materials, plant, equipment and manpower
- Most effective handling of materials
- Improved flow of work
- Standardization of methods and procedures
- Improved safety standards
- Better working conditions

STEPS IN METHOD STUDY

Method improvement involves systematic, orderly and scientific approach to problems. One should have an open mind, maintain a questioning attitude, collect all relevant facts, consult others including workers, list reasons/causes for various effects. The given below are the steps in method study:

1. ***Select:*** Select the work to be studied.
2. ***Record:*** record all the relevant facts of the present (or Proposed) method by direct observation
3. ***Examine:*** Examine the facts critically in sequence, using special critical examination sheet.
4. ***Develop:*** Develop the best method i.e. the most practical, economic and effective method under prevailing circumstances.
5. ***Install:*** Install that method as standard practice
6. ***Maintain:*** Maintain that standard practice by regular routine check.

Among all the steps *Record* and *Examine* are very important and it needs detailed discussion.

RECORDING

In order to carry out any investigation, data or relevant facts pertaining to the existing method must be collected and recorded. The recording may trace the movements of men, material or details of various processes. The different recording techniques are charts, diagrams, models and photographic aids.

Recording Techniques

Recording Technique			Information Recorded
(a)	**Charts**		
	1.	Outline Process Chart	Principle Operations and inspection of the processes.
	2.	Flow Process Chart	Activities of men, material or equipment are analyzed into five events viz., operations, transport, inspection, delay and storage.
	3.	Two-handed process chart	Movement of two hands or limbs of the operator
	4.	Multiple activity chart	Simultaneous/interrelated activities of operators and/or machines on a common time scale.
	5.	Simultaneous motion cycle (SIMO) Chart	Movement of body members of the operator, expressed in terms of therbligs on a common time scale.
(b)	**Diagrams and Models**		
	1.	Flow diagram	Path of men, materials and equipments on a scale model.
	2.	String diagram	Same as above except for the variation that it uses string to trace the path.
(c)	**Photographic Aids**		
	1.	Cycle graph	Movement of hand obtained by exposing a photographic plate to the light emitted from small bulbs attached to the operator's fingers.
	2.	Chrono-cycle graph	Modification of cycle graph in which recording is made using flash lights.

Symbols used in Process Chart

Symbol	Activity	Purpose for which it is used
○	Operation	It indicates the main steps in a process, method of procedure, usually the part, material or product concerned which is modified or changed during the operation.
→	Transport	It indicates movement of workers, material or equipment from place to place.
□	Inspection	It indicates any type of inspection, check, measurement, visual scrutiny for quality and/or quantity.
D	Temporary Storage or delay	It indicated a delay in the sequence of events.
▽	Storage	It indicates a controlled storage in which material is received into or issued from stores under some form of authorization or an item is retained for reference purpose.

SELECTED RECORDING TECHNIQUES

The following are the selected recording techniques:

(a) Outline Process Chart
(b) Flow Process Chart
(c) Two-Handed Process Chart
(d) Multiple Activity Chart

(a) Outline Process Chart. An outline process chart is a flow diagram showing only the activities, "Operations" and "inspection".

(b) Flow Process Chart. A flow process chart is a process chart which shows the sequence of flow of all activities which occur while producing a product/component or executing a procedure. The flow process chart can be classified into three types as listed below.

1. Flow Process Chart (Material type)
2. Flow Process Chart (Man type)
3. Flow Process Chart (Equipment type)

Material type shows the sequence of flow of materials of a product/component while manufacturing/servicing it.

Man type shows the movement of employees related to production/inspection of a product.

Equipment type shows the sequence of usage of equipments.

(c) Two-Handed Process Chart. Two-handed process chart records the sequence of activities performed by both hands of an operator side by side. This chart is very much useful to analyze the activities of the operator and come out with an improved method of performing the integrated task of importance.

(d) Multiple Activity Chart. In many situations, certain facilities/machines/equipments will be managed by a single individual or by a group of individuals. A multiple activity chart is a pictorial representation of activities of individuals and associated facilities/machines/equipments simultaneously on a common time scale.

EXAMINE STEP

This is the most important step in method study. This step aims:

- ✓ To eliminate the activity altogether if it is unnecessary
- ✓ To combine it with other activities
- ✓ To change the sequence of activities so that work delay is reduced
- ✓ To reduce the work content or time consumption.

TIME STUDY

The time study is considered to be one of the most-widely used means of work-measurement. Basically, by using time study, an analyst will be taking a small sample of a single worker's activity and using it to derive a standard for tasks of that nature.

The steps of time study are as follows:

Step – 1: First select the job to be studied. Breakdown the work content of the job into smallest possible elements. Then inform the worker and define the best method.

Step – 2: Observe the time for appropriate number of cycles (such as 25 to 30)

Step – 3: Determine the average cycle time (CT)

$$CT = \frac{\text{Times}}{\text{No. of Cycles}}$$

Step – 4: Determine the normal time (NT)

$$NT = CT\ (PR)$$

Step – 5: Determine the standard time using the following formula

$$ST = NT\ (AF)$$

Where AF = $\dfrac{1}{1 - \%\ \text{Allowance}}$

AF being the allowed factor.

In step – 2, n can be calculated using the following formulas.

$$n = \frac{Z^2\left[n_1 \sum x^2 - (\sum x)^2\right]}{h^2 (\sum x)^2}$$

Where, n_1 = Preliminary sample size
x = recorded stopwatch times
h = half the precision interval in % (for example, if the precision interval is $\pm$ 5%, then h = 0.05)
z = the standard normal statistic for the desired confidence level.

PROBLEMS

Problem 1: In a welding shop, a direct time study was done on a welding operation. One inexperienced industrial engineer and one experienced industrial engineer conducted the study simultaneously. They agreed precisely on cycle time (shown below) but their opinion on rating the worker differed. The experienced engineer rated the worker 100% and the other engineer rated the worker 120%. They used a 19% allowance

Cycle Time (in minutes)	: 20	24	29	32
Number of Times Observed	: 2	1	1	1

From the above statement,

a) Determine the standard time using the experienced industrial engineer's worker rating.
b) Find the standard time using the worker rating of inexperienced industrial engineer.
c) Comment on the reliability of time study engineers.

Solution:

(a) Rating the worker at 100% by the experienced industrial engineer

Cycle Time (CT) $= \dfrac{20\text{x}2 + 24\text{x}1 + 29\text{x}1 + 32\text{x}1}{5}$
= 25 minutes

Normal Time (NT) = CT X PR
= 25 x 100%
= 25 minutes

Standard Time (ST) = (NT) x [1/(1-%A)]
= 25 x 1.23
= 30.75 minutes

(b) Rating the worker at 120% by the inexperienced industrial engineer

Cycle Time (CT) $= \dfrac{20\text{x}2 + 24\text{x}1 + 29\text{x}1 + 32\text{x}1}{5}$
= 25 minutes

Normal Time (NT) = CT X PR
= 25 x 120%
= 30 minutes

Standard Time (ST) = (NT) x [1/(1-%A)]
= 30 x 1.23
= 36.9 minutes

(c) Comment

The results in part (a) and part (b) show differences in normal time and standard time. The task of estimating performance rating of a worker requires certain experience. So, we can rely on the results obtained by the experienced industrial engineer. Rating exercise is an art. So, the consistency in rating skill can be improved by repeatedly seeing rating films and/or by attending short courses on performance rating.

Problem 2: A time study engineer has studied the time taken to machine crank shafts. He has taken 40 observations and these are summarized in the form of frequency distribution as shown below.

Time (in minutes)	20	21	22	23
Frequency	15	10	10	5

The performance rating of the operator machining the crank shaft is 110%. Find the standard time for machining the crank shaft by assuming allowance of 15%.

Solution:

Rating the operator machining the crank shaft 110%

Cycle Time (CT) = $\frac{20x15 + 21x10 + 22x10 + 23x5}{40}$

= 21.13 minutes

Normal Time (NT) = CT X PR
= 21.13 x 110%
= 23.24 minutes

Standard Time (ST) = (NT) x [1/(1-%A)]
= 23.24 x 1.18
= 27.42 minutes

Problem 3: The following data was collected form a time study Job during 40 hours work week. Determine the standard time per part.

Idle time = 20% Rating factor = 135%
Total parts produced = 300 Allowance for this work = 10%

Solution:

Total time of study = 40 hours
= 40 x 60 minutes
= 2400 minutes

Working time = 1 – idle time
= 1 – 20%
= 0.8

Performance rating = 135%
= 1.35

Normal Time = $\frac{\text{(Total time of study) x (Working time in \%) x (Performance rating)}}{\text{Total units produced}}$

$= \frac{2400 \times 0.8 \times 1.35}{300}$

= 8.46 minutes

Standard Time (ST) = (NT) x [1/(1-%A)]

= 8.64 x 1.11

= 9.6 minutes

Standard time per part = 9.6 minutes.

Problem 4: A work measurement study was conducted in a company for 8 hours and the following results were obtained. Determine the standard time for this task.

Idle time = 15% Rating factor = 120%

Total number of task = 320 Allowance time = 12% of Normal time.

Solution:

Total time of study = 8 hours

= 8 x 60 minutes

= 480 minutes

Working time = 1 – idle time

= 1 – 15%

= 0.85

Performance rating = 120%

= 1.2

Normal Time $= \frac{\text{(Total time of study) x (Working time in \%) x (Performance rating)}}{\text{Total units produced}}$

$= \frac{480 \times 0.85 \times 1.2}{320}$

= 1.53 minutes

Standard Time (ST) = (NT) x [1/(1-%A)]

= 1.53 x 1.21

= 1.85 minutes

Standard time per part = 1.85 minutes.

Problem 5: A time study of an assembly line worker in a car plant produced the following results, Cycle time of 2.5 minutes, worker performance rating of 95%, average allowance for the activity 10% of the job time. Calculate the standard time.

Solution:

Fist we have to calculate normal time, which is given by,

Normal Time = Average cycle time X Performance rating

= 2.5 x 95%

= 2.375

Standard Time = (NT) x [1/(1-%A)]

= 2.375 x 1.11 = 2.63 minutes

Standard Time = 2.63 minutes.

Problem 6: For a certain element of work, the basic time is established to be 20 seconds. If for three observations, a time study observer records ratings of 100, 125 and 80 respectively, on a '100-normal scale', what are the observed timings?

Solution:

(Observed time) X (Observed rating) = (Basic or Normal time) X (Standard rating)

Therefore, Observed time = $\frac{\text{(Basic or Normal time) X (Standard rating)}}{\text{Observed rating}}$

Basic or Normal time = 20 seconds

Standard rating = 100

For observation No. 1, Observed rating = 100

Therefore, Observed time = (20 X 100)/100 = 20 seconds

For observation No. 2, Observed time = (20 X 100)/125= 16 seconds

For observation No. 3, Observed time = (20 X 100)/80 = 25 seconds

Problem 7: 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 hors = (8 x 60) / 8 = 60 units

WORK SAMPLING

Work sampling is also a technique for establishing standard times for activities. This method was introduced by L.H.C. Tippett in 1934. This method is more suitable for analyzing group activities and repetitive activities which take longer duration.

If a given individual performs more than one activity, then the time standard for each activity may be computed using this method. In this method, the standards for these activities may be determined using the work sampling method.

The steps for the work-sampling method are listed below:

1. Perform the following preliminary tasks

    a) Select the job which is to be studied
    b) Inform the workers about the method study
    c) Prepare a detailed list of activities of the job

2. Decide the total duration of observations

    Total duration of observations = (No. of hours/shifts) X (No. of shifts per day) X (No. of days)

3. Determine the number of observations to be made

$$n^* = \frac{Zpq}{h^2}$$

where,

Z = Standard normal statistic at a given confidence level
p = Value of sample proportion
q = 1 – p
h = Half the precision interval (Half of the width of the confidence level)

This is only a rough estimate. As the study progresses, if the value of ***p*** is more than ***p* ± *h***, then again the value of n should be revised.

4. Prepare a tour schedule to take the specified number of observations over the specified time duration.

5. Record performance rating of the workers and their activities as per the schedules.

6. Determine the acceptable number of units produced during the period.

7. Compute the percentage of working on a given task using the following formula

$$\text{Percentage of working} = \frac{\text{Frequency of performance of a task}}{\text{Total number of observation}} \times 100$$

8. Determine the normal time

$$NT = \frac{(\text{Total time})\ (\%\text{ of working})\ \boldsymbol{PR}}{\text{No. of acceptable units produced}}$$

9. Determine the standard time

$$ST = NT \times AF$$

$$= NT\ \frac{1}{1 - \text{Percentage Allowance}}$$

PROBLEMS

Problem 1: A job consists of three work elements and all are performed by the same operator. An analyst conducted work sampling to determine the standard time for the job. The duration of the study is one shift with 400 minutes of effective time. The details of observations are summarized in the following table. The total number of acceptable units produced during the study period is 150 units. Determine the standard time by assuming allowance of 10%.

Work element No.	:	1	2	3
Frequency of Performance	:	70	80	50
Performance Rating	:	80%	120%	110%

Solution:

Total duration = 400 minutes

Total number of observations = 200

The calculations for determining normal time and standard time of each of the work elements are summarized in the following table.

Work element number	Percentage of working	Normal time (minutes)	Standard Time (minutes)
1	(70/200) x 100 = 35%	(400 x 0.35 x 0.8)/150 = 0.75	0.75/0.9 = 0.83
2	(80/200) x 100 = 40%	(400 x 0.40 x 1.2)/150 = 1.28	1.28/0.9 = 1.42
3	(50/200) x 100 = 25%	(400 x 0.25 x 1.1)/150 = 0.73	0.73/0.9 = 0.81
Total = 3.06			

The Standard time of the job = 3.06 minutes.

Problem 2: A job consists of four work elements and all are performed by the same operator. An analyst conducted work sampling to determine the standard time for the job. The duration of the study is one day with two shifts. Each shift has 420 minutes of effective time. The details of observations are summarized in the following table. The total number of acceptable units produced during the study period is 225 units. Determine the standard time by assuming allowance of 12%.

Work element No.	:	1	2	3	4
Frequency of Performance	:	50	90	75	85
Performance Rating	:	90%	150%	100%	115%

Solution:

Total duration = 420 x 2 minutes = 840 minutes

Total number of observations = 300 (50+90+75+85)

The calculations for determining normal time and standard time of each of the work elements are summarized in the following table.

Work element number	Percentage of working	Normal time (minutes)	Standard Time (minutes)
1	(50/300) x 100 = 16.67%	(840 x 0.17 x 0.9)/225 = 0.57	0.57 x 1.14 = 0.65
2	(90/300) x 100 = 30%	(840 x 0.3 x 1.5)/225 = 1.68	1.68 x 1.14 = 1.91
3	(75/300) x 100 = 25%	(840 x 0.25 x 1.0)/225 = 0.93	0.93 x 1.14 = 1.06
4	(85/300) x 100 = 28.33%	(840 x 0.28 x 1.15)/225 = 1.2	1.2 x 1.14 = 1.37
Total = 5 min			

The Standard time of the job = 5 minutes.

Problem 3: A Work sampling study showed that 20% of a work week of 48 hours was consumed by unavoidable delays. If each time a work sampling observations was made the operation was rated and the average of such ratings was 110%. If 100 units were produced by the operator in that period, calculate the standard time.

Solution:

Total time of study = 48 hours
= 48 x 60 minutes
= 2880 minutes

Working time in % = 80%
= 0.8

Average performance rating = 110%
= 1.1

Number of units produced = 100

Normal time $= \frac{2880 \times 0.8 \times 1.1}{100}$
= 25.34 minutes

Since allowance % is not given. Standard time per unit = Normal time

Standard time = 25.34 minutes

Problem 4: An industrial operation consists of the following observed times along with their performance ratings.

Element	A	B	C	D	E	F
Observed Time (minutes)	0.20	0.10	0.5	0.12	0.18	0.25
Frequency	80	85	90	75	85	90

Assuming rest and personal allowance as 15% and contingency allowance as 4% of the basic time, calculate standard time per piece.

Solution:

Normal time = Sum (Average time x Performance rating)

Element	Observed time (minutes)	Performance rating %	Normal time
A	0.20	80% = 0.8	(0.20 X 0.8) = 0.16
B	0.10	85% = 0.85	0.085
C	0.5	90% = 0.9	0.45
D	0.12	75% = 0.75	0.09
E	0.18	85% = 0.85	0.153
F	0.25	90% = 0.9	0.225
Total: 1.163			

Normal time = 1.163 minutes

Standard time = Normal time + Allowance time (as allowance is given % of normal time)
= 1.163 + 19% (1.163) = 1.384

Therefore, rest, personal + contingency = 15% + 4% = 19%

Standard time per piece = 1.384 minutes

Problem 5: A work study practitioner who conducted a work sampling study assesses the activity level of worker to be 70%. During the space of 8 hours working, this worker turns out 320 components. If the company policy is to inflate the normal time arrived at by work sampling study by 20%, what should be the allowed time per unit?

Solution:

Activity level as per work sampling study = 70%

Actual working time per shift of 8 hours = 8 x (70/100) = 5.6 hours

Normal time taken per unit = (5.6 x 60) / 320 = 1.05 minutes

Allowed time = 1.05 x (120/100) = 1.26 minutes

Problem 6: Calculate the standard time per article produced from the following data obtained by a work sampling study.

Total no. of observations = 2500 No. of working observations = 2100
No. of units produced in 100 hours duration = 6000 numbers
Proportion of manual labour = 2/3 Proportion of machine time = 1/3
Observed rating factor = 115% Total allowances = 12% of normal time

Solution:

Actual working time in the duration of 100 hours = 100 x (2100/2600) = 84 hours

Time taken per article = (84 x 60)/6000 = 0.84 minutes

Observed manual labour time per article = 0.84 x (2/3) = 0.56 minute

Observed machine time per article = 0.84 x (1/3) = 0.28 minutes

Normal labour time per unit = Observed time/unit X rating factor
= 0.56 x 1.15 = 0.644 minutes

Standard labour time per unit = 0.644 + (12/100 x 0.644) = 0.721 minutes

Standard time per unit of article produced = 0.721 + 0.28 = 1 minute

Meaning of Work Measurement

Work Measurement is the process of determining the **standard time** required for a qualified worker to complete a specific task using a prescribed method under normal working conditions.

It helps to find *How long should this job take?*

Objectives of Work Measurement

1. To set standard time for jobs
It helps determine the time a qualified worker should take to complete a task. This standard becomes the basis for planning and control.

2. To help in production planning and scheduling
Knowing job times makes it easier to prepare production schedules. It ensures smooth workflow and timely completion of orders.

3. To estimate labour requirements
Work measurement shows how many workers are needed for a job. This prevents both labour shortage and excess manpower.

4. To fix wage incentive schemes
Standard times are used to design bonus and incentive plans. Workers are rewarded fairly for higher efficiency.

5. To improve productivity
By studying time taken, unnecessary delays can be reduced. This leads to better output with the same resources.

6. To compare alternative methods of work
Different methods of doing a job can be evaluated based on time taken. The most efficient method can then be selected.

Importance of Work Measurement

1. Helps in cost estimation
Accurate job times help calculate labour cost per unit. This supports pricing and budgeting decisions.

2. Assists in line balancing
Work measurement ensures equal distribution of work among workers. This reduces bottlenecks and idle time.

3. Improves labour utilization
It ensures workers are neither overburdened nor idle. Proper utilization increases overall efficiency.

4. Reduces idle time
By identifying delays and inefficiencies, corrective steps can be taken. This improves productive working hours.

5. Provides a basis for performance evaluation
Worker performance can be compared with standard time. This helps in identifying training needs and rewarding efficiency.

6. Supports capacity planning
Standard times help calculate the production capacity of machines and workers. This aids in meeting future demand.

Uses of Work Measurement

1. Fixing standard time
It establishes the time required for completing a job under normal conditions. This becomes a reference for future work.

2. Determining manpower needs
It helps calculate the number of workers required for production targets. This avoids overstaffing or understaffing.

3. Planning production schedules
Knowing job times helps prepare realistic production plans. It ensures on-time delivery of products.

4. Controlling labour cost
Standard time helps monitor whether labour time is being used efficiently. This prevents unnecessary labour expenses.

5. Setting incentive wage plans
It forms the basis for performance-based pay systems. Efficient workers can earn rewards for higher output.

Techniques (Methods) of Work Measurement

1. Time Study (Stopwatch Method)

- Measures time taken for each element of a job
- Best for **repetitive tasks**
  Most widely used method

Steps in Time Study:

1. Select the job
2. Break the job into elements
3. Record time for each element
4. Determine average time
5. Apply performance rating
6. Add allowances (fatigue, delay, personal needs)
7. Fix **standard time**

2. Work Sampling

- Uses **random observations** to determine how workers spend their time
- Suitable for **non-repetitive jobs**
- Less costly than time study

3. Predetermined Motion Time System (PMTS)

- Uses previously established time values for basic human motions (reach, move, grasp, etc.)
- Examples: **MTM (Methods Time Measurement), MOST**
- No stopwatch needed

4. Standard Data Method

- Uses **previously collected time data** for similar tasks
- Speeds up time estimation

Advantages of Work Measurement

1. Improves Productivity
By identifying the standard time for tasks, unnecessary delays can be reduced. This helps increase output with the same resources.

2. Better Production Planning
Accurate time standards help in preparing realistic production schedules. This ensures smooth workflow and timely completion of work.

3. Effective Labour Utilization
Work measurement helps assign the right amount of work to each worker. This avoids overloading or underutilizing employees.

4. Basis for Incentive Schemes
Standard time allows fair performance comparison. Workers can be rewarded based on efficiency and output.

5. Cost Control
It helps in estimating labour cost per unit accurately. This supports budgeting and cost reduction efforts.

6. Line Balancing
Ensures equal distribution of tasks among workers or machines. This reduces bottlenecks and idle time.

7. Performance Evaluation
Actual performance can be compared with standard time. It helps in identifying efficient workers and training needs.

8. Supports Method Improvement
By measuring time, inefficient methods can be detected. Better and faster work methods can then be adopted.

Limitations of Work Measurement

1. Not Suitable for All Jobs
It is difficult to apply in creative or non-repetitive tasks. Such jobs do not have a fixed time pattern.

2. Worker Resistance
Employees may feel pressured or fear job cuts. This can lead to lack of cooperation during studies.

3. Time-Consuming Process
Conducting time studies and analysis takes considerable time. It may delay decision-making initially.

4. Requires Skilled Analysts
Accurate measurement needs trained personnel. Errors in study can lead to wrong standards.

5. May Ignore Human Factors
Factors like motivation, morale, and personal problems are hard to measure. This can affect the accuracy of standards.

6. Cost of Implementation
Conducting studies and training staff involves expenses. Small firms may find it costly.

7. Risk of Unrealistic Standards
If allowances are not properly added, standards may be too tight. This can cause worker dissatisfaction and fatigue.

Basis	**Time Study**	**Work Sampling**	**PMTS (Predetermined Motion Time System)**	**Standard Data Method**
Meaning	Measures time taken for each element using a stopwatch	Uses random observations to find how time is spent	Uses pre-set time values for basic human motions	Uses previously recorded time data for similar jobs
Nature of Job	Suitable for repetitive jobs	Suitable for non-repetitive or irregular jobs	Suitable for short, repetitive manual tasks	Suitable for similar and repeated operations

Use of Stopwatch	Yes	No	No	No
Accuracy Level	High if done properly	Moderate	Very high	Depends on past data accuracy
Time Required to Conduct Study	Time-consuming	Less time compared to time study	Initial setup takes time	Very quick once database is available
Skill Requirement	Requires trained analyst	Less skill required	Highly skilled and trained experts needed	Moderate skill needed
Cost of Study	Moderate	Low	High (due to analysis and system setup)	Low after data is prepared
Best Used When	Job cycle is short and repetitive	Many activities occur randomly	Precise time standards are required	Similar work has been measured earlier
Example	Assembly line operation	Supervisor checking worker activities	Measuring hand movements in small assembly work	Using past data for drilling operations

Time Study uses a stopwatch, Work Sampling uses observation, PMTS uses motion data, and Standard Data uses past records.

UNIT – II

FACILITY OR PLANT LOCATION

Plant location may be understood as the function of determining where the plant should be located for maximum operating economy and effectiveness. The selection of a place for locating a plant is one of the problems, perhaps the most important, which faced by an entrepreneur while launching a new enterprise.

A selection on pure economic considerations will ensure an easy and regular supply of raw materials, labour force, efficient plant layout, proper utilization of production capacity and reduced cost of production. An ideal location may not, by itself, guarantee success: but it certainly contributes to the smooth and efficient working of an organization.

A bad location, on the other hand, is a severe handicap for any enterprise and it finally bankrupts it. It is, therefore, very essential that utmost care should be exercised in the initial stages to select a proper place. Once a mistake is made in locating a plant, it becomes extremely difficult and costly to correct it, especially where large plants are concerned.

Business systems utilize facilities like, plant and machineries, warehouses, etc., while performing the task of producing products/services. A proper planning of these facilities would definitely reduce their cost of operation and maintenance.

One of the most important strategic decisions made by companies engaged either in manufacturing goods or in providing services is where to locate their operations. All firms need to address the location decision because location greatly affects both fixed and variable costs. Also, it has a major impact on the overall profitability of the firm.

Plant location decisions are very important because they have direct bearing on factors like, financial, employment and distribution patterns. In the long run, relocation of plant may even benefit the organization. But, the relocation of the plant involves stoppage of production, and also cost for shifting the facilities to a new location. In addition to these things, it will introduce some inconvenience in the normal functioning of the business.

Hence, at the time of starting any industry, one should generate several alternate sites for locating the plant. After a critical analysis, the best site is to be selected for commissioning the plant. Location of warehouses and other facilities are also having direct- bearing on the operational performance of organizations.

What is Facility or Plant Location?

Facility location or plant location is the process of determining a geographical site for a firm’s operations achieving maximum operating economy and effectiveness.

Reasons for plant location study. The following events are quite common in any business venture.

- Establishment of a new venture.
- Expansion of existing business.
- Significant change in existing demand, supply and marketing locations.
- Significant change in the cost structure.
- Government policies.

Because of these events, an organization will be keen in additional or alternate sites for its production activities. So, the plant location becomes an important decision which in turn influences plant layout and facilities needed. Also, it influences capital investment and operating costs.

FACTORS INFLUENCING PLANT LOCATION

The factors which influence plant location can be classified into general factors and specific factors.

General factors

1. Availability of land for present and future needs and cost of land and land development and building etc.
2. Availability of inputs such as labour, raw materials, etc.
3. Closeness to the market places.
4. Stability of demand.
5. Availability of communication facilities.
6. Availability of necessary modes of transportation like road, rail, airport and water ways.
7. Availability of infrastructure facilities such as power, water, financial institutions, banks, etc.
8. Disposal of waster and effluent and their impact on the environment.
9. Government support, grant, subsidy, tax structure.
10. Availability of housing facilities and recreational facilities.
11. Security, culture of society.
12. Fuel cost.

Specific factors

A multinational company, desiring to set up plant should consider the following aspects in addition to the normal factors.

1. The economic stability of the country and the concern of the country towards outside investments are to be considered.
2. The success of operation of the factory depends on the cultural factors, language and cultural differences, which can present operating, control and even policy problems. Units of measurement are also very important in international business.
3. Analysis must be based on the factors like wage rate, policy, duties, etc.
4. The company can set up joint ventures with any leading local giants that will solve many operational problems.

STEPS IN LOCATION

To be systematic, in choosing a plant location, the entrepreneur would do well to proceed step by step, the steps being;

(a) Within the country or outside;
(b) Selection of the region;
(c) Selection of the locality or community;
(d) Selection of the exact site.

(a) Deciding on Domestic or International Location

The first step in plant location is to decide whether the facility should be located domestically or internationally. A few years ago, this factor would have received little consideration. But with increasing internationalization of business, the issue of home or foreign country is gaining greater relevance. If the management decides on foreign location, the next logical step would be to decide upon a particular country for location.

(b) Selection of Region

The selection of a particular region out of the many natural regions of a country is the second step in plant location. The following factors influence such selection:

(i) Availability of Raw Materials:

As a manufacturing unit is engaged in the conversion of raw materials into finished products, it is very essential that it should be located in a place where the supply of raw materials is assured at minimum transport cost.

Nearness to raw materials offers such advantages as:

- Reduced cost of transportation;
- Regular and proper supply of materials uninterrupted by transportation breakdowns and
- Savings in the cost of storage of materials.

(ii) Nearness to the Market

Since goods are produced for sale, it is very essential that the factory should be located near their market. A reduction in the cost of transporting finished goods to the market; the ability to adjust the production programme to suit the likes and dislikes of consumers; the ability to render prompt service to the consumers, provide after-sale services and execute replacement orders without delay - these are some of the advantages that accrue to the entrepreneur if he establishes his factory near his market.

(iii) Availability of Power

Power is essential to move the wheels of an industry. Coal, electricity, oil and natural gas are the sources of power. Where coal is the source of power, as in the case of the iron and steel industry, the factory has to be located near the coal fields. Examples of such industries are: the iron and steel industry in Germany, Pennsylvania, in the U.S.A. and Jamshedpur in India.

(iv) Transport facilities

While making a study of a location, an entrepreneur considers the question of the availability of transport facilities. Transport facilities are essential for bringing raw materials and men to the factory and for carrying the finished products from the factory to the market. A place, which is well connected by rail, road and sea, is ideal for a plant location. It may be said that industry follows transportation.

(v) Suitability of Climate

The climate has its own importance in the location of a plant because of two reasons. There are certain industries which, because of the nature of their production, require particular climatic conditions; for example, humid climate for cotton textiles and jute. Such industries have to be located in places where humid climatic conditions are available.

(vi) Government Policy

The influence of Government policies and programmes on plant location is apparent in every country, particularly in planned economies like ours. In the name of balanced regional development, many backward regions in India have been selected for the location of new industries, which would generate the regions economy and on a larger canvas, the national economy.

The Government of India has been influencing plant location in a number of ways. Some of these are:

- Licensing policy;
- Freight rate policy;
- Establishing a unit in the public sector in a remote area and developing it to attract other industries;
- Institutional finance arid government subsidies.

(vii) Competition Between States

States vie with each other to attract new industries. Various states offer investment subsidies and sales tax exemptions to new units. The incentives may not be of big help to big sized plants. But for small and medium-sized plants, the incentives do matter. The owners of these plants certainly consider incentive in selection of region.

(c) *Selection of Community*

Selecting a particular locality or community in a region is the third step in plant location. The selection of a locality in a particular region is influenced by the following factors:

(i) Availability of Labour

Despite the talk of mechanization and automation, the importance of labour on the industrial side has not been completely lost. Labour is an important factor in the production of goods. An adequacy of labour supply at reasonable wages is very essential for the smooth and successful working of an organization. The development of the plantation industry in India has been due to, among other things, the availability of adequate labour at cheap rates.

(ii) Civic Amenities for Workers

Besides good working conditions inside the factory, the employees require certain facilities outside it. Recreation facilities such as clubs, theatres and parks must be provided for the employees. They require schools for their children. A place which abounds in all these facilities will naturally be preferred to another place which lacks them.

(iii) Existence of Complementary and Competing Industries

The existence of complementary industries is favourable to the location of industries because an industrial unit, in association with other units, can get the following benefits:

- An industrial unit, in collaboration with other similar units, can secure materials on better terms than it can do it by itself.
- The concentration of similar industries at one place improves the labour market, both for the employer and the employee.
- In specialized centers, banks become familiar with the requirements of the industry. This makes the granting of loans easy.
- A group of plants will attract a variety of ancillary plants such as *foundries,* machine shops tool makers and the like.
- The new units established in the same locality will share the reputation built up by the existing units.

(iv) Finance and Research Facilities

Adequate capital is essential for the successful working of any organization. A place where facilities for raising capital are available attracts new industries. This is particularly true in developing countries, where capital is not available uniformly throughout the country. In advanced countries, the case is different because, in such countries, capital is distributed uniformly.

(v) Availability of Water and Fire-fighting Facilities

Some industries require plentiful supply of water for their working. Water maybe obtained from the local authority, from the canal, from a river or a lake, or by sinking a bore well. In any case, the supply of water should be considered with respect to its regularity, cost and purity.

Industrial units are exposed to fire hazards. A fire may break out either from within or from neighboring units. In either case, adequate fire-fighting facilities must be available.

(vi) Local Taxes and Restrictions

Local authorities collect charges for the supply of water, electricity and other facilities, They also collect various taxes from industrial units. They impose restrictions on the location of new units in the public interest.

(viii) Personal Factors

There are entrepreneurs, especially small industrialists, who locate their plants purely on personal grounds, disregarding economic considerations. Such locations sometimes totally disapprove the many current theories of plant location.

(d) Selection of the Site

The selection of an exact site in a chosen locality is the fourth step in plant location. This selection *is* influenced by the following considerations:

(i) Soil, Size and Topography

For factories producing engineering goods, the fertility or otherwise of the soil may not be a factor influencing plant location. But for agro-based industries, a fertile soil is necessary for ensuring a strategic plant location.

The area of the land should He such as to accommodate not only the existing manufacturing facilities, but offer scope for future expansion programmes as well. Besides the area, the cost of land deserves consideration.

The topography of the place deserves consideration to sortie extent. A hilly, rocky and rough terrain is unsuitable for a plant location because a great deal of expenditure has to be incurred to level it.

(ii) Disposal of Waste

The problem of the disposal of effluents is common to many industries, particularly chemical, sugar, steel and leather industries and breweries. The site selected for the location of the plant should have provision for the disposal of waste. There must be enough vacant land for the dumping of solid waste.

LOCATION MODELS

Various models are available which help identify a near location. The most popular models are:

1. Factor Rating Method.
2. Point Rating Method.
3. Quantitative Factor Analysis.
4. Break-even Analysis.

1. Factor Rating Method

These are many factors, both qualitative and quantitative to be considered in choosing a location. Some of these factors are more important than others and hence managers can use weightings to make the decision process more objective.

2. Point Rating Method

The significance of point rating method is the relative importance of tangible cost factors when compared to intangible cost factors. Only intangible factors are assigned points. However, evaluation is done to know whether the difference between the intangible factor is worth between tangible factors of the competing locations.

3. Qualitative Factor Analysis

In economic criteria (costs, revenues or profits) alone are not sufficiently influential to determine the location alternative, a system of assigning weights to qualitative factors and quantitative factors separately and combining them to arrive at a total score is useful in making the location decision. This approach is known as qualitative factor analysis method.

4. Break-even Analysis

Locational break-even analysis is the use of cost-profit-volume analysis to make an economic comparison of location alternatives. By identifying fixed and variable costs and drawing the graphs of quantity versus total costs for each location, we can determine the location which has the lowest cost over a range of volume produced. Locational break-even analysis can be done mathematically or graphically. The locational break-even analysis provides the range of volume over which each location is preferable.

Break even analysis.

- The objective of any location problem is to maximize profit.
- In comparing several potential locations on an economic basis, only revenues and costs need to be considered. These will vary from one location to another.
- An economic analysis can be done by using break-even analysis.
- For any business organization, for manufacturing a product, there are two major costs, namely, fixed cost and variable cost.
- The sum of these two costs is known as the total cost of the product.
- The fixed cost is constant irrespective of production volume of a product which is manufactured by the organization.
- But, the variable cost is a function of the production volume of the product.
- For low volume of production, the sales revenue of the product will be less than the total cost and after reaching a certain level of production volume, it will be more than the total cost.
- The point at which the sales revenue becomes equal to the total cost is known as the break even point. At this point, there is no loss or gain to the organization. This analysis is termed as break even analysis.
- This analysis is termed as break even analysis.

TC represents the Total Cost, and FC represents the Fixed Cost.

Total Cost (TC) = FC + Variable Cost

Where, B - Intersection point of TC and sales curves (no loss or no gain situation)
A - Break even sales point
C - Break even quantity/Break even point (B.E.P.)

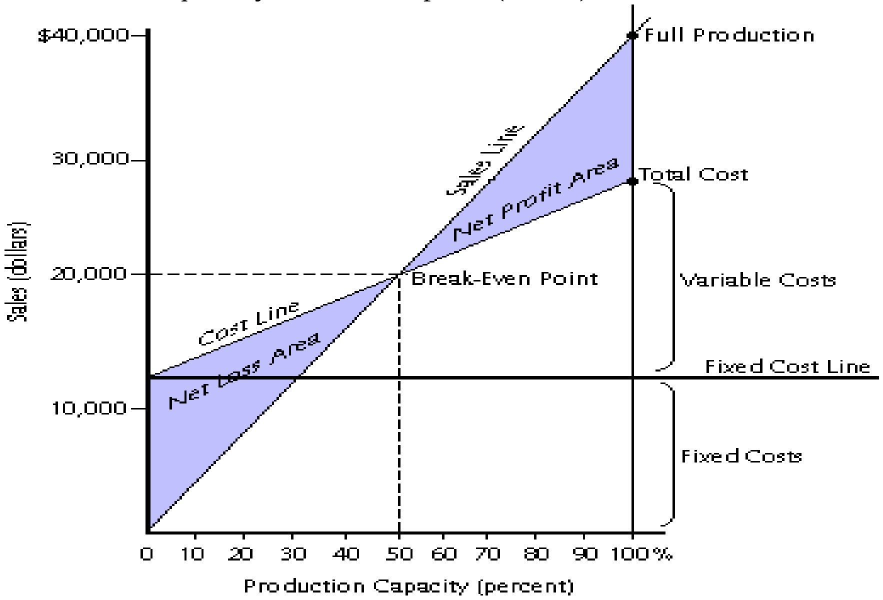


Figure 1
A Break-Even Graph

The formula for the breakeven point (B.E.P) is given below. Application of this formula to arrive at the make or buy decision is illustrated with some examples.

$$\text{B.E.P.} = \frac{\text{FC}}{\text{Selling price - Variable cost}}$$

A generalized methodology for locational break-even analysis is given below.

1. Determine all relevant costs for each of the locations.
2. Classify the costs for each location into annual fixed costs (FC) and variable cost per unit (VC).
3. Plot the total costs associated with each location on a single chart of annual cost versus annual volume.
4. Select the location with the lowest total annual cost (TC) at the expected production volume.

PROBLEMS

Problem 1: A manufacture of motor cycles buy side box at RS. 240each. in case he makes it himself , the fixed and variable costs would be RS.300 000 and RS. 90per side box, respectively. Should the manufacture make or buy the side box if there is a demand for 2500 side boxes?

Solution:

Selling price/unit (SP) = Rs. 240
Variable cost/unit (VC) = Rs. 90
Fixed cost (FC) = Rs. 3,00,000

$$\text{B.E.P.} = \frac{3{,}00{,}000}{240 - 90} = 2000 \text{ units}$$

Problem 2: There are three alternatives available to meet the demand of a particular product. They are as follows:

1. Making the product using Process A.
2. Making the product using Process B.
3. Buying the product.

The details are follows:

Cost Elements	Making using Process A	Making using Process B	Buy
Fixed Cost/year (Rs.)	100,000	300,000	-----
Variable cost/unit (Rs.)	75	70	-----
Purchase price/unit (Rs.)	-----	-----	80

The annual demand for the product is 10,000 units.

1. Should the company make the product using Process A or Process B, or buy it?
2. At what annual volume should the company switch from buying to making using Process A?
3. At what annual volume should the company switch from Process A to Process B?

Solution:

1. *Compute the annual cost for each alternative.*

Annual cost of process A = FC + (VC x Volume)
= 100,000 + (75 x 10,000) = Rs. 850,000

Annual cost of process B = FC + (VC x Volume)
= 300,000 + (70 x 10,000) = Rs. 1,000,000

Annual cost of buying = Purchase price/unit x Volume
= 80 x 10,000 = Rs. 800,000

Since, the annual cost of buy option is minimum among all the alternative costs, the company should buy the product.

2. *Let Q be the volume at which the company switches from buying to making, using process A*

Hence, total annual cost of process A $\leq$ Total annual cost of buying

$$100{,}000 + (Q \times 75) \leq Q \times 80$$
$$100{,}000 \leq 5Q$$
$$5Q \geq 100{,}000$$
$$Q \geq 20{,}000 \text{ units}$$

Thus, if the volume of production is more than 20,000 units the company should switch from buying to making option using process A.

3. *Let Q be the volume at which the shift from making using process A to making using process B is preferable.*

Total annual cost of process A $\geq$ Total annual cost of process B

$$100{,}000 + 75Q \geq 300{,}000 + 70Q$$
$$5Q \geq 200{,}000$$
$$Q \geq 40{,}000 \text{ units}$$

Thus, if the production volume is more than 40,000 units, the company can shift from process A to process B.

Problem 3: Potential locations A, B and C have cost structures shown below for manufacturing a product expected to sell for 2700 per unit. Find the most economical location for an expected volume of 2000 units per year.

Site	Fixed Cost/Year (Rs.)	Variable Cost/Unit (Rs.)
A	6,000,000	1500
B	7,000,000	500
C	5,000,000	4000

Solution:

For each plant find the total cost using the following formula:

Total cost (TC) = Fixed cost (FC) + (Variable cost x Sales Volume)

Total cost at location A = 6,000,000 + (1500 x 2000) = 9,000,000

Total cost at location B = 7,000,000 + (500 x 2000) = 8,000,000

Total cost at location C = 5,000,000 + (4000 x 2000) = 13,000,000

From the above calculations it is clear that the cost of location B is minimum. Hence, it is to be selected for locating the plant.

In the increasing order of the production volume the switch over from one site to another takes place as per the following order.

Site C to Site A to Site B

Let Q be the volume at which the switch from Site C to Site A

Total cost of Site C $\geq$ Total cost of Site A

$$TC_c \geq TC_A$$
$$FC + (VC \times SV) \geq FC + (VC \times SV)$$
$$5{,}000{,}000 + 4000Q \geq 6{,}000{,}000 + 1500Q$$
$$4000Q - 1500Q \geq 6{,}000{,}000 - 5{,}000{,}000$$
$$2500Q \geq 1{,}000{,}000$$
$$Q \geq \frac{1{,}000{,}000}{2500}$$
$$Q \geq 400 \text{ units}$$

If the production volume is more than 400 units, the company can shift from Site C to Site A

Let Q be the volume at which the switch from Site A to Site B

Total cost of Site A $\geq$ Total cost of Site B

$$TCA \geq TCB$$
$$FC + (VC \times SV) \geq FC + (VC \times SV)$$
$$6{,}000{,}000 + 1500Q \geq 7{,}000{,}000 + 500Q$$
$$1500Q - 500Q \geq 7{,}000{,}000 - 6{,}000{,}000$$
$$2000Q \geq 1{,}000{,}000$$
$$Q \geq \frac{1{,}000{,}000}{1000}$$
$$Q \geq 1000 \text{ units}$$

If the production volume is more than 1000 units, the company can shift from Site A to Site B

Problem 4: Location A would result in fixed costs of \$3, 00,000 with variable costs of \$ 63 per unit and revenues of \$ 68 per unit. Annual fixed costs at location B are \$ 8, 00,000 with variable costs of \$ 32 per unit and revenue of \$ 68 per unit. Sales volume is estimated to be 25,000 units/year. Which location is most attractive?

Solution:

Total cost of production at location A = FC + (VC x SV)
= 300,000 + (63 x 2500) = Rs. 1,875,000

Total cost of production at location B = FC + (VC x SV)
= 800,000 + (32 x 2500) = Rs. 1,600,000

Total revenues at location A = Revenues X Sales Volume
= 68 x 2500 = Rs. 1,700,000

Total revenues at location B = Revenues X Sales Volume
= 68 x 2500 = Rs. 1,700,000

Total profit at Location A = Total revenue at location A – Total cost of production at location A
= 1,700,000 – 1,875,000 = - Rs. 175,000

Total profit at Location B = Total revenue at location B – Total cost of production at location B
= 1,700,000 – 1,600,000 = Rs. 100,000

Since location B gives a profit of Rs. 100,000 as compare to loss of Rs. 175,000 at location A. Hence location B is most attractive.

Problem 5: Potential locations A, B and C have the cost structures shown for producing a product expected to sell at Rs. 100 per unit. Find the most economical location for an expected volume of 2000 units/year. Also determine the range of annual volume of production for which, each of the locations A, B and C would be most economical.

Location	**Fixed Cost/Year (Rs.)**	**Variable Cost/Unit (Rs.)**
A	25,000	50
B	50,000	25
C	80,000	15

Solution:

For each plant find the total cost using the following formula:

Total cost (TC) = Fixed cost (FC) + (Variable cost x Sales Volume)

Total cost at location A = 25,000 + (50 x 2000) = 125,000

Total cost at location B = 50,000 + (25 x 2000) = 100,000

Total cost at location C = 80,000 + (15 x 2000) = 110,000

From the above calculations it is clear that the cost of location B is minimum. Hence, it is to be selected for locating the plant.

In the increasing order of the production volume the switch over from one site to another takes place as per the following order.

Site A to Site C to Site B

Let Q be the volume at which the switch from Site A to Site C

$$\text{Total cost of Site A} \geq \text{Total cost of Site C}$$
$$TCA \geq TCC$$
$$FC + (VC \times SV) \geq FC + (VC \times SV)$$
$$25{,}000 + 50Q \geq 80{,}000 + 15Q$$
$$35Q \geq 55{,}000$$
$$Q \geq \frac{55{,}000}{35}$$
$$Q \geq 1571 \text{ units}$$

If the production volume is more than 1571 units, the company can shift from Site A to Site C

Let Q be the volume at which the switch from Site C to Site B

$$\text{Total cost of Site C} \geq \text{Total cost of Site B}$$
$$TCC \geq TCB$$
$$FC + (VC \times SV) \geq FC + (VC \times SV)$$
$$80{,}000 + 15Q \geq 50{,}000 + 25Q$$
$$25Q - 15Q \geq 80{,}000 - 50{,}000$$
$$Q \geq \frac{30{,}000}{10}$$
$$Q \geq 3000 \text{ units}$$

If the production volume is more than 3000 units, the company can shift from Site A to Site C

PLANT LAYOUT

Plant layout is the arrangement of production machinery, machine tools, work centers and additional facilities and activities, e.g., inspection, handling of material, storage and transport, for the purpose of securing efficiency in manufacturing products or supplying consumer services. A bad plant layout would lead to loss of efficiency, waste of time and energy, inconveniences and botherations in the actual operations and in the process of production. A good layout ensures orderly and efficient arrangement of work facilities and personnel.

Plant layout has been defined as: *"A technique of locating machines, processes and plant services within the factory in order to secure the greatest possible output of high quality at the lowest possible total cost of production."*

The objectives of plant layout are:

- Minimize investment in equipment.
- Minimize overall production time.
- Utilize existing space most effectively.
- Provide for employee convenience, safety and comfort.
- Maintain flexibility of arrangement and operation.
- Minimize materials-handling cost.
- Facilitate the manufacturing process.
- Facilitate the organizational structure.

FACTORS AFFECTING PLANT LAYOUT

1. **Type of Production:** The layout for an engineering unit will be quite different from that of a flour factory.
2. **Production System:** The plant layout in a continuous production system will be totally different from that under the intermittent production system.
3. **Scale of Production:** The plant layout and material handling equipment in the large-scale organization will be different from that in the small-scale manufacturing activity.
4. **Type of Machines:** The use of single-purpose and multipurpose machines substantially affects the plant layout. Similarly noisy and vibrating machines require special attention in the plant layout decision.
5. **Type of Building Facilities:** The plant layout in a single-storey building will be different from that in a multi-storey building.
6. **Availability of Total Floor Area:** The allocation of space for machines, work-benches, sub-stores, aisles, etc. is made on the basis of the available floor area. Use of overhead space is made in-case of shortage of space.
7. **Possibility of Future Expansion:** Plant layout is made in the light of the future requirements and installation of additional facilities.
8. **Arrangement of Material Handling Equipment:** The plant layout and the material handling services are closely related and the latter has a decisive effect on the arrangement of production process and plant services.

CLASSIFICATION OF LAYOUT

A layout essentially refers to the arranging and grouping of machines which are meant to produce goods. Grouping is done on different lines. The choice of a particular line depends on several factors. Layouts can be classified into the following four categories.

1. Process Layout or Functional Layout
2. Product layout
3. Group layout (Combination layout)
4. Fixed position layout

1. PROCESS LAYOUT

Under Process layout, all machines of the same kind, used in a given labour operation, and grouped together in one place. Thus in an engineering factory all types of lathes are placed together. It is the layout by operation for job lot manufacture. Process layout is generally adopted for job order industries like engineering, printing, etc. in which the requirements of every job are different from every other job, making it impossible for materials to flow uniformly through all the processes.

Advantages of Process Layout:

1. Machines are better utilized: fewer machines are required.
2. A high degree of flexibility in terms of task allocation to machines exists.
3. Comparatively low investment in machine is required.
4. The diversity of tasks offers a more interesting and satisfying occupation for the operator.

Limitations of Process Layout:

1. Material handling cost will be high.
2. Production planning and control systems are more involved.
3. Throughput time is longer.
4. Large amounts of in-process inventory will result.
5. Space and capital are tied up by work in process.
6. Higher grades of skill are required.

2. PRODUCT LAYOUT

Under product layout, all the machines of each kind needed for balanced operations on a given production or assembly line are located adjacent to it in labour operation sequence. Product Layout is suitable in continuous flow and mass production industries. It involves a continuous flow of materials through the required processes in a definite sequence.

Advantages of Product Layout:

1. The flow of product will be smooth and logical in flow lines.
2. In-process inventory is less.
3. Throughput time is less.
4. Material handling cost is minimum.
5. Operators need not be skilled.
6. Simple production planning and control systems are possible.
7. Less space is occupied by work in transit and for temporary storage.

Limitations of Product Layout:

1. A breakdown of one machine in a product line may cause stoppages of machines in the downstream of the line.
2. A Change in product may require major alterations in the layout.
3. The line output is decided by the bottleneck machine.
4. Comparatively high investment in equipments is required.

Difference between Process & Product Layout

Process Layout	Product Layout
1. Reduction in the investment on machines as they are general purpose machines	1. Mechanization of materials handling and consequent reduction in materials handling cost.
2. Greater flexibility in production	2. Avoidance of bottlenecks
3. Better and more efficient super vision possible through specialization	3. Economy in manufacturing time
4. Better scope for expansion	4. Better production control
5. Better utilization of men and machines	5. Less floor area required per units production
6. Easier to handle breakdown of equipment by transferring work to another machine or station	6. Minimum investment in work-in-progress
7. Full utilization of the plant	7. Early detection of mistakes or badly produced items
8. Greater incentive to individual workers to raise the level of their performance	8. Greater incentives to group of workers to raise their performance

3. GROUP LAYOUT

A 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, the m-machines and n-components will be divided into distinct number of machine-component cells such that all the components assigned to a cell are almost processed within that cell itself.

Advantages: Group technology layout can increase the items given in List A and it can decrease the items given in List B.

List A
1. Component Standardization and rationalization
2. Reliability of estimates
3. Effective machine operation
4. Productivity
5. Costing accuracy
6. Customer services
7. Order potential

List B
1. Planning effort
2. Paper work
3. Setting time
4. Down time
5. Work in progress
6. Work movement
7. Overall production times
8. Finished part stock
9. Overall cost

Limitations: 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.

4. FIXED POSITION LAYOUT

As the term itself implies, the fixed position Layout involves the movement of men and machines to the product which remains stationary. In this type of layout, the material or major component remains in a fixed location and tools, machinery and men as well as other pieces of materials are brought to this location. The movement of men and machines to the product is advisable because the cost of moving them would be less than the cost of moving the product which is very bulky.

Advantages of Fixed Position Layout:

1. Men & machines can be used for a wide variety of operations producing different products.
2. The investment on layout is very small.
3. The worker identifies himself with the product and takes pride in it when the work is completed.
4. The high cost and difficulty in transporting bulky product are avoided.

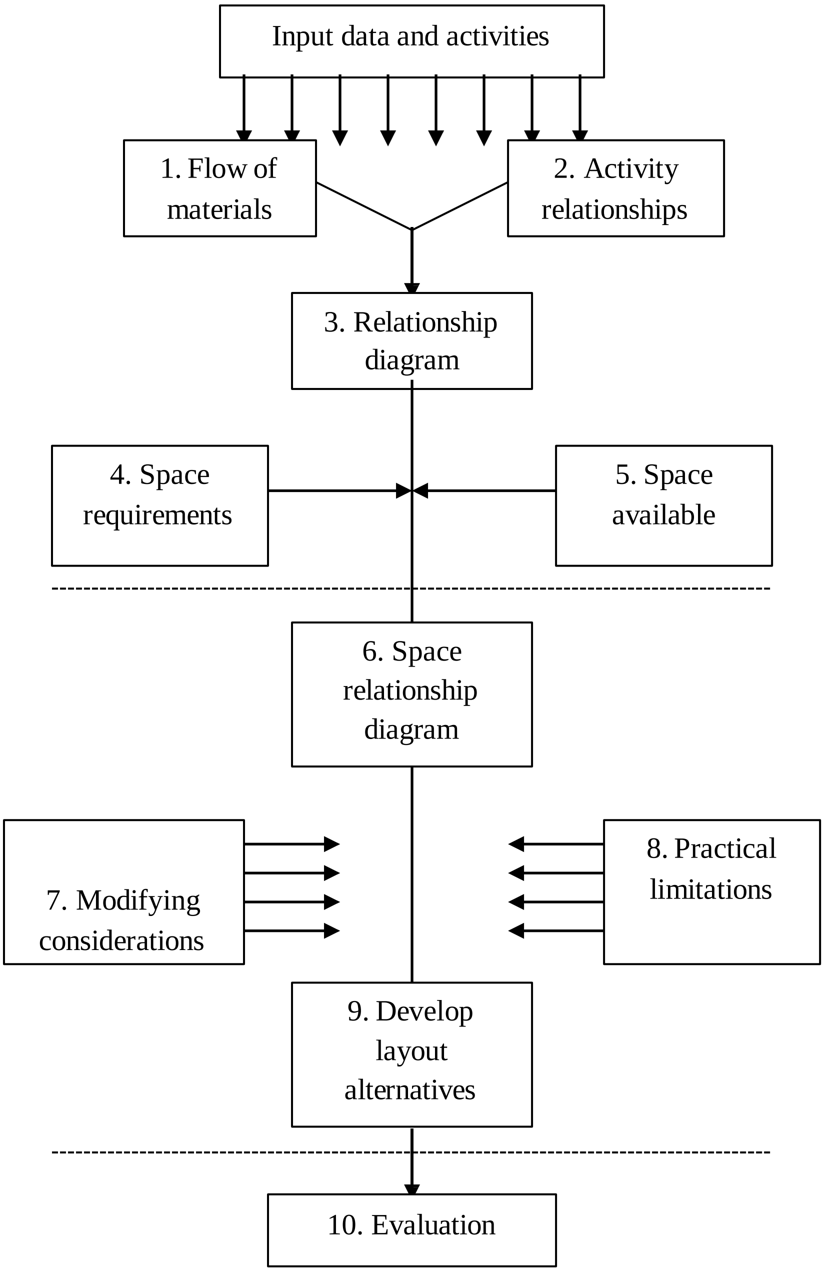
Limitations of Fixed Position Layout:

1. Transportation of all production facilities such as (machines, tools, equipments etc.) consumes more time.
2. Highly skilled workers are required.
3. Complicated jigs and fixtures may be required in fixing jobs and tools etc.

LAYOUT DESIGN PROCEDURES

Layout design procedures can be classified into *Systematic Layout Design Procedure (SLDP) and Computerized Relative Allocation of Facilities Technique (CRAFT)*.

1. SYSTEMATIC LAYOUT DESIGN PROCEDURE (SLDP)



Systematic layout planning procedure (from France and White, 1974)

An organizational approach to layout planning has been developed by Muther and has received considerable publicity due to the success derived from its application is solving a large variety of layout problems. This approach is referred to as systematic layout planning or simply SLP. The Space Relationship diagram is constructed by combining space considerations with the relationship diagram. In comparison with the steps in the design process, SLP begins after the problem is formulated.

MERITS OF SLDP (Systematic Layout Design Procedure)

If Production Management is the "conductor," then **SLDP (Systematic Layout Design Procedure)** is the blueprint for the stage they stand on. Developed by Richard Muther, it is the gold standard for organizing how departments, machines, and people are positioned in a facility.

Instead of just "putting things where they fit," SLDP uses a logical, data-driven flow. Here are the primary merits of using this approach:

1. Minimized Material Handling Costs

The biggest "hidden" cost in a factory is moving stuff around. SLDP uses **Relationship Diagrams** (closeness ratings) to ensure that departments with high interaction are physically adjacent.

- **The Result:** Shorter travel distances, fewer forklift trips, and less wear and tear on transport equipment.

2. Optimized Space Utilization

SLDP forces you to look at your square footage three-dimensionally. By calculating the exact space requirements for machinery, maintenance access, and operator movement before installation, you avoid "dead zones."

The Result: Higher output per square meter and delayed need for expensive building expansions.

3. Enhanced Workflow and Reduced Bottlenecks

Because SLDP prioritizes the **Sequence of Operations**, the layout follows the natural "life cycle" of the product.

The Result: A "straight-line" or logical flow that prevents "backtracking" (where products move backward in the chain), which is a major cause of confusion and delays.

4. Improved Employee Safety and Morale

A systematic layout accounts for "human factors"—lighting, noise isolation, and clear walkways.

The Result: By separating hazardous processes (like a high-heat forge) from high-traffic office areas, you reduce accidents and create a more comfortable working environment.

5. Flexibility for Future Growth

One of the core steps in SLDP is considering **Modifying Constraints**. It encourages designers to build in "slack" or modularity.

The Result: When you need to add a new machine next year, you aren't stuck moving the entire factory because you planned for scalability from day one.

2. COMPUTERIZED RELATIVE ALLOCATION OF FACILITIES TECHNIQUE (CRAFT)

CRAFT algorithm was originally developed by Armour and Buffa. It starts with an initial layout and improves the layout by interchanging the department's pair wise so that the transportation cost is minimized. The algorithm continues until no further interchanges are possible to reduce the transportation cost. The result given by CRAFT is not optimum in terms of minimum cost of transportation. But the result will be good and close to optimum in majority of applications.

CRAFT Requirements:

1. Initial layout
2. Flow data
3. Cost per unit distance
4. Total number of departments
5. Fixed departments
   Number of such departments
   Location of those departments
6. Area of departments

CRAFT Procedure:

The steps of CRAFT algorithm are summarized below:

Step 1. Input: 1. Number of departments
2. Number of interchangeable departments
3. Initial layout
4. Cost matrix
5. Flow Matrix
6. Area of departments

Step 2. Compute centroids of departments in the present layout.

Step 3. Form distance matrix using the centroids.

Step 4. Given data on flow, distance and cost, compute the total handling cost of the present layout.

Step 5. Find all the possible pair wise interchanges of departments based on common border or equal area criterion. For each possibility, interchange the corresponding centroids and compute approximate costs.

Step 6. Find the pair of departments corresponding to the minimum handling cost from among all the possible pairs of interchanges.

Step 7. Is the cost in the previous step less than the total cost of the present layout? If yes, go centroids, distance matrix and total cost.

Step 8. Interchange the selected pair of departments. Call this as the NEW LAYOUT. Compute centroids, distance matrix and total cost.

Step 9. Is the cost of new layout less than the cost of the present layout? If yes, go to step 10. If not, go to Step 11.

Step 10. The new layout is here after considered as the PRESENT LAYOUT. Its data on centroids, layout matrix and the total cost is retained. Go to Step 5.

Step 11. Print the present layout as the FINAL LAYOUT.

Step 12. Stop.

Merits of CRAFT (Computerized Relative Allocation of Facilities Technique)

CRAFT is a computerized layout improvement technique used in production and operations management. It helps in developing a more efficient plant layout by reducing material handling costs.

▪ **Reduces Material Handling Cost:**
CRAFT identifies better arrangements of departments by analyzing the flow of materials between them. By minimizing the distance materials travel, it significantly reduces material handling cost.

▪ **Improves Existing Layout:**
CRAFT does not require designing a layout from scratch. It improves the current layout by suggesting exchanges of departments that result in lower total cost. This makes it very practical for existing factories.

▪ **Computer-Based and Accurate:**
Since CRAFT is a computerized technique, it can handle large amounts of data and complex calculations quickly and accurately, which would be difficult to do manually.

▪ **Saves Time in Layout Planning:**
Manual trial-and-error methods for layout improvement take a lot of time. CRAFT speeds up the process by automatically evaluating different layout alternatives.

▪ **Provides Quantitative Results:**
CRAFT gives numerical values for material flow and cost, making it easier for managers to compare different layout options and select the most economical one.

▪ **Flexible and Adaptable:**
CRAFT can be applied to different types of industries and plant sizes. It can handle various numbers of departments and different flow patterns.

Better Utilization of Space:
By rearranging departments in an efficient way, CRAFT helps in better space utilization and smoother movement of materials and workers.

Supports Managerial Decision Making:
CRAFT provides logical and data-based suggestions, which help managers make informed decisions regarding plant layout improvements.

Reduces Production Delays:
By improving the layout and reducing unnecessary movement of materials, CRAFT helps in smoother workflow and fewer delays in production.

Feature	SLDP (Manual)	CRAFT (Computerized)
Best For	New facilities / Qualitative factors	Existing facilities / Quantitative flow
Primary Input	Relationship Chart (Vowels)	From-To Chart (Numerical volumes)
Shape Handling	Flexible	Very flexible (block-based)
Logic	Construction-based (Builds from scratch)	Improvement-based (Tweaks an existing plan)

In short , CRAFT is a powerful layout improvement tool that reduces material handling cost, saves time, improves accuracy, and helps in developing an efficient and economical plant layout.

FACILITY MANAGEMENT (MAINTENANCE MANAGEMENT)

MEANING AND DEFINITION

Maintenance may be understood as a set of activities, which help keep plant, machinery and other facilities in good conditions. A formal definition of maintenance is "*that function of manufacturing management that is concerned with the day-to-day problem of keeping the physical plant in good operating condition.*"

It is an essential activity in every manufacturing establishment, because it is necessary to insure the availability of machines, buildings and services needed by other parts of the organization for the performance of their functions at an optimum return on the investment, whether this investment is in machinery, materials or employees.

Viewed from this, it may be stated that maintenance is not just repairs. Maintenance is much wider in its scope unlike repairs.

Maintenance is one function, which has not been rendered obsolete by, advanced technology, has not faded away with the passage of time and has not lost its stature in the industry, though other functions have witnessed fluctuating fortunes from time to time.

SCOPE OF MAINTENANCE

Every manufacturing organization needs maintenance because,

- Machines break down
- Parts wear out
- Buildings deteriorate over a period of time of use

All segments of a factory – *buildings, machinery, equipments, tools, cranes, jigs and fixtures, heating and generating equipments, waste disposal system, air-conditioning equipments, wash rooms, dispensaries* and so on, need attention.

Maintenance covers two broad categories of functions as outlined below:

(a) *Primary functions*

1. Maintenance of existing plant and equipments
2. Maintenance of existing plant buildings and grounds
3. Equipment inspection and lubrication
4. Alterations to existing equipments and buildings
5. New installations of equipments and buildings

(b) *Secondary functions*

1. Storekeeping
2. Plant protection including fire protection
3. Waste disposal
4. Salvage
5. Insurance administration
6. Property accounting
7. Pollution and noise abatement or control
8. Any other service delegated towards maintenance by the plant management

IMPORTANCE OF MAINTENANCE MANAGEMENT

1. Dependability of service is one of the performance measures by which a company can distinguish itself from others.

2. Maintenance is an important factor in quality assurance, which is another basis for the successful competitive edge.

3. Many manufacturing organizations, particularly those with JIT (Just-In-Time) programmes are operating with inventories so low that, they offer no protection in the event of a lengthy equipment failure.

4. Good Maintenance Management is important for the company's cost control.
5. Organizations like airlines and oil refineries have huge investments in the equipment.

IMPACT OF POOR MAINTENANCE

Maintenance operations include all efforts to keep production facilities and equipments in an acceptable operating condition. Failure or mal-functioning of machines and equipments in manufacturing and service industries have a direct impact on the following:

1. ***Production capacity:*** Machines idled by breakdowns cannot produce, thus the capacity of the system is reduced.
2. ***Production costs:*** Labour costs per unit rise because of idle labour due to machine breakdowns. When machine malfunctions result in scrap, unit labour and material costs increases.
3. ***Product and* service *quality:*** Poorly maintained equipments produce low quality products. Equipments that have not been properly maintained have frequent break downs and cannot provide adequate service to customers.
4. ***Employee or customer safety:*** Worn-out equipment is likely to fail at any moment and these failures can cause injuries to the workers, working on those equipments
5. ***Customer satisfaction:*** When production equipments break down, products often cannot be produced according to the master production schedules, due to work stoppages. This will lead to delayed deliveries of products to the customers.

OBJECTIVES OF MAINTENANCE MANAGEMENT

The following are some of the objectives of maintenance management:

1. Minimizing the loss of productive time because of equipment failure (i.e., minimizing idle time of equipment due to break down)
2. Minimizing the repair time and repair cost
3. Minimizing the loss due to production stoppages
4. Efficient use of maintenance personnel and equipments
5. To keep all productive assets in good working condition.
6. To minimize accidents through regular inspection and repair of safety devices.
7. To minimize the total maintenance cost which includes the cost of repair, cost of preventive maintenance and inventory carrying costs, due to spare parts inventory.
8. To improve the quality of products and to improve productivity.

AREAS OF MAINTENANCE

The major areas of maintenance are:

1. Civil Maintenance: Building construction and maintenance, maintaining service facilities such as water, gas, steam, compressed air, heating and ventilating, air conditioning, painting, plumbing and carpentry work.

2. Mechanical Maintenance: Maintaining machines and equipments, transport vehicles, material handling equipments, steam generators, boilers, compressors and furnaces. Lubricating the machines is also part of mechanical maintenance work.

3. Electrical Maintenance: Maintaining electrical equipments such as generators, transformers, switchgears, motors, telephone systems, electrical installations, lighting, fans, meters, gages instruments, control panels and battery charging.

PLANT MAINTENANCE METHODS

In all the above stated areas, organization may use any or all the five types of maintenance, viz.:

I. Break down maintenance or corrective maintenance

II. Preventive maintenance
III. Predictive maintenance
IV. Routine maintenance
V. Planned maintenance

I. Break down Maintenance or Corrective Maintenance

As the name suggests, corrective maintenance occurs, when there is a work stoppage because of machine breakdown. In this sense, maintenance becomes repair work. Repairs are made after the equipment is out of order – an electric motor will not start, a conveyor belt is ripped, or a shaft has broken. In cases such as these, the maintenance department checks into the difficulty and makes the necessary repairs. Role of the department is almost passive.

Nevertheless, corrective maintenance seeks to achieve the following objectives:

1. To get equipment back into operation as quickly as possible in order to minimize interruption to production. These objectives can directly affect production capacity, production costs, and product quality and customer satisfaction.
2. To control the cost of repair crews, including regular time and overtime labour costs.
3. To control the cost of the operation of repair shops.
4. To control the investment in replacement spare parts that is used when machines are repaired.
5. To control the investment in replacement spare machines, which are also, called stand-up or back-up machines, these replaces manufacturing machines until the needed repairs are completed.
6. To perform the appropriate amount of repairs to each malfunction. The decision about how far to go with a repair ranges from a band-aid and bubble gum fix to a complete overhaul. Some parts can be replaced early to extend the time until the next repair is required.

II. Preventive Maintenance

In marked contrast to corrective maintenance, is preventive maintenance, which is undertaken before the need arises and aims to minimize the possibility of un-anticipated production interruptions or major breakdowns. Preventive maintenance consists of:

1. Proper design and installation of equipment,
2. Periodic inspection of plant and equipment to prevent break downs before they occur
3. Repetitive servicing, upkeep and overhaul of equipment and
4. Adequate lubrication, cleaning and painting of buildings and equipment

The key to all good preventive maintenance is inspection. Inspection should cover virtually everything. Including production machinery, motors it controls materials handling equipment, process equipment, lighting, buildings and plant services. Some organizations inspect only costly items, but others cover almost all.

Preventive maintenance offers several benefits to the users: They include greater safety for worker decreased production downtime, fewer large scale and repetitive repairs, less cost for simple repairs made before breakdown, less standby equipment required, better spare parts control, identification of items with high maintenance costs and lower unit cost of manufacture.

III. Predictive Maintenance

One of the newer types of maintenance that may be anticipated to gain increasing attention is called predictive maintenance. In this, sensitive instruments (eg., vibration analyzers, amplitude meters, audio gauges, optical tooling, pressure, temperature and resistance gauges) are used to predict trouble.

PREDICTIVE MAINTENANCE

Predictive Maintenance is a modern maintenance strategy in which the condition of machines and equipment is continuously monitored to predict when a failure might occur. Maintenance is then performed **only when necessary**, just before a breakdown happens. This helps in avoiding unexpected machine failures and reduces maintenance costs.

Unlike breakdown maintenance (repair after failure) and preventive maintenance (regular scheduled maintenance), predictive maintenance is based on the **actual condition of equipment**.

Objectives of Predictive Maintenance

- To detect potential equipment failures in advance
- To reduce unexpected machine breakdowns
- To minimize maintenance cost
- To increase equipment life
- To ensure smooth and continuous production

How Predictive Maintenance Works

In predictive maintenance, machines are monitored using various tools and techniques. Data is collected about machine performance, and this data is analyzed to find early signs of wear or failure. When abnormal conditions are detected, maintenance is carried out before a serious breakdown occurs.

Techniques Used in Predictive Maintenance

▪ **Vibration Analysis:**
Detects imbalance, misalignment, or bearing defects in rotating machines.

▪ **Thermography (Temperature Monitoring):**
Uses infrared cameras to detect overheating in motors, wiring, or bearings.

▪ **Oil Analysis:**
Checks the condition of lubricating oil to detect contamination or metal particles, indicating machine wear.

▪ **Ultrasonic Testing:**
Identifies leaks in compressed air systems or electrical faults.

▪ **Condition Monitoring Sensors:**
Modern machines use sensors to continuously monitor performance parameters like pressure, temperature, and speed.

Advantages of Predictive Maintenance

▪ **Reduces Unexpected Breakdowns:**
Problems are detected early, preventing sudden machine failure.

▪ **Lower Maintenance Cost:**
Maintenance is done only when needed, avoiding unnecessary routine servicing.

▪ **Increases Equipment Life:**
Early detection of faults prevents severe damage.

▪ **Improves Production Efficiency:**
Less downtime means smoother production flow.

▪ **Better Safety:**
Prevents accidents caused by sudden equipment failure.

▪ **Optimal Use of Maintenance Resources:**
Labour and spare parts are used only when required.

Disadvantages of Predictive Maintenance

▪ High initial cost of monitoring equipment and sensors
▪ Requires skilled technicians to analyze data
▪ Not suitable for all types of equipment

Conclusion

Predictive maintenance is an advanced and efficient maintenance approach that focuses on monitoring equipment condition and predicting failures before they occur. It helps industries reduce downtime, lower maintenance costs, improve safety, and increase productivity, making it highly important in modern production systems.

Basis	Breakdown Maintenance	Preventive Maintenance	Predictive Maintenance
Meaning	Maintenance is done after the machine fails	Maintenance is done at regular time intervals	Maintenance is done based on machine condition
When Maintenance is Done	Only after breakdown occurs	Before breakdown, as per fixed schedule	Just before failure, based on monitoring data
Planning	No planning	Pre-planned and scheduled	Planned based on condition analysis
Cost of Maintenance	Low initially, but high repair cost later	Moderate cost	Initially high, but economical in long run
Downtime	High and unexpected	Reduced, but still some scheduled downtime	Very low and mostly planned downtime
Machine Life	Reduced due to sudden failures	Improved compared to breakdown maintenance	Maximum machine life due to timely care
Production Loss	High due to sudden stoppage	Less compared to breakdown maintenance	Very low as failures are predicted
Use of Technology	No special tools required	Basic maintenance tools	Uses sensors, vibration analysis, thermography, etc.
Suitability	Small, non-critical equipment	Medium importance machines	Critical and high-value machines
Example	Repairing a motor after it burns out	Servicing a machine every 3 months	Replacing a bearing after vibration levels increase

Conclusion

Breakdown maintenance reacts **after failure**, preventive maintenance acts **before failure on a schedule**, while predictive maintenance acts **before failure based on actual machine condition**. Among the three, predictive maintenance is the most advanced and cost-effective for critical equipment.

IV. Routine Maintenance

This includes activities such as periodic inspection, cleaning, lubrication and repair of production equipments after their service life.

1. *Running maintenance* in which, the maintenance work '^carried out while the equipment is in the operating condition
2. *Shut down maintenance* in which the maintenance work is carried out when the machine or equipment is out of service i.e., after shutting down the machine or equipment, e.g., repairing (i.e., discaling) boiler tubes of a boiler.

V. Planned Maintenance

Breakdown of a machine or equipment does not occur in a planned manner but maintenance work can be planned well in advance. Planned maintenance is also known as *scheduled maintenance or productive maintenance.*

REPLACEMENT POLICIES – UNIT AND GROUP REPLACEMENT POLICIES

Replacement policies help management decide the most economical time to replace machines or components that wear out or fail. Proper replacement reduces breakdowns, maintenance cost, and production interruptions.

▪ **Unit Replacement Policy:**
Under this policy, individual items are replaced one by one as and when they fail or become inefficient. There is no fixed schedule, and each unit is treated separately. This policy is suitable when items are costly and their failures are not frequent. It avoids unnecessary replacement of working units but may lead to unexpected breakdowns and higher downtime.

▪ **Group Replacement Policy:**
In this policy, all similar items are replaced together at fixed intervals, even if some of them are still in working condition. However, items that fail before the scheduled group replacement are replaced individually. This method is suitable when items are inexpensive and fail frequently after a certain period. It helps reduce overall maintenance cost and production disturbances, though some usable items may be replaced early.

▪ **Objective of Replacement Policies:**
The main aim is to determine the most economical time for replacement so that the total cost of operation, maintenance, and downtime is minimized.

▪ **Cost Consideration:**
Replacement decisions are based on comparing the increasing maintenance and repair cost of old equipment with the cost of new equipment.

▪ **Reduction of Breakdowns:**
Proper replacement policies help avoid sudden failures and ensure smoother production operations.

▪ **Improved Efficiency:**
Replacing old or worn-out equipment improves performance, reduces energy consumption, and increases productivity.

In conclusion, unit replacement is suitable when failures are rare and items are costly, while group replacement is economical when many similar items fail frequently. Selecting the right replacement policy helps in cost control and uninterrupted production.

UNIT REPLACEMENT POLICY

Unit replacement policy refers to replacing **individual machines or components separately** as and when they fail or become uneconomical to maintain. Each unit is treated independently, and replacement decisions are taken based on its performance and maintenance cost.

Meaning:
Under unit replacement, a unit is replaced only after it breaks down or when its running and repair costs become higher than the cost of a new unit.

No Fixed Schedule:
There is no predetermined time for replacement. Each item is replaced at a different time depending on its condition and failure.

Based on Economic Life:
Replacement is often decided by comparing the rising maintenance cost of the old unit with the cost and efficiency of a new unit.

Suitable for Costly Equipment:
This policy is best for expensive machines or components where replacing all units together would be too costly.

Reduces Unnecessary Replacement:
Working units are not replaced before failure, so there is no waste of usable equipment.

Higher Risk of Sudden Breakdown:
Since replacement happens only after failure, there may be unexpected stoppages and production delays.

Frequent Small Expenditure:
Costs occur in small amounts at different times instead of one large replacement cost.

Example:
Replacing a motor in a machine only after it stops working, instead of changing all motors at the same time.

unit replacement policy is economical when items are expensive and their failures are irregular. However, it may lead to unexpected breakdowns and higher downtime compared to planned replacement methods.

GROUP REPLACEMENT POLICY

Group replacement policy refers to replacing **all similar items together at a fixed interval of time**, even if some of them are still functioning. However, items that fail before the scheduled group replacement are replaced individually.

Meaning:
Under group replacement, a large number of similar components are replaced at one time after a certain period, instead of waiting for each one to fail.

Fixed Replacement Interval:
All units are replaced together after a predetermined time based on the average life and failure pattern of the items.

Individual Replacement Between Intervals:
If any item fails before the group replacement date, it is replaced individually to avoid production stoppage.
Suitable for Low-Cost Items:
This policy is most suitable for inexpensive items that have a high and increasing failure rate after some time.
Reduces Frequent Breakdowns:
By replacing items before they reach the high-failure stage, this policy reduces sudden breakdowns and interruptions.
Economical in the Long Run:
Though some working items are replaced early, the overall cost is reduced due to lower downtime and maintenance expenses.
Easy Maintenance Planning:
Since replacement is done at fixed intervals, maintenance work can be planned in advance, saving time and effort.

Example:
Replacing all electric bulbs in a factory every year, while replacing any fused bulbs individually before the annual replacement.

group replacement policy is economical when many similar items fail frequently after a certain period. It reduces unexpected failures and helps in better planning of maintenance activities.

Basis	Unit Replacement	Group Replacement
Replacement Time	When each unit fails	At fixed intervals for all units
Number of Items Replaced	One at a time	All items together
Cost Pattern	Frequent small costs	Periodic large cost
Downtime	More frequent	Less frequent
Suitability	Expensive items, low failure rate	Cheap items, high failure rate

MODELS OF MAINTENANCE MANAGEMENT

1. Expected Value Model for Estimating Breakdown Cost

Preventive maintenance is more effective when service requirements are well known or failures can Be predicted with some degree of reliability. When the firm has maintained good records of the frequency and cost of breakdowns in the past, by using a simple concept of expected value, the current breakdown policy can be compared with a given maintenance policy.

Illustration: XYZ firm has experienced the stated number of break-downs per month over the past n years.

Number of break-downs	X_0	X_1	X_2	X_3	X_4
Number of months this occurred	m_0	m_1	m_2	m_3	m_4

Average breakdown cost = C_{bm}

Preventive maintenance cost under a preventive maintenance cost under a preventive maintenance policy which limits the break downs to X per month = C_{pm}

Which maintenance policy is preferable from cost point view?
The current breakdown or a new preventive maintenance policy?

Solution:

No. of break downs x	**Frequency in months f(x)**	**Frequency P(x)**	**Expected Value x.P(x)**
X_0	m_0	m_0/M	$X_0 * m_0/M$
X_1	m_1	m_1/M	$X_1 * m_1/M$
X_2	m_2	m_2/M	$X_2 * m_2/M$
X_3	m_3	m_3/M	$X_3 * m_3/M$
X_4	m_4	m_4/M	$X_4 * m_4/M$
	Total = M months		**Total = Y**

Expected breakdown cost per month under current breakdown policy = $Y * C_{bm} = YC_{bm}$

Preventive maintenance cost per month under new preventive maintenance policy = $(X * C_{bm} + C_{pm})$
$= XC_{bm} + C_{pm}$

If □ $XC_{bm} + C_{pm} < YC_{bm}$, then the new preventive maintenance policy is advisable.

Problem: PQR Company has kept records of breakdown of its machines for a 300 day work year as shown below:

No. of break down	0	1	2	3	4	Total
Frequency in days	40	150	70	30	10	300

The firm estimated that each breakdown cost Rs. 650/- and is considering adopting a preventive maintenance program, which would cost Rs. 200 per day and limit the number of break down to an average of one per day. What is the expected annual savings from preventive maintenance programme?

Solution:
To determine the expected number of breakdowns per year:

No. of breakdowns (x)	**Frequency of breakdowns in days i.e, f(x)**	**Probability distribution of breakdowns P(x)**	**Expected value of breakdowns [x P(x)]**
0	40	40/300 = 0.133	Nil
1	150	150/300 = 0.5	0.5
2	70	70/300 = 0.233	0.466
3	30	30/300 = 0.1	0.3
4	10	10/300 = 0.033	0.132
Total	300	1	1.4

Total no. of breakdowns per day = 1.4
Cost of breakdown per day = 1.4 x 650 = Rs. 910
Cost of preventive maintenance programme per day = Rs. 200 + Rs. 650 = Rs. 850
Expected annual savings from the preventive maintenance programme = (910 – 850) x 300 days
= Rs. 18, 000.

2. Simulation Model for Estimating Break-down Cost

~~Simulation technique enables maintenance managers to 'try out' numerous maintenance policies on a computer~~

before actually implementing them. The data regarding simulated breakdowns and repair time values could be used to estimate the breakdown cost and reach a decision about the appropriate crew size.

Problem: In a simulated operation, a firm's maintenance crew received requests for service and provided services during an 8 hour period as shown below:

Request arrival (clock) time	0.00	1.00	3.30	4.0	7.0
Service time (hours)	1.5	0.5	2.0	0.5	1.0

The maintenance labour cost is Rs. 140 per hour and the delay time cost is Rs. 450 per hour.

1. Find the idle time cost for the maintenance crew.
2. Find the delay time cost for the machinery.

Solution:

Request arrival time (Clock time)	**Repair time for one crew**		**Repair time (clock time)**		**Machine down time**		
	Hours	**Minutes**	**Begins**	**Ends**	**Waiting time**	**Repair time**	**Total time**
00.00	1.50	90	00.00	01.30	Nil	1.5	1.5
01.00	0.50	30	01.30	02.00	0.5	0.5	1.0
03.30	2.00	120	03.30	05.30	Nil	2.0	2.0
04.00	0.50	30	05.30	06.00	1.5	0.5	2.0
07.00	1.00	60	07.00	08.00	Nil	1.0	1.0
Total	5.50 hrs				2.0	5.5	7.5

Idle time for the maintenance crew = 8 – 5.5 = 2.5 hrs
Idle time cost for maintenance crew = 2.5 x 140 = Rs. 350
Delay time or waiting time = 2.0 hrs
Delay time cost for the machinery = 2.0 x 450 = Rs. 900

3. Probability Model for Selecting Preventive Maintenance Policy

This helps decide whether to follow breakdown or preventive maintenance policy. The model involves the following steps:

Step No. 1: Data are collected on

a. The preventive maintenance servicing cost
b. The breakdown cost and
c. The probability of breakdown.

Step No. 2: The cumulative expected number of breakdowns B in M (month) is

$$\mathbf{B_n = N\,[\textstyle\sum P_n] + B_{n-1}P_1 + B_{n-2}P_2 + \ldots\ldots\; B_1P_{n-1}}$$

Where N = Number of units or machines/equipments
P = Probability of breakdown during a given month after maintenance
n = Maintenance period in which maintenance is performed.

Step No. 3: After calculating the expected number of breakdown $\mathbf{B_n}$ for various preventive maintenance policies, the cost of preventive maintenance and expected cost of breakdown maintenance and the total maintenance cost per month is determined.

Step No. 4: The policy, which minimizes the total maintenance cost per month, is the choice.

Problem 1: The probability of failure after maintenance for a machine is given in the table below:

Years after maintenance	1	2	3	4	5
Probabilities of breakdown	0.2	0.4	0.2	0.1	0.1

If there are 50 machines in the facility, what is the expected number of breakdowns in the 3rd year?

Solution:

Expected no. of breakdowns (B_n) = N [$\sum P_n$] + $B_{n-1}P_1$ + $B_{n-2}P_2$ + ……. B_1P_{n-1}

Where,

N = Number of units or machines/equipments
P = Probability of breakdown during a given month after maintenance
n = Maintenance period in which maintenance is performed.

Given that N = 50; n = 3; P1 = 0.2; P2 = 0.4; P3 = 0.2

Put n = 1, $B_1 = N P_1 = 50 \times 0.2 = 10$
Put n = 2, $B_2 = N (P_1 + P_2) + B_1P_1$ = 50 (0.2 + 0.4) + (10 x 0.2) = 32
Put n = 3, $B_3 = N (P_1 + P_2 + P_3) + B_2P_1 + B_1P_2$
= 50 (0.2+0.4+0.2) + (32x0.2) + (10x0.4) = 40+6.4+4 = 50.4

Therefore, expected no. of breakdowns in a 3rd year = 50.4

Problem 2: It costs Rs. 4,000 to perform preventive maintenance on a group of 10 machines. If one of the machines breaks down between preventive maintenance inspections, the breakdown maintenance costs Rs. 8000. The break down history on the machines is given below:

Weeks b/n PM (n)	1	2	3	4
Probability of breakdown	0.1	0.2	0.3	0.4

If only costs are considered, how often preventive maintenance should be performed to minimize the total maintenance cost (i.e., cost of preventive maintenance + Cost of breakdown maintenance).

Solution:

Step 1: Calculation of expected no. of breakdowns for each preventive maintenance policy.

Expected no. of breakdowns (B_n) = N [$\sum P_n$] + $B_{n-1}P_1$ + $B_{n-2}P_2$ + ……. B_1P_{n-1}

Where,

N = Number of units or machines/equipments
P = Probability of breakdown during a given month after maintenance
n = Maintenance period in which maintenance is performed.

Given that N = 10; n = 4; P1 = 0.1; P2 = 0.2; P3 = 0.3; P4 = 0.4

Put n = 1, $B_1 = N P_1 = 10 \times 0.1 = 1$
Put n = 2, $B_2 = N (P_1 + P_2) + B_1P_1$
= 10 (0.1 + 0.2) + (1 x 0.1) = 3.1
Put n = 3, $B_3 = N (P_1 + P_2 + P_3) + B_2P_1 + B_1P_2$
= 10 (0.1+0.2+0.3) + (3.1x0.1) + (1x0.2) = 6+0.31+0.2 = 6.51
Put n = 4, $B_4 = N (P_1 + P_2 + P_3 + P_4) + B_3P_1 + B_2P_2 + B_1P_3$
= 10 (0.1+0.2+0.3+0.4) + (6.51x0.1) + (3.1x0.2) + (1x0.3)
= 10+0.651+0.62+0.3 = 11.57

Step 2: Calculation of expected breakdown cost, preventive maintenance cost and total maintenance cost for each preventive maintenance policy.

PM policy every 'n' weeks	Expected no. of breakdowns	Expected no. of breakdowns per week	Expected cost of breakdown per week (Rs.)	Cost of PM per week	Total maintenance cost
1	1	1/1 = 1	1x8000 = 8000	4000/1 = 4000	8000+4000 = 12000
2	3.1	3.1/2 = 1.55	1.55x8000 = 12,400	4000/2 = 2000	12400+2000 = 14400

3	6.51	6.51/3 = 2.17	2.17x8000 = 17,360	4000/3 = 1333	17360+1333 = 18693
4	11.57	11.57/4 = 2.89	2.89x8000 = 23,120	4000/4 = 1000	23120+1000 = 24120

The policy that minimize at the cost is to perform preventive maintenance every week i.e. n = 1.

PROCESS DESIGN

1. Meaning of Process Design

Process Design refers to the systematic planning and structuring of production activities in order to convert raw materials into finished goods efficiently and economically. It involves deciding how production operations will be performed, what sequence they will follow, which machines and equipment will be used, and how workflow will move from one stage to another.

In production management, process design answers the fundamental question: **"How will the product be manufactured?"** It bridges the gap between product design and actual production. Once a product is designed, process design determines the methods and procedures required to produce it.

Process design includes:

- Selection of production methods
- Determination of sequence of operations
- Selection of appropriate machinery and tools
- Design of workflow and material handling system
- Standardization of operating procedures

A well-designed process ensures that production activities are carried out smoothly, economically, and with minimum wastage. Poor process design, on the other hand, leads to bottlenecks, higher costs, lower productivity, and quality issues.

Thus, process design plays a vital role in achieving organizational efficiency and competitiveness.

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2. Objectives of Process Design

The primary aim of process design is to develop an efficient system for manufacturing goods or delivering services. The major objectives are explained below in detail:

1. To Ensure Smooth Production Flow

One of the main objectives of process design is to create a logical and systematic sequence of operations. When processes are properly arranged, materials move smoothly from one stage to another without delays or interruptions. This reduces waiting time, congestion, and confusion on the shop floor.

Smooth production flow increases efficiency and ensures timely completion of orders.

2. To Select the Most Economical Method of Production

Process design aims at identifying the most cost-effective way of manufacturing a product. Different production methods may exist for the same product, but the goal is to choose the one that minimizes cost while maintaining quality.

Economical production methods help reduce material wastage, labour cost, energy consumption, and overhead expenses, thereby improving profitability.

3. To Achieve Required Quality Standards

Process design ensures that production methods are standardized and controlled. Proper selection of equipment, tools, and techniques helps maintain consistency in product quality.

By designing processes carefully, organizations can reduce defects, rework, and customer complaints, thereby enhancing customer satisfaction and brand reputation.

4. To Reduce Production Time and Cost

Efficient process design minimizes unnecessary movements, delays, and duplication of work. By optimizing workflow and selecting appropriate machinery, production time can be reduced significantly.

Lower production time results in faster delivery, reduced labour cost, and better utilization of resources.

5. To Make the Best Use of Machines and Labour

Process design ensures proper allocation and utilization of machines, workers, and materials. It prevents overloading or underutilization of equipment and manpower.

Effective utilization of resources increases productivity and reduces idle time, thereby improving overall operational efficiency.

3. Importance of Process Design

Process design plays a crucial role in the success of production management. Its importance can be understood through the following points:

1. Cost Reduction

A well-designed process minimizes waste of raw materials, reduces unnecessary movements, and avoids duplication of activities. It helps in selecting efficient methods and suitable machinery that lower operational expenses.

Reduced production cost leads to higher profit margins and better competitive position in the market.

2. Efficient Resource Utilization

Process design ensures that all available resources—machines, labour, materials, and space—are used effectively. Proper sequencing of operations avoids idle time and bottlenecks.

Efficient resource utilization improves output without increasing investment, leading to better productivity.

3. Improved Product Quality

Standardized processes help maintain uniformity in production. When operations are clearly defined and controlled, the chances of errors and defects are reduced.

High-quality products increase customer satisfaction and strengthen the company’s market image.

4. Smooth Workflow

Proper process design establishes a logical flow of materials and information. This avoids unnecessary backtracking, congestion, and delays.

Smooth workflow enhances coordination among departments and ensures uninterrupted production activities.

5. Increased Productivity

Efficient processes allow more output to be produced within the same time frame. By eliminating unnecessary steps and improving methods, productivity levels rise.

Higher productivity leads to better capacity utilization and improved organizational performance.

6. Better Production Planning and Control

Process design provides a clear understanding of the sequence of operations and time required for each stage. This helps in preparing realistic production schedules and monitoring progress effectively.

It supports effective production planning and control systems.

7. Flexibility and Adaptability

A good process design allows organizations to adapt to changes in product design, technology, or demand levels. Flexible processes help businesses respond quickly to market changes.

This adaptability is essential in today's competitive and dynamic business environment.

Process design is a fundamental component of production management that determines how products are manufactured efficiently and economically. It involves selecting the appropriate methods, equipment, sequence of operations, and workflow to ensure smooth production.

A well-developed process design leads to cost reduction, improved quality, higher productivity, better resource utilization, and enhanced customer satisfaction. Therefore, effective process design is essential for achieving organizational success and long-term growth.

Factors Affecting Process Design

Process design does not happen randomly. It is influenced by several internal and external factors. These factors determine the type of production system, equipment selection, workflow, and overall efficiency of operations. The major factors affecting process design are explained below in detail.

1. Nature of Product

The design and characteristics of the product play a major role in deciding the process.

If the product is **simple and standardized**, a mass or flow production system can be adopted. However, if the product is **complex or customized**, a job or batch production process is more suitable.

Products with high precision requirements may require specialized machinery and skilled labour. On the other hand, simple products can be manufactured using general-purpose machines.

Thus, product design directly influences the choice of production methods and equipment.

2. Production Volume

The quantity of products to be produced significantly affects process design.

- **Low volume production** generally uses job production methods.
- **Medium volume production** uses batch production.
- **High volume production** uses mass or continuous production systems.

When production volume is high, automated and specialized equipment is preferred to reduce cost per unit. For low volume production, flexible systems are more suitable.

Therefore, the scale of production determines the type of process design adopted.

3. Technology Available

The level of technology available in the organization greatly influences process design.

Advanced technology such as automation, robotics, CNC machines, and computer-integrated manufacturing improves speed, accuracy, and consistency. However, it requires higher investment.

If modern technology is not available, the process design may rely more on manual operations and traditional machinery.

Technological advancement also increases flexibility and improves product quality.

4. Skill of Labour

The skill level of workers is another important factor.

If highly skilled labour is available, complex and specialized processes can be implemented. Skilled workers can handle advanced machinery and perform precision tasks efficiently.

If labour is unskilled or semi-skilled, simpler processes and automated systems may be preferred to reduce errors and training requirements.

Thus, process design must match the capabilities of the workforce.

5. Cost Considerations

Budget limitations play a crucial role in selecting the production process.

High-tech and automated systems require heavy capital investment. Small firms with limited financial resources may choose simpler and less expensive methods.

Process design must balance cost and efficiency to ensure profitability. Both initial investment and operating costs should be considered.

Cost-effective process design ensures long-term sustainability of the business.

6. Plant Layout

The physical arrangement of machines, departments, and work areas affects process design.

Available space determines whether a product layout, process layout, or combination layout can be adopted. Limited space may require compact and flexible process planning.

Proper coordination between plant layout and process design ensures smooth material flow and reduces handling cost.

7. Quality Requirements

Customer expectations and market standards influence process design significantly.

If high-quality standards are required, advanced machinery, strict inspection procedures, and controlled production processes must be adopted.

For products where quality is a competitive advantage, the process design must emphasize precision and reliability.

Maintaining quality through proper process design enhances customer satisfaction and brand value.

Process design is influenced by multiple factors such as product nature, production volume, technology, labour skill, cost, plant layout, and quality standards. These factors must be carefully analyzed before selecting an appropriate production process.

An effective process design balances efficiency, cost, quality, and flexibility to achieve organizational goals successfully.

PROCESS DESIGN – CLASSIFICATION

Process design can be classified based on the **type of production system** adopted by an organization. The classification mainly depends on production volume, product variety, and process flow.

1. Job Process (Job Shop Production)

This type of process is used when products are made **as per customer requirements**. Each product or job is different from others, and production is usually carried out in small quantities.

Machines are arranged according to function, and workers are highly skilled. The process is flexible but involves high cost and longer production time.

Examples: Tailoring shops, repair workshops, custom furniture manufacturing.

2. Batch Process

In batch production, goods are produced in **groups or batches**. After one batch is completed, production shifts to another batch of the same or different product.

This method offers a balance between flexibility and efficiency. Equipment is used for a certain period to produce one batch before being adjusted for the next.

Examples: Bakery products, pharmaceuticals, garments manufacturing.

3. Mass (Flow) Process

Mass production is used for producing **large quantities of standardized products**. The production process follows a fixed sequence of operations, and materials move continuously from one stage to the next.

Special-purpose machines and assembly lines are used. It provides high efficiency and low cost per unit but offers little flexibility.

Examples: Automobile assembly, television manufacturing, bottled drinks production.

4. Continuous Process

This process is used in industries where production runs **continuously without interruption**. The process is highly automated and involves a continuous flow of materials.

It is suitable for very high-volume production and usually operates 24/7. Stopping the process can be expensive and difficult.

Examples: Oil refineries, cement plants, chemical industries, steel production.

Summary Table

Type of Process	Production Volume	Product Variety	Flexibility	Example
Job Process	Low	High	Very High	Custom furniture
Batch Process	Medium	Medium	Moderate	Bakery products
Mass Process	High	Low	Low	Car assembly
Continuous Process	Very High	Very Low	Very Low	Oil refinery

Conclusion

The classification of process design helps organizations choose the most suitable production system based on product type, production volume, and market demand. Each type has its own advantages and limitations, and the choice depends on the company’s objectives and resources.

Merits of Process Design

Process design plays an important role in ensuring efficient production operations. Its main merits are:

1. **Smooth Production Flow**
   Proper sequencing of operations reduces delays and bottlenecks, ensuring continuous production.
2. **Reduction in Production Cost**
   Efficient processes minimize wastage of materials, labour, and time, lowering overall production cost.
3. **Better Utilization of Resources**
   Machines, manpower, and materials are used effectively, reducing idle time and increasing efficiency.

4. **Improved Product Quality**
   Standardized production methods help maintain consistent quality and reduce defects.

5. **Higher Productivity**
   Streamlined workflow and elimination of unnecessary steps lead to increased output in less time.

Preventive Maintenance

Preventive maintenance refers to **regular and planned maintenance activities** carried out before a machine breaks down. The goal is to **prevent failures** and keep equipment in good working condition.

It includes activities like inspection, cleaning, lubrication, tightening of parts, and periodic replacement of worn components. These tasks are performed at fixed time intervals based on schedules prepared in advance.

Purpose: To reduce unexpected breakdowns and extend the life of machines.
Example: Servicing a machine every month or changing engine oil after a fixed number of hours.

Advantages

- Reduces sudden equipment failure
- Increases machine life
- Ensures smooth production
- Improves safety

Limitation

Sometimes maintenance is done even when it is not actually needed, leading to extra cost.

Predictive Maintenance

Predictive maintenance is a **condition-based maintenance method**. Maintenance is carried out only when indicators show that the machine is likely to fail soon.

This method uses monitoring tools such as vibration analysis, temperature measurement, oil analysis, and sensors to check the health of equipment. Maintenance is done only when there are signs of wear or abnormal performance.

Purpose: To predict failures in advance and avoid unnecessary maintenance.
Example: Replacing a bearing after vibration levels exceed the normal limit.

Advantages

- Reduces unnecessary maintenance
- Prevents major breakdowns
- Saves cost in the long run
- Improves reliability of equipment

Limitation

Requires advanced equipment and skilled technicians, which increases initial cost.

Preventive maintenance is time-based, while predictive maintenance is condition-based.

Basis	Breakdown Maintenance	Preventive Maintenance	Predictive Maintenance
Meaning	Repair is done after machine failure	Maintenance done at regular time intervals	Maintenance done based on machine condition
Nature	Reactive approach	Planned and time-based	Condition-based and analytical
When Performed	After breakdown occurs	Before breakdown, as per schedule	When monitoring shows signs of failure
Planning	No prior planning	Planned in advance	Planned based on data analysis
Cost	Low initial cost, high repair cost	Moderate cost	High initial cost, low long-term cost
Machine Downtime	High downtime	Reduced downtime	Minimum downtime
Risk of Failure	Very high	Low	Very low
Suitability	Small or non-critical equipment	Regular production equipment	Critical and high-value equipment
Example	Repairing motor after it stops	Servicing machine every month	Replacing bearing after vibration analysis

Replacement Policies – Unit Replacement & Group Replacement

Machines, tools, bulbs, and small components wear out or fail over time. Replacement policies help decide **when and how items should be replaced** to minimize total cost.

1. Unit Replacement Policy

Under unit replacement, items are **replaced individually** when they fail or become inefficient.

Each unit is replaced separately, without waiting for other units to fail.

When It Is Used

- When items fail at **different and unpredictable times**
- When the **cost of failure is not very high**
- When group replacement is not economical

Advantages

- No need to replace working units
- Suitable when failure rate is low

Disadvantages

- Frequent interruptions
- Higher labour and downtime cost if failures are frequent

Example

Replacing a machine part only when it breaks down.

2. Group Replacement Policy

In group replacement, **all items are replaced together at fixed intervals**, even if some are still working. Individual replacements may still be done between group replacements if items fail early.

This policy is adopted when many similar items are used and their failure rate increases with time.

When It Is Used

- When items have **similar life expectancy**
- When failure rate increases after a certain period
- When replacing items in bulk reduces cost

Advantages

- Reduces frequent breakdowns
- Lower replacement cost due to bulk replacement
- Less downtime and better planning

Disadvantages

- Some items are replaced before failure
- Initial cost may be higher

Example

Replacing all electric bulbs in a factory every 6 months, even if some are still working.

Difference Between Unit and Group Replacement

Basis	Unit Replacement	Group Replacement
Meaning	Replace items one by one on failure	Replace all items together at fixed time
Cost	Lower immediate cost	Economical in the long run
Downtime	Frequent	Reduced
Suitability	Independent failures	Similar items with increasing failure rate
Example	Replacing a broken machine part	Replacing all bulbs in a building periodically

Unit replacement is suitable when failures are random and infrequent, while group replacement is economical when many identical items fail over time and bulk replacement reduces cost.

UNIT – III

PRODUCTION PLANNING AND CONTROL

The planning process within an organization is dynamic and continuous. It is nothing but deciding future courses of action of the organization well in advance so that executives at different level will play their role as per these guidelines.

- Strategic decisions, which are taken at top, level management.
- Tactical decisions, which are taken at middle level management.
- Operational decisions, which are taken at bottom level management.

Strategic Decisions

Some examples of strategic decisions are warehouse location, distribution systems, building a new plant, mergers and acquisitions, new product planning, compensation planning, quality assurance planning, R&D planning, forming new technology department, dropping a product from the existing product mix, social responsibility planning, etc. The type of decisions taken at this level is often highly unstructured in nature.

Tactical Decisions

Some examples of tactical decisions are pricing a product, product improvement through value analysis, maintenance crew size determination, preventive maintenance policy, budget analysis, short-term forecasting, make or buy analysis, credit evaluation, plant layout, project scheduling, reward system design, negotiating, buying equipment etc. The type of decision taken at this level is mostly semi-structured in nature.

Operational Decisions

Some examples of operational level decisions are designing sampling plan to inspect the raw materials at stores while receiving materials from vendors, deciding price discount at salesman level in the field, scheduling of maintenance manpower, machine loading, daily operator scheduling, order entry, production scheduling, inventory control, buying software, approving loans etc. The type of decision taken at this level is mostly structured in nature.

The planning is considered to be an essential step in any business mainly because the end results depend on the input and the approach followed at this stage. So, the productivity of an organization can be improved by better planning efforts. Similarly, control process within an organization plays a major role in organizational productivity improvement. In reality, most of the decisions may not be implemented as per the plans. This is because of uncertainty, which is involved in many of the business processes.

The raw material quality may not be as per the assessed level. The machine breakdown rate may be higher than the predicted rate of breakdown. The operator efficiency may not be matching with the time standards. All these deviations would introduce some difficulty in producing products and services as per the plan. So, a careful control system with a proper feedback mechanism is a must to correct the whole business process at appropriate time to manufacture and deliver the goods as per the plan.
Production planning and control has three phases.

1. Planning phase
2. Action phase
3. Control phase

Production planning is an exercise of intelligent anticipation in order to establish how an objective can be achieved or a need fulfilled in circumstances, which are invariably restrictive. The outcome of planning is either dropping the whole idea or the formulation of a new plan in-line with the objective. Production planning determines the optimal schedule and sequence of operations, economic batch quantity, machine assignment and dispatching priorities for sequencing.

Action phase provides guidelines for implementing all the plans into practice.

Production control phase provides necessary guidelines to control the production system through a feedback mechanism. It involves follow up of the production plans. The detailed steps of production planning, action and control are discussed below.

1. Planning phase: It has two categories of planning namely prior planning and active planning. *Prior planning* means pre-production planning. This includes all the planning efforts, which are taking place prior to the active planning. *Active planning* means the actual production planning which includes various activities directly related to the production at micro level immediately following the prior planning.

The modules of **prior planning** are Product development and design, Forecasting, Aggregate planning, Master scheduling, Order writing, MRP, etc.

The modules of **active planning** are: Process planning and routing, Materials planning, Tools planning, Loading, Scheduling, etc.

2. Action phase: Action phase has the major step of dispatching. Dispatching is the transition from planning phase to action phase. In this phase, the worker is ordered to start manufacturing the product.

The tasks, which are included in dispatching, are Job order, Store issue order, Tool order, Time ticket, Inspection order, Move order, etc.

3. Control phase: The control phase has the following two major modules:

- *Progress reporting.* In progress reporting, the data regarding what is happening with the job is collected. Also, it helps to make comparison with the present level of performance. The various data pertaining to materials rejection, process variations, equipment failures, operator efficiency, operator absenteeism, tool life, etc., are collected and analyzed for the purpose of progress reporting. These data are used for performing variance analysis, which would help us to identify critical areas that deserve immediate attention for corrective actions.
- *Corrective action.* The tasks under corrective action primarily make provisions for an unexpected event. Some examples of corrective actions are: creating schedule flexibility, schedule modifications, capacity modifications, make or buy decision, expediting the work, pre-planning, and so on.

Due to unforeseen reasons such as, machine breakdown, labour absenteeism, too much rejection due to poor material quality etc., it may not be possible to realize the schedule as per the plan. Under such conditions, some minor adjustments are required to have schedule flexibility in short-run (day-to-day basis or, weekly basis).

After having initiated the process of manufacturing a product, sometime we may receive message to cancel a portion of the order size, which has been previously confirmed or, ordered. This would seriously affect the whole production schedule starting from materials procurement. Under such condition, it is better to reschedule the whole product mix so that we get a clear picture of the situation to progress further.

SCHEDULING

INTRODUCTION

- Scheduling is considered to be a major task for shop floor productivity improvement.
- Scheduling is the allocation of resources applying the limiting factors of time and cost to perform a collection of tasks.
- Scheduling problem is taken up only after solving the fundamental planning problem.
- It is of secondary importance when compared to the planning problem.
- Scheduling is considered only after answering these planning questions and knowing the availability of resources.
- Scheduling theory is concerned primarily with mathematical models that relate to the scheduling function and the development of useful models and techniques.

- The objective function generally consists of all costs in the system depending upon the type of scheduling decisions.

Technological planning deals with questions of facility design, vehicle/equipment utilization and personnel deployment. Once these decisions have provided a profile of the resources available, it is then possible to deal with scheduling problems. These examples address themselves to three kinds of questions:

- ✓ What product or service is to be provided?
- ✓ On what scale will it be provided? and
- ✓ What resources will be made available?

Planning function provides answers to these questions. The scheduling function assumes that answers to these questions are already available. In particular, the quantitative approach translates the decision-making goals into an explicit objective function and various decision making restrictions into explicit constraints.

Frequently, an important cost-related measure of system performance (such as machine idle time, job waiting time or job lateness or a combination of these measures) can be used as a substitute for total system cost.

Two kinds of feasibility constraints are commonly found in scheduling problems.

1. The first set of constraints is related to the amount of resource available (like number of machines available in each type).
2. The second set of constraints is based on technological restrictions on the sequence in which tasks can be performed.

The objectives of the scheduling problem are listed below. Determining the sequence in which tasks are to be performed.

- Determining the start time and finish time of each task.
- In other words, the essence of scheduling is to make allocation decisions pertaining to start and finish times for tasks

Scheduling can be classified into

1) Single Machine Scheduling
2) Flow shop Scheduling and
3) Job shop Scheduling.

LINE BALANCING

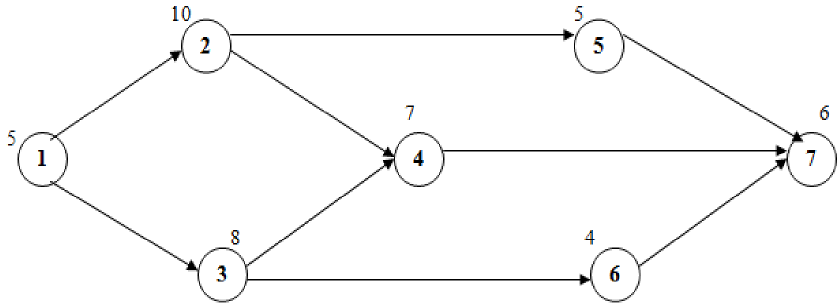
CONCEPT OF MASS PRODUCTION SYSTEM

Many differences exist in the management of production activities in make-to-order and make-to-stock firms. In make-to-order situations, due dates are important, and hence the sequencing of customer orders at various machine centers is an essential function. This involves both planning and control of activities. Make-to-stock products are generally high-volume consumer goods, such as telephones, automobiles, wristwatches, etc.

In high-volume items, it requires flow shops control for effective production. A flow shop consists of a set of facilities through which work flows in a serial fashion. The same operations are performed repeatedly in every workstation, thus requiring lower-level skilled workers. The flow shop generally represents a mass production situation.

In flow shops, items enter the finished goods inventory one after another, often in the same order of the inputs for these goods, leaving very low in-process inventories. Since the items are mostly make-to-stock, forecasting is a difficult job, and hence the finished goods levels in terms of anticipation inventories are very high.

The production control system of continuous production is called flow control. The main objective of flow control in flow shop is to balance the assembly line. The assembly line is represented in the form of a precedence diagram.



A Sample precedence diagram (timings are in minutes)

A precedence diagram specifies the order or sequence in which the activities must be performed.

- Each Circle [O] is a node
- Number inside the circle identifies particular operation
- Number outside the circle represents the duration of the operation
- Arrow indicates the direction of flow of operation
- Timings will be in minutes

CYCLE TIME

Cycle Time (CT) is directly related to the production rate of the assembly line.

CT = Productive Time / Demand per period

The range for the cycle time is given below:
$t_{max} \leq CT \leq \ t_i$

Where t_i is the processing time of the operation i and t_{max} is the maximum processing time among various operations.

OBJECTIVE OF ASSEMBLY LINE BALANCING

The objective of assembly line balancing is to subdivide the network into several sub networks (stations) without violating the precedence relationships and allocating operations to each station without exceeding the cycle time, i.e., the sum of the times of operations allocated to each station without exceed the cycle time.

While allocating operations to each station, the precedence relationship must be maintained. If these are followed, then we can ensure production of the specified volume of products or items using the assembly line.

This type of problem comes under combinational category. So we will have to use some efficient heuristics for this purpose.

In this section the following heuristics are discussed.

1. Ranked Positional Weight (RPW) method.
2. COMSOAL

The first one is mainly based on the ranks generated for each operation. The second heuristic uses simulation as the basis. Irrespective of techniques, a generalized procedure for line balancing is given below.

GENERALIZED ALGORITHM OF LINE BALANCING

Step 0: Input: Cycle Time (CT), precedence matrix, total number of work elements (M), work elements times.

Initialize: unassigned cycle time (UACT) = CT, station number (SN =1) and total number of assigned work elements (N) = 1.

Step 1. Print the station number (SN)

Step 2. Initialize the total number of assigned work elements counter to one, i.e. ***I* = 1.**

Step 3. If the I^{th} work element is already assigned, go to step 7, otherwise go to step 4.

Step 4. If all the immediate precedors of the I^{th} work element are assigned, then go to step 5; otherwise go to step 7.

Step 5. In the I^{th} work element time is less than or equal to the unassigned cycle time (UACT), then go to Step 6, otherwise go to Step 7.

Step 6. Include the I^{th} work element in the List A which consists of work elements whose all immediate precedors are assigned and the processing time of each work element is less than the unassigned cycle time (UACT).

Step 7. Increment the total number of assigned work elements counter by one, i.e. ***I* = *I* + 1.**

Step 8. If $I \leq M$, then go to Step 3; otherwise go to step 9.

Step 9. If the number of work elements in the List A is more than 0, then go to step 11; otherwise go to Step 10.

Step 10. Perform the following and then go to Step 2.

i. Add UACT to the sum of unassigned cycle time (SUACT)
ii. Update UACT = CT
iii. Update SN = SN + 1
iv. Print SN

Step 11. If the number of work elements in the List A is equal to one, then assign that work element to the current station; otherwise select a work element from the List A using a given HEURISTIC.

Step 12. Subtract the recently assigned work element time from UACT and print the recently assigned work element's number.

Step 13. Update N = N + 1
Step 14. If N ≤ M, then go to Step 2; otherwise go to Step 15.

Step 15. Compute the Balancing Efficiency (BE) in percentage.

BE = [1 – (SUACT / CT * SN)] * 100
Step 16. Stop.

RANKED POSITIONAL WEIGHT METHOD

- Helgeson and Brinie developed the ranked positional weight method.
- This method assigns those jobs first whose followers have the largest total time.
- The positional weight of a work element is its own processing time plus the processing times of all the following work elements.
- The work element with the highest positional weight is selected and assigned to the current station.

COMSOAL METHOD

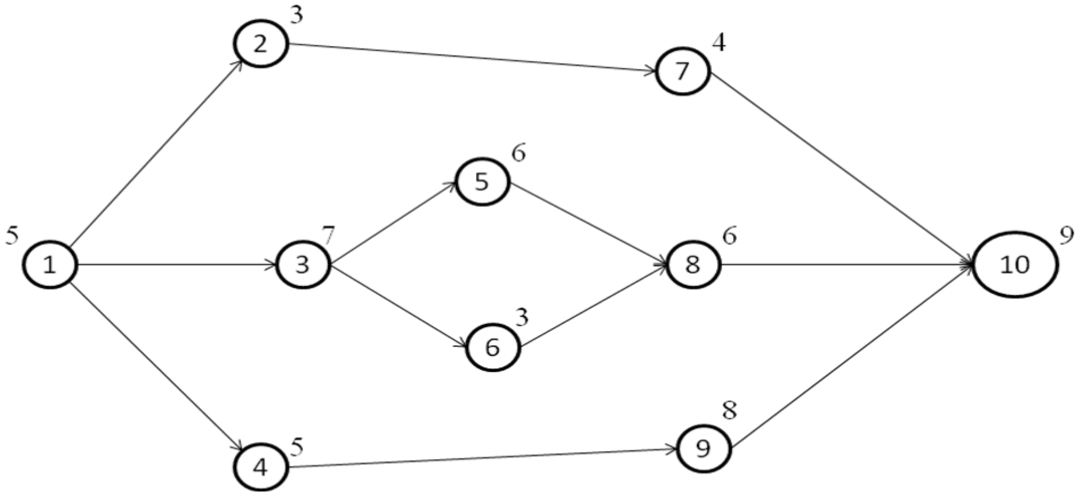
- Arcus developed the Comsoal Method.
- It generates large number of feasible solutions using a simulation (the process of designing the data) method.
- Among them we choose the solution that satisfies our needs most.

After forming the list A, use the following rules in the Step 11 of the generalized algorithm for assigning tasks to the current station from the List A. Rules are as follows:

1. All its immediate predecessors are already assigned.
2. Its processing time is less than or equal to the UACT.

Apply all steps to get a complete solution. Comsoal is an iterative method.
The solution with the maximum Balancing Efficiency out of several iterations is selected as the best solution for implementation.

Problem: Consider the assembly network shown below which shows the precedence relationships in assembling a product.



The number by the side of each node represents the processing time in minutes. The required production volume in 8 hour shift is 24 completed assemblies. Design an assembly line using RPW method.

Solution:

$$\text{Cycle time (CT)} = \frac{\text{Production time}}{\text{Production volume}}$$

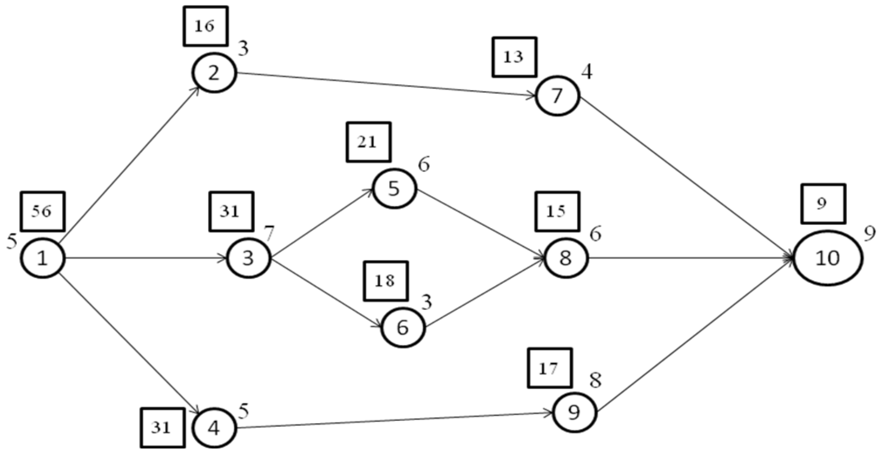
$$= \frac{8 \times 60}{24} = 20 \text{ minutes}$$

Compute the positional weight of all the work elements in the network as shown below:

Details of Work Element

Work Element No.	Time	Positional Weight	Immediate Predecessors		
1	5	56	-	-	-
2	3	16	1	-	-
3	7	31	1	-	-
4	5	31	1	-	-
5	6	21	3	-	-
6	3	18	3	4	-
7	4	13	2	-	-
8	6	15	5	6	-
9	8	17	4	-	-
10	9	9	7	8	9

Precedence Diagram with Positional Weights



A work element can be included in the List A if it can satisfy the following two conditions:

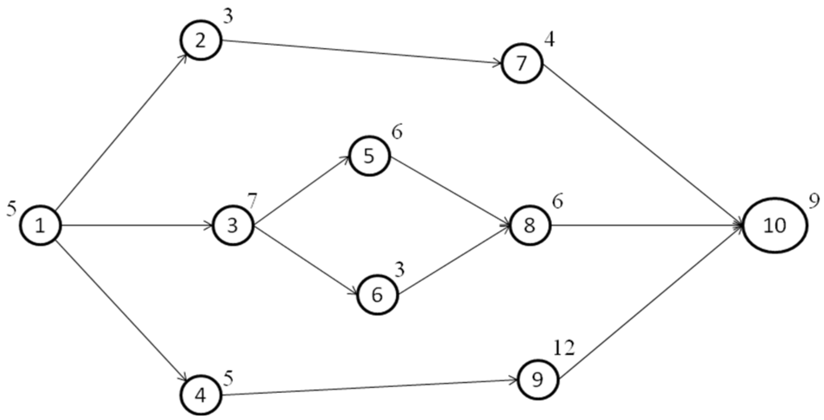
1. All its immediate predecessors are already assigned to some stations.
2. Its processing time is less than or equal to the UACT.

Details of Station

Station No.	List A	Work Element Selected	Unassigned Cycle Time UACT	Remarks
1	-	-	20	-
	1	1	20 – 5 = 15	-
	2, 3, 4	4	15 – 5 = 10	Break tie b/n 3 & 4 randomly
	2, 3, 9	3	10 – 7 = 3	-
	2, 6	6	3 – 3 = 0	Change over to next station
2	-	-	20	-
	2, 5, 9	5	20 – 6 = 14	-
	2, 8, 9	9	14 – 8 = 6	-
	2, 8	2	6 – 3 = 3	Change over to next station
3	-	-	20	-
	7, 8	8	20 – 6 = 14	-
	7	7	14 – 4 = 10	-
	10	10	10 – 9 = 1	-

Balancing Efficiency (BE) = [1 – (SUACT / CT * SN)] * 100
= [1 – (4 / 20x3)] * 100 = 93.33%

Problem: Consider the assembly network shown below which shows the precedence relationships in assembling a product.



The number by the side of each node represents the processing time in minutes. The required production volume in 8 hour shift is 24 completed assemblies. Design an assembly line using COMSOAL method.

Details of Work Element

Work Element No.	Time	Immediate Predecessors		
1	5	-	-	-
2	3	1	-	-
3	7	1	-	-
4	5	1	-	-
5	6	3	-	-
6	3	3	4	-
7	4	2	-	-
8	6	5	6	-
9	8	4	-	-
10	9	7	8	9

Iteration I

Details of Station

Station No.	List A	Work Element Selected	Unassigned Cycle Time UACT	Remarks
1	-	-	20	-
	1	1	20 – 5 = 15	No need to use any rule
	2, 3, 4	3	8	Task 3 is selected
	2, 4, 5	5	2	Task 5 is selected
2	-	-	20	-
	2, 4	4	15	Task 4 is selected
	2, 6, 9	9	3	Task 9 is selected
	2, 6	2	0	Task 2 is selected
3	-	-	20	Task 7 is selected
	6, 7	7	16	No need to use any rule
	6	6	13	No need to use any rule
	8	8	7	Change over to next station
4	-	-	20	-
	10	10	11	-

Balancing Efficiency (BE) = [1 – (SUACT / CT * SN)] * 100

= [1 – (20 / 20x4)] * 100 = 75%

Station Details

Station No.	1	2	3	4
Work Element Assigned	1, 3, 5	2, 4, 9	6, 7, 8	10

Iteration II

Details of Station

Station No.	List A	Work Element Selected	Unassigned Cycle Time UACT	Remarks
1	-	-	20	-
	1	1	15	No need to use any rule
	2, 3, 4	3	8	Task 3 is selected
	2, 4, 5	5	2	Task 5 is selected
2	-	-	20	-
	2, 4	4	15	Task 4 is selected
	2, 6, 9	9	3	Task 9 is selected
	2, 6	6	0	Task 6 is selected
3	-	-	20	-
	2, 8	8	14	Task 8 is selected

	2 7	2 7	11 7	No need to use any rule Change over to next station
4	- 10	- 10	20 11	- -

Balancing Efficiency (BE) = [1 – (SUACT / CT * SN)] * 100
= [1 – (20 / 20x4)] * 100 = 75%

Station Details

Station No.	1	2	3	4
Work Element Assigned	1, 3, 5	4, 6, 9	2, 7, 8	10

Extra Problems:

Problem 1: Consider the following assembly network relationship of the product. The number of shifts per day is 3 and the number of working hours per shift is 8. The company aims to produce 60 units of the product per day. Group the activities into work stations using RPW method and compute balancing efficiency.

S. No.	Immediate Preceding Task	Duration (Minutes)
1	-	8
2	1	12
3	1	15
4	2	10
5	2	14
6	2	9
7	3	11
8	3	16
9	3	20
10	4, 5	8
11	6, 7	13
12	7, 8, 9	17
13	10, 11	6
14	11, 12	5
15	13, 14	12

(Answer: BE = 81.48%)

Problem 2: Considered the following assembly network relationship of a product. The number of shifts per day is 1 and the number of working hours per shift is 8. The company aims to produce 40 units of the product per shift. Group the activities into work stations using RPW method and compute balancing efficiency.

S. No.	Immediate Preceding Task	Duration (Minutes)
1	-	8
2	1	3
3	1	2
4	1	4
5	1	7
6	3, 7	4
7	2	5
8	4, 5	6
9	2, 6	8
10	6, 8, 9	9
11	5	4
12	9, 10	3
13	8, 10, 11	6
14	12, 13	3

(Answer: BE = 85.71%)

Problem 3: Consider the following assembly network relationship of a product. The number of shifts per day is 2 and the number of working hours per shift is 8 hours. The company aims to produce 80 units of the product per day. Group the activities into work stations using RPW & COMSOL method and compute balancing efficiency.

S. No.	Immediate Preceding Task	Duration (Minutes)
1	-	7
2	1	2
3	1	2
4	1	5
5	2, 3	8
6	3, 4	3
7	5	4
8	5, 6	7
9	4, 6	9
10	7, 8, 9	8

(Answer: RPW: BE = 76.39% & COMSOL: BE = 76.39%)

Problem 4: Assembly line for manufacture of the company considered the precedence diagram of the assembly line is shown below. If the production time volume per shift is 300 units. They require production volume per day in one shift is 28,800 seconds. Design the assembly line using RPW method such that the balancing efficiency is maximized.

S. No.	Immediate Preceding Task	Duration (Seconds)
1	-	15.3
2	1	43.3
3	2	61.4
4	3	65
5	4	57.2
6	5	3.3
7	6	2.2
8	7	4.5
9	8	20.3
10	-	17.5
11	10	9.4
12	11	10
13	12	7
14	-	9
15	13, 14	30
16	15	10.5
17	16	6.3
18	17	25
19	9, 18	94.1
20	19	32.3
21	19	62.5
22	21	10.5
23	20, 22	95.7

(Answer: BE = 85.71%)

QUALITY CONTROL

Those activities which assure that quality creation is performed in such a manner that the resulting product will be, in fact performing its intended function. When used in this sense, quality control can be divided into two fundamental endeavors: assurance that the product characteristics selected will achieve the intended result and assurance that items produced contain the specified characteristics. In a more limited sense, quality control is frequently used to refer to a specific organization within the industrial enterprise which is assigned responsibility for many of the activities necessary to achieve quality objectives. In short, we can say that quality control is a technique of management for achieving required standard of products.

- In any business organization, profit is the ultimate goal. To achieve this, there are several approaches.
- Profit may be maximized by cutting costs for the same selling price per unit.
- If it is a monopolistic business, without giving much of importance to the cost reduction programs, the price may be fixed suitably to earn sufficient profit.
- But, to survive in a competitive business environment, goods and services produced by a firm should have the minimum required quality.
- Extra quality means extra cost. So, the level of quality should be decided in relation to other factors such that the product is well absorbed in the market.
- In all these cases, to have repeated sales and thereby increased sales revenue, no one will deny the fact that the basic quality is considered to be one of the supportive factors.

Quality is a measure of how closely a good or service conforms to specified standard. Quality standards may be any one or a combination of attributes/variables of the product being manufactured. The attributes will include performance, reliability, appearance, commitment to delivery time, etc. Variables may be some measurement variables like, length, width, height, diameter, surface finish, etc. Quality assurance is the system of policies, procedures and guidelines which help in building specified standards of product/service quality.

There is no simple way to define a quality system. In general, a quality system is a part of overhead. The system does not add any value to the products. It only ensures that the product works and meets customer expectations.

A quality system is a process that combines with manufacturing process *to ensure that a manufacturing process produces quality-perfect products*. The scope of a quality system is more than a manufacturing process.

A quality system covers areas related to the suppliers who produce parts for the product. It also covers other departments in the company to ensure that customers are properly informed, trained and serviced whenever problems are presented. Finally, it covers the design department to ensure that products are designed to specifications and they perform as intended.

What Is Quality? Quality may be defined as the sum total of features of a product which influence its ability to satisfy a given demand.

Basically the quality of products and services is not defined or determined by producing firms, it is determined by customers."The quality of Product or service is a customer's perception of the degree to which the product or service meets his expectations.
Dimensions of product Quality: Some dimensions of product quality are:

(1) **Performance:** How will the product service perform and meet the customer's intended use. For example, the speed of a sports car.
(2) **Features:** The special characteristics that appeal to customers. For example, the power steering of an automobile.
(3) **Reliability:** The likelihood of breakdowns, malfunctions, or need fortepianos. Higher the reliability lesser will be the likelihood of breakdowns.

(4) Serviceability: The speed, cost and convenience of repairs and maintenance. Higher the serviceability better will be the quality of the product.
(5) Appearance: The effect or human senses, the look, feel, taste, smell or sound.
(6) Customer Service: The treatment received by customers before, during and after the Sale.
(7) Safety: How well the product protects users before, during and after use.

Objectives: The ultimate aim of quality control is to provide Products which are dependable, satisfactory and economical. A quality control system is designed to ensure economical production of products of uniform quality which is acceptable to the customer.

Quality control aims at preventing the defects rather than detecting the defects.

Benefits of Quality Control

- **M**inimum scrap or rework due to reduced defectives.
- Reduced cost of labour and material as a result of reduced defectives.
- Uniform quality and reliability of product help in increasing sales turn over.
- Reduced variability resulting in_higher quality and reduced production bottle necks.
- Reduced inspection and reduced inspection costs.
- Reduced customer complaints.
- Increased quality consciousness among employees.
- Higher operating efficiency.
- Better utilization of resources.
- Better customer satisfaction and employee satisfaction.

Quality Assurance: Quality assurance is the activity of providing the evidence needed to establish confidence that the quality related activities are being performed effectively. It is defined as “all those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirement for quality”. Quality assurance encompasses **Quality planning, quality control, quality improvement, quality audit and reliability.**

Organization for Quality Control

Quality control is a staff function concerned with the prevention of defects in manufacturing so that items may be made right at the first time and not to be rejected latter. In order to achieve this end, several activities to be performed. There must be inspection and control of incoming raw materials to ensure that they meet specification there must be planning and control of manufacturing processes to ensure that suitable methods are being used and that machines and equipment are performing satisfactorily there must be in process inspection and testing for product performance. In pursuance of these activities, several techniques must be employed.

In order to carry on these functions a separate department is created which is called Quality control department or simply, department of quality. The person who heads this department carries the title of manager of quality control, assurance or chief inspector. The level quality control in an organization is influenced by several factors, namely, the quality level of significance thus each company must establish a type of organization which best fulfils its needs. Frequently, the quality control department its composed of a quality engineering function, an inspection function, and a laboratory function.
It should be stated that quality control is not the responsibility of only the personnel in the quality control department. Everybody in the organization must be equally responsible to ensure quality of the end product.

Quality involves the members of management who set the quality policies, the salesmen who contract to sell products of a certain quality, the design engineers who set the product specifications, the buyers who purchase raw materials of the right quality and the manufacturing personnel who are responsible for making product according to the prescribed specification. It is only through the whole heated cooperation of all the people that a sustained quality control programme can be maintained.

Ensuring Quality

Ensuring Quality involves action on several fronts. To be specific, quality control involves the following steps:

A. Control of Engineering Quality

- Assist in the evaluation of customer requirements to arrive at a clear understanding of the product quality objectives.
- Review design documentation for conformance to design standards and practice and for identification of potential quality problems.
- Validate the accuracy and completeness of design proof tests and qualification tests.
- Audit the release and distribution of design documents to assure that all drawings and specifications in use are current and correct.
- Provide information on previous quality problems encountered for consideration in new product designs or current product improvements.

B. Control of Purchased Material Quality

- Assist in the evaluation and selection of potential suppliers or subcontractors.
- Review purchase orders and subcontractors for correctness and completeness of quality requirements.
- Assure that purchased material conforms to the requirements of purchase orders and specifications.
- Initiate corrective action with suppliers and subcontractors when purchased material is not of an acceptable quality level.

C. Control of Manufacturing Quality

- Evaluate and approve manufacturing equipment, processes, testing, and test equipment.
- Assure that measuring and test equipment is properly calibrated and maintained.
- Establish points of inspection and tests at selected points in the production processes.
- Perform inspection and tests at selected points in the production processes.
- Collect and analyze inspection and test data and provide information on process and product quality levels.
- Initiate corrective action on out of control conditions and related quality problems.
- Conduct follows up to assure that corrective action is accomplished in a timely manner.
- Control the handling, preservation, and packaging of material and equipment from receipt through shipment of the final product.

D. Action Supporting the Product after Delivery

- Assure that product service specifications are clear and correct.
- Assure that spare parts conform to quality requirements.
- Assure that repair and modification are performed in accordance with company quality requirements.
- Gather and analyze complaint data from the field to measure the degree of customer satisfaction and initiate appropriate corrective action.

NEED FOR QUALITY CONTROL

In the absence of quality, the following will result:

(a) No yardstick for comparing the quality of goods/services.
(b) Difficulty in maintaining consistency in quality.
(c) Dissatisfied customers due to increased maintenance and operating costs of products/ services.
(d) Increased rework cost while manufacturing products/providing services.
(e) Reduced life time of the products/services.
(f) Reduced flexibility with respect to usage of standard spare parts.

Hence, controlling quality is an essential activity.

OBJECTIVES OF QUALITY CONTROL

- To make the company's product more acceptable by the customer and thereby increase the sales of the company.
- To reduce cost of production by proper control of outgoing products by reducing the defects.
- To maintain quality of products by taking necessary corrective measures.
- To develop quality consciousness in the organization.
- To ensure that sub-standard products do not reach the customers.

The basic components of product quality are listed below:

- Careful consideration of product design specifications.
- Adequate inspection procedures for manufactured or assembled products.
- Acceptance procedures for purchased raw materials and parts, and control practices to maintain quality levels in in-process stage.
- Commitment from top management, lower levels of management and supervisors towards quality.
- Formulation for quality assurance procedures which are necessary to integrate and coordinate all these functions

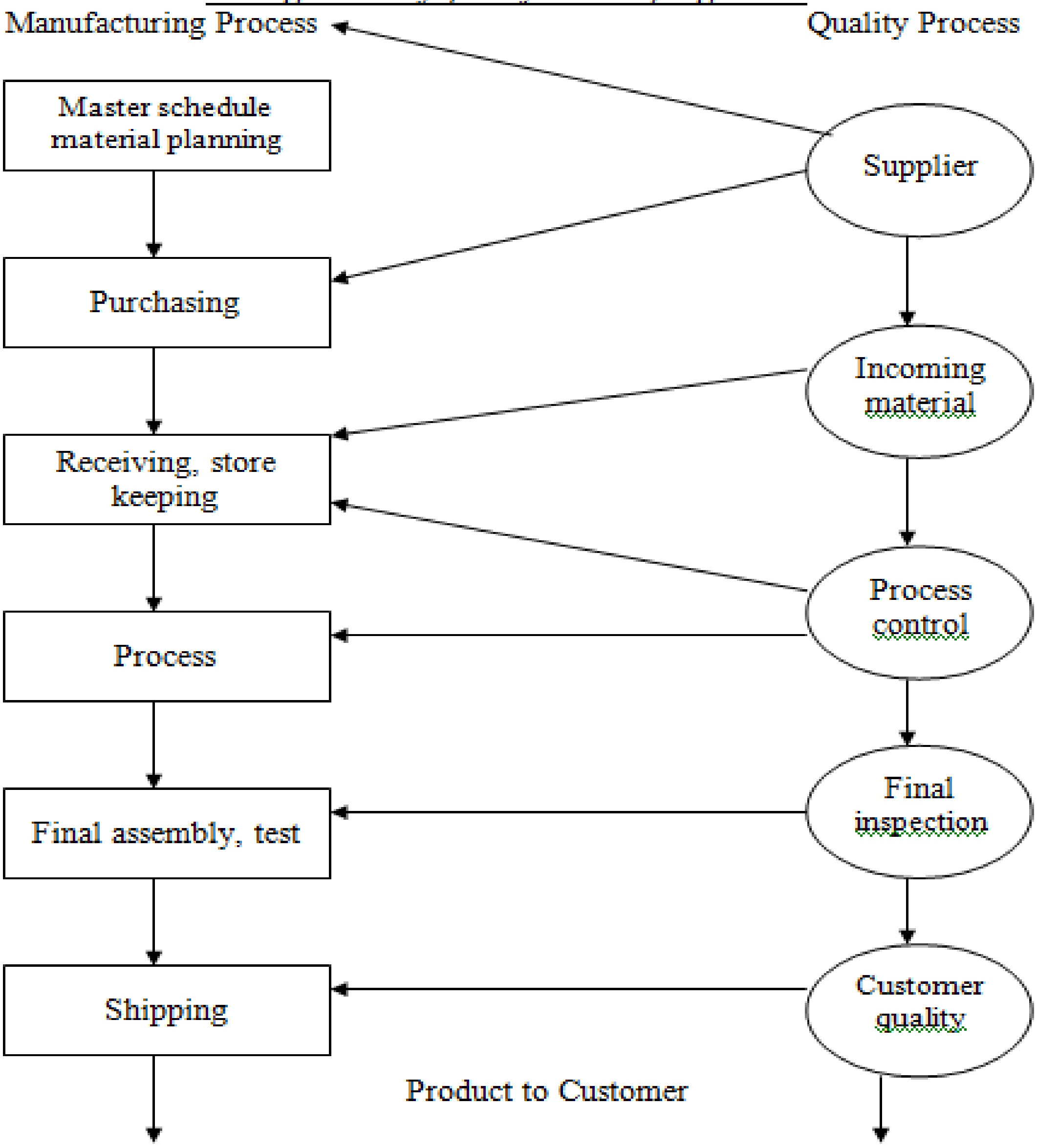
STRATEGIC AREA OF QUALITY CONTROL PROGRAMME

Strategic areas of quality control program in manufacturing are as follows:

1) Supplier quality
2) Incoming raw materials quality
3) Process quality
4) Final Inspection
5) Customer quality

Statistical quality control deals with decisions related to the functions of specification, production or inspection.

Strategic area of quality control programme



CLASSIFICATION OF QUALITY CONTROL TECHNIQUES

The quality control techniques can be classified as shown below:

Quality Control Techniques

- Control Charts
  - For Variables
    - X chart
    - R chart
  - For Attributes
    - P chart
    - C chart
- Acceptance Sampling
  - For Variables
    - Plan with α
    - Plan with α and β
  - For Attributes
    - Single sampling plan
    - Double sampling plan
    - Multiple sampling plan

CONTROL CHARTS

It is very simple but powerful graphic method of finding if a process is in statistical control or not. The chart contains 3 horizontal lines viz.

1. Control line to indicate the process control level
2. An upper control limit (UCL) – upper limit of tolerance
3. A lower control limit (LCL) – lower limit of tolerance.

Control chart has a central line which indicates the desired average quality level of the product. The two lines, one above and one below this line are called the upper and the lower control limits, respectively. These limits are established to assist in judging the significance of the variation in the quality of the product. It may be noted that the control limits are different from the specification limits. Whereas the specification limits refer to the quality characteristic of an individual unit of the product, the control limits are used to evaluate the variation in quality from sample to sample.

ACCEPTANCE SAMPLING

The objective of acceptance sampling is to take decision whether to accept or reject a lot based on sample's characteristics. The lot may be incoming raw materials or finished parts. An accurate method to check the quality of lots is to do 100% inspection. But, 100% inspection will have the following limitations.

- The cost of inspection is high.
- Destructive methods of testing will result in 100% spoilage of the parts.
- Time taken for inspection will be too long.
- When the population is large or infinite, it would be impossible or impracticable to inspect each unit.

Hence, acceptance sampling procedure has lot of scope in practical application. Acceptance sampling can be used for attributes as well as variables.

Acceptance sampling deals with accept or reject situation of the incoming raw materials and finished goods. Let the size of the incoming lot be N and the size of the sample drawn be n. The probability of getting a given number of defective/good parts out of a sample consisting of n pieces will follow Binomial Distribution. If the lot size is infinite or very large, such that when a sample is drawn from it and not replace, then the usage of binomial distribution is justified. Otherwise, we will have to use hyper-geometric distribution.

Specifications of a single sampling plan will contain a sample size (n) and an acceptance number C. As an example, if we assume the sample size as 50 and the acceptance number as 3, the interpretation of the plan is explained as follows: Select a sample of size 50 from a lot and obtain the number of defective pieces in the sample. If the number of defective pieces is less than or equal to 3, then accept the whole lot from which the sample is drawn. Otherwise, reject the whole lot. This is called single sampling plan. There are several variations of this plan.

In this process, one will commit two types of error, viz. Type I error and Type II error. If the lot is really good, but based on the sample information, it is rejected, and then the supplier/producer will be penalized. This is called producer's risk or Type I error. The notation for this error is a. On the other hand, if the lot is really bad, but it is accepted based on the sample information, then the customer will be at loss. This is called consumer's risk or Type II error. The notation for this error is 0. So, both parties should jointly decide about the levels of producer's risk (a) and consumer's risk (β) based on mutual agreement.

TOTAL QUALITY CONTROL (TQC)

It is quality control and improvement from shop floors to board rooms. It is an effective system for integrating quality development, quality maintenance and quality improvement efforts of various groups in an organizations.

What is Total Quality Management (TQM)

A philosophy that involves everyone in an organization in a continual effort to improve quality and achieve customer satisfaction.

Six Basic Concepts in TQM

1. Top management commitment and support.
2. Focus on both internal and external customers.
3. Employee involvement and empowerment.
4. Continuous improvement (KAIZEN)
5. Partnership with suppliers
6. Establishing performance measures for processes

8 Essentials of TQM Focus

1. Customer satisfaction
2. Leadership
3. Quality policy
4. Organization structure
5. Employee involvement
6. Quality costs
7. Supplier selection and development
8. Recognition and reward

Seven Underlying Principles in TQM

1. Strive for quality in all things
2. The customer is the creation of quality
3. Improve the process or systems by which products are produced
4. Quality improvement is continuous, never ending activity
5. Worker involvement is essential
6. Ground decisions and actions on knowledge
7. Encourage teamwork and cooperation

Scope of TQM

- Are integrated organizational infrastructure
- A set of management practices
- A wide variety of tools and techniques

Deming’s 14 Points for Quality Management

W. Edwars Deming is an USA statistician & consultant known as father of quality control.

1. Create constancy of purpose for continual improvement of product/services
2. Adopt the new policy for economic stability
3. Cease dependency on inspection to achieve quality
4. End the practice of awarding business on price tag alone
5. Improve constantly and forever the system of production and service
6. Institute training on the job

7. Adopt and institute modern method of supervision and leadership
8. Drive out fear
9. Breakdown barriers between departments and individuals
10. Eliminate the use of slogans, posters and exhortations
11. Eliminate work standards and numerical quotas
12. Remove barriers that rob the hourly worker of the right to pride in workmanship
13. Institute a vigorous program of education and retraining
14. Define top management's permanent commitment to ever improving quality and productivity

Deming Wheel / Deming Cycle / P-D-C-A Cycle

- P – Plan (process) the improvement
- D – Do implement the plan
- C – Check-Check how closely result meets goals
- A – Act-Use the improved process as standard practice

ISO CERTIFICATION

ISO is the International Organization for Standardization, set up with the objective to promote the development of standards and related activities, for facilitating international exchange of goods and services.

It is mechanism by which customer can have confidence in a company and is most effective when carried out by a national certification body. The ISO certification is application to quality management system encompassing quality in all functions such as marketing design, purchase, manufacture, assembly testing, packing, shipping, installations, after sales service and all other activities of an organization. A properly established quality management system will help to reduce cost, improve quality, and develop confidence and a good image in the minds of customers and public. This requires consistent implementation, careful auditing and total commitment of the whole organization.

CHARACTERISTICS OF ISO

1. ISO 9000 is the only available internationally accepted standard for quality management system.
2. It does not replace but complements the product standards.
3. ISO 9000 is applicable to all types of industries or organization in manufacturing or service sector.
4. It stands for systematic standardization and certification rather than product standardization and certification.
5. ISO 9000 is a documentation oriented system which allows complete freedom on selection and use of processes and framing of operating procedures and work instruction.
6. A mistake made in selection of proper product standard can never be compensated by ISO 9000 implementation.

ISO 9000: ISO 9000 series of standards developed in 1987, relate to quality systems. It has evolved from the standardization of quality policy assurance system standards of several nations all over the world. The standards allow a wide flexibility, but at the same time, are rigid too. They permit a supplier to formulate his own quality policy and write the quality manual, producers and instructions in his own way, within the framework of the system elements, but does not allow rendering on non-conforming products or services.

CHARACTERISTICS OF ISO 9000

1. ISO 9000 can be implemented in any type and size of organization.
2. It is independent of the product, size and country.
3. It has international acceptance and recognition.
4. It ensures consistent improvement in quality.

DIFFERENT AREAS IN ISO 9000 SERIES

There are five standards in the ISO 9000 series Viz. ISO 9000, ISO 9001, ISO 9002, ISO 9003 and ISO 9004. ISO 9000, 9001, 9002 & 9003 are applicable to contractual situation.
ISO 9004 is for non-contractual cases and is used for internal management purpose.

1. ISO 9000 provides the guidelines for selection and use of the quality standards.
2. ISO 9001 is a quality system model for quality assurance in design/development, production, installation and servicing. This is most exhaustive standard. The engineering organizations, where the manufacturing capabilities are based on in-house designs have to work for ISO 9001 certification manufacturing of

    i) Household goods like TV, refrigerator etc,
    ii) Perishable consumer goods like toothpaste etc., which have both servicing and design/development, have to work towards ISO 9001.

3. ISO 9002 provides a model for quality assurance only in production and installation. This does not cover areas of design or development and servicing. ISO 9002 also looks at internal quality audits, steel plants, department stores, hospitals, chemical plants etc., where the designing and servicing do not constitute the key activities, may prefer ISO 9002.
4. ISO 9003 deals only with quality systems related to final inspection and testing.
5. ISO 9004 provides guidelines for quality management and quality system elements.

In addition to the ISO 9000 series, ISO 8402 deals with vocabulary used in the ISO 9000 series.

ADVANTAGES OF ISO STANDARDS

ISO standards give tremendous advantages to those holding their certification. Some of these advantages are briefly discussed below for different categories of groups or institutions.

1. For Users

a) Confidence in quality and reliability of product and services received
b) Economy and competitive prices
c) Assured after sales services
d) Traceability of manufacturer, design and specification

2. For Suppliers

a) Easy vendor identification
b) Rationalization of component product based on international standard/specification.
c) Simplified controls for long-range contracts
d) Availability of a worldwide on-line database called CODUS

3. For Manufacturers

a) Rationalization of product range
b) No huge investment of Inward Goods Inspection (IGI) departments
c) No need to have separate vendor identification/development/evaluation process
d) No multiple agency certification of quality
e) Cost reduction due to reduced reward and scraps

4. For Marketing

a) Global Visibility
b) Provide national/international reputation
c) Competitiveness
d) Assured international quality level

Production Planning and Control (PPC) Processes

Production Planning and Control is the process of navigating the transformation of raw materials into finished goods by managing people, machines, and materials. It is generally divided into three main stages: **Planning**, **Action**, and **Monitoring/Control**.

1. The Planning Phase (Pre-Production)

This stage involves establishing the roadmap for production before any physical work begins.

A. Demand Forecasting

Estimating the quantity of products customers will purchase in the future. This serves as the foundation for all subsequent planning.

B. Aggregate Planning

Creating a high-level production plan for the medium term (typically 3 to 18 months). It balances production rates, workforce levels, and inventory to meet forecasted demand at minimum cost.

C. Master Production Schedule (MPS)

The "Disaggregation" of the aggregate plan. It specifies exactly which end items will be produced and when.

- **Input:** Customer orders and forecasts.
- **Output:** A weekly or daily production requirement list.

D. Routing

Determining the precise path (sequence of operations) a product must take through the factory.

- Defines which machines will be used.
- Establishes the standard time for each operation.
- Sets the quality checkpoints.

E. Loading

Assigning specific work to specific machines or work centers.

- **Infinite Loading:** Assigning work without regard to capacity (used to see where bottlenecks appear).
- **Finite Loading:** Assigning work only up to the actual capacity of the work center.

F. Scheduling

The final step of planning that assigns start and end times to every operation.

- **Forward Scheduling:** Starting a job as soon as requirements are known.
- **Backward Scheduling:** Starting from the due date and working backward to determine the latest possible start date.

2. The Action Phase (Execution)

This phase bridges the gap between the "paper plan" and the shop floor.

A. Dispatching

The transition from planning to execution. It involves issuing formal orders to:

- Release raw materials from the warehouse.
- Authorize the start of work on specific machines.
- Provide technical drawings and instruction sheets to operators.

3. The Control Phase (Post-Execution)

This stage ensures that the actual production matches the planned production.

A. Progress Reporting (Follow-up)

Monitoring the actual progress of work on the floor. It identifies deviations from the schedule.

B. Expediting

Taking action to clear bottlenecks or speed up "behind-schedule" jobs. This might involve authorizing overtime, shifting workers, or changing machine priorities.

C. Inspection

Verifying that the output meets the quality standards set during the planning phase.

D. Corrective Action & Evaluation

Analyzing why gaps occurred between the plan and the actual performance.

- **Feedback Loop:** If a machine consistently underperforms, the "Routing" and "Loading" data must be updated for future cycles to ensure plans remain realistic.

Summary of the PPC Cycle

1. **Plan:** What, How, Where, and When?
2. **Execute:** Authorize and Start.
3. **Control:** Monitor, Compare, and Adjust.

Job Shop Production System

A **Job Shop** is a manufacturing process in which small batches of a variety of custom products are made. In this system, each "job" or order typically requires a unique sequence of operations and a specific set of instructions, making it the most flexible yet most complex production environment to manage.

1. Core Characteristics

- **High Variety, Low Volume:** The primary differentiator. It handles a vast range of products in very small quantities (often "one-off" items).
- **General-Purpose Machines:** Unlike mass production lines, job shops use versatile machines (e.g., CNC mills, lathes, 3D printers) that can perform multiple types of tasks.
- **Highly Skilled Workforce:** Operators must be versatile enough to interpret different technical drawings and set up machines for varied tasks.
- **Functional Layout:** Equipment is grouped by function (e.g., all welding machines in one area, all grinding machines in another) rather than by the sequence of a specific product.
- **Jumbled Flow:** Materials move in non-linear paths across the shop floor depending on their specific routing requirements.

2. The Job Shop Workflow

The lifecycle of a job in this system follows a non-standardized path:

1. **Quotation:** Since every job is different, the process starts with a cost estimate based on customer designs.
2. **Routing:** Engineers determine the specific sequence of departments the product must visit.
3. **Scheduling:** This is the most difficult step. Planners must decide when each job will hit each machine, often dealing with competing priorities from other jobs.
4. **Execution:** The job moves through functional departments. Work-in-Progress (WIP) levels are typically high because parts "wait" for machines to become available.
5. **Quality Control:** Every unique product requires individual inspection against its specific blueprints.

3. Advantages & Disadvantages

Advantages	Disadvantages

Flexibility: Can handle almost any custom request.	**High Costs:** Higher labor costs and no economies of scale.
Lower Initial Investment: General-purpose machines are often cheaper than specialized automated lines.	**Complex Planning:** Scheduling is a constant "puzzle" due to varying job paths.
Worker Satisfaction: Highly varied work keeps skilled operators engaged.	**Long Lead Times:** Jobs often spend 80-90% of their time waiting in queues.
Innovation: Ideal for prototyping and new product development.	**High WIP:** Lots of unfinished inventory cluttering the shop floor.

4. Key Examples

- **Custom Machine Shops:** Creating specialized components for aerospace or medical industries.
- **Commercial Printing:** Handling unique orders for books, brochures, and posters.
- **Bespoke Furniture:** Handcrafting tables or cabinets to specific customer dimensions.
- **Tool & Die Shops:** Manufacturing the molds and tools used by *other* factories.

5. PPC Challenges in Job Shops

In Production Planning and Control (PPC), job shops are notorious for **bottlenecks**. Because different jobs might all require the same "key" machine at the same time, queues form rapidly.

- **Loading:** Managers must carefully balance the "load" across departments to prevent some machines from being overwhelmed while others sit idle.
- **Expediting:** Frequently requires "hot jobs" to be moved to the front of the line, which disrupts the existing schedule.

Job Sequencing and Priority Rules

Job sequencing is the process of determining the order in which a set of tasks or jobs should be processed through one or more work centers. The goal is to optimize specific performance metrics such as minimizing lateness, reducing work-in-process (WIP) inventory, or maximizing machine utilization.

1. Common Priority Sequencing Rules

These rules are typically used in single-machine environments or at individual work centers

Rule	Description	Best For...
FCFS (First-Come, First-Served)	Jobs are processed in the order they arrive at the work center.	Perceived "fairness" to customers; simplicity.
SPT (Shortest Processing Time)	The job with the shortest processing time is done first.	Minimizing average flow time and WIP; high throughput.
EDD (Earliest Due Date)	The job with the earliest due date is processed first.	Minimizing maximum lateness and meeting deadlines.
LPT (Longest Processing Time)	The job with the longest processing time is done first.	Often used in multiple-machine settings to "get the big ones out of the way."
STR (Slack Time Remaining)	Slack Time = (Due Date − Current Time) − Remaining Processing Time the smallest slack time	Identifying jobs that are most at risk of being late.
CR (Critical Ratio)	Critical Ratio = (Due Date − Current Time) ÷ Remaining Processing Time The smallest ratio goes first	Dynamic environments where priorities change based on time.

2. Advanced Sequencing Algorithms

Johnson's Rule (jobs on 2 machines)

Used to minimize the total elapsed time (makespan) for a group of jobs that must pass through two machines in the same order (Machine A Machine B).

The Algorithm:

1. List all jobs and their processing times for both machines.
2. Find the smallest processing time among all remaining jobs on either machine.
3. **Rule:**
   - If the smallest time is on **Machine 1**, place that job as **early** as possible in the sequence.
   - If the smallest time is on **Machine 2**, place that job as **late** as possible in the sequence.
4. Remove the job from the list and repeat until all jobs are sequenced.

Job Sequencing with Deadlines (Greedy Algorithm)

Used when jobs have specific deadlines and varying profits. The goal is to maximize total profit by completing as many high-value jobs as possible within their deadlines.

3. Performance Metrics

To decide which rule is "best," managers evaluate the results using these formulas:

1. **Mean Flow Time:**
2. **Average Number of Jobs in System:**
3. **Average Lateness:**
4. **Utilization:**

4. Summary Comparison

- **SPT** is generally the best for reducing the number of jobs waiting in the shop and minimizing average flow time. However, it can cause long jobs to be delayed indefinitely ("starvation").
- **EDD** is the industry standard when the primary concern is customer satisfaction and meeting delivery dates.
- **FCFS** is common in service industries (like banks or retail) because it is easy to explain to customers, though it is often inefficient for manufacturing.

Johnson's Rule

Johnson's Rule is used for sequencing jobs through two machines (Machine 1 Machine 2). All jobs must follow the same processing order.

The Logic (Step-by-Step)

1. **Identify the Minimums:** Look at the processing times for all jobs on both machines. Find the absolute smallest value.
2. **Placement Rule:**
   - If the minimum time is on **Machine 1**, place that job at the **beginning** (the leftmost available slot) of the sequence.
   - If the minimum time is on **Machine 2**, place that job at the **end** (the rightmost available slot) of the sequence.
3. **Eliminate and Repeat:** Once a job is placed, cross it off your list. Repeat the process for the remaining jobs until the sequence is full.

Detailed Example (Problem 3 Breakdown)

Given the data from Problem 3:

Job	Machine 1 (Grinding)	Machine 2 (Painting)
1	5	2
2	3	6

3	8	4
4	10	7
5	7	12

Iteration 1

- **Smallest Value:** 2 (Job 1, Machine 2).
- **Action:** Since it is on Machine 2, Job 1 goes **LAST**.
- **Sequence:** [ ] - [ ] - [ ] - [ ] - [1]

Iteration 2

- **Smallest Value remaining:** 3 (Job 2, Machine 1).
- **Action:** Since it is on Machine 1, Job 2 goes **FIRST**.
- **Sequence:** [2] - [ ] - [ ] - [ ] - [1]

Iteration 3

- **Smallest Value remaining:** 4 (Job 3, Machine 2).
- **Action:** Since it is on Machine 2, Job 3 goes as **LATE** as possible (in the last available slot before Job 1).
- **Sequence:** [2] - [ ] - [ ] - [3] - [1]

Iteration 4

- **Smallest Value remaining:** 7. This appears twice: Job 4 (Machine 2) and Job 5 (Machine 1).
- **Action for Job 5:** It's on Machine 1, so it goes as **EARLY** as possible (after Job 2).
- **Action for Job 4:** It's on Machine 2, so it goes as **LATE** as possible (before Job 3).
- **Final Sequence:** [2] - [5] - [4] - [3] - [1]

Why does it work?

Johnson's Rule works by:

1. **Loading Machine 1 quickly:** By putting jobs with short M1 times at the start, Machine 2 can start working as soon as possible (minimizing initial idle time).
2. **Emptying Machine 2 slowly:** By putting jobs with short M2 times at the end, we ensure Machine 2 remains productive for as long as possible while Machine 1 finishes its final tasks.

Limitations

- It only works for **two machines**. (For three machines, you can sometimes use a "virtual two-machine" conversion, but it is not always optimal).
- It assumes the **order** of machines is fixed (M1 then M2).

The Six Sigma Approach

Six Sigma is a disciplined, data-driven methodology for eliminating defects and reducing variability in any process—from manufacturing to transactional and from product to service.

1. What is "Six Sigma"?

Statistically, Six Sigma refers to a process in which **99.99966%** of all opportunities to produce some feature are expected to be free of defects. This equates to no more than **3.4 defects per million opportunities (DPMO)**.

Sigma Level	Yield (Percent)	Defects per Million (DPMO)
2 sigma	69.1%	308,538

4sigma	99.38%	6,210
6sigma	**99.99966%**	**3.4**

2. Core Methodologies

DMAIC (For Improving Existing Processes)

This is the most common Six Sigma roadmap.

1. **Define:** Identify the problem, the project goals, and the customer (internal or external) requirements (CTQ - Critical to Quality).
2. **Measure:** Quantify the current process performance. Establish a baseline.
3. **Analyze:** Use data analysis to find the root cause of defects and identify sources of variation.
4. **Improve:** Implement and verify the solution. Optimize the process based on analysis.
5. **Control:** Maintain the gains by documenting standard operating procedures and monitoring the process with Control Charts.

DMADV (For Creating New Processes)

Also known as **DFSS** (Design for Six Sigma).

- **Define** goals.
- **Measure** and identify CTQs.
- **Analyze** design alternatives.
- **Design** the process/product.
- **Verify** the design performance.

3. Key Six Sigma Tools

Six Sigma integrates various statistical and management tools:

- **SIPOC Diagram:** (Supplier, Input, Process, Output, Customer) to map the high-level process.
- **Fishbone (Ishikawa) Diagram:** For root cause analysis.
- **Pareto Chart:** To identify the "Vital Few" problems (80/20 rule).
- **FMEA:** (Failure Mode and Effects Analysis) to predict and prevent potential failures.
- **SPC Charts:** (X-R, NP, C charts) to monitor process stability.

4. The Belt Hierarchy

Six Sigma projects are led by trained professionals organized into "Belts":

- **White Belt:** Understands basic concepts; supports local problem-solving.
- **Yellow Belt:** Participates as a project team member; reviews process improvements.
- **Green Belt:** Leads smaller projects; assists Black Belts with data collection and analysis.
- **Black Belt:** Leads complex projects full-time; mentors Green Belts; high-level statistical mastery.
- **Master Black Belt:** Strategic level; trains Black and Green Belts; manages the Six Sigma program across the organization.

5. Lean Six Sigma

Modern organizations often combine **Lean** (which focuses on eliminating waste and increasing speed) with **Six Sigma** (which focuses on reducing variation and improving quality). Together, they create a highly efficient, high-quality production environment.

Six Sigma Approach

Six Sigma is a comprehensive and disciplined approach to quality management that focuses on improving processes by reducing defects and minimizing variation. It is a data-driven methodology that uses statistical tools and systematic problem-solving techniques to achieve high levels of process performance and customer satisfaction. The concept was developed in the 1980s by Motorola when the company faced serious quality issues and needed a structured approach to reduce manufacturing defects. Later, it gained worldwide recognition when General Electric adopted it under the leadership of Jack Welch and achieved remarkable improvements in quality and profitability.

The term "Six Sigma" refers to a statistical measure of process capability. In statistics, sigma (σ) represents standard deviation, which indicates variation in a process. Achieving Six Sigma level means that the process produces only 3.4 defects per million opportunities (DPMO), which is considered near-perfect performance. The main aim of Six Sigma is not only to reduce defects but also to eliminate the root causes of errors and improve overall efficiency.

Six Sigma is based on a strong focus on customer requirements. It begins with understanding what the customer defines as quality and then aligns business processes to meet those expectations. It emphasizes fact-based decision-making rather than assumptions. Data collection and statistical analysis play a crucial role in identifying process weaknesses and measuring improvements.

The most commonly used methodology in Six Sigma is DMAIC, which is applied to improve existing processes. DMAIC stands for Define, Measure, Analyze, Improve, and Control. In the Define phase, the problem is clearly identified, project goals are established, and customer requirements are understood. In the Measure phase, relevant data is collected to determine the current performance level of the process. In the Analyze phase, statistical tools are used to identify the root causes of defects and process variations. In the Improve phase, solutions are developed and implemented to eliminate the causes of defects. Finally, in the Control phase, monitoring systems are established to ensure that improvements are maintained and the process does not return to its previous state.

For designing new products or processes, Six Sigma uses another methodology called DMADV, which stands for Define, Measure, Analyze, Design, and Verify. This approach is mainly used when an existing process is not capable of meeting customer requirements and a completely new design is required.

Six Sigma also introduces a structured hierarchy of trained professionals known as "belts," similar to martial arts ranking. These include White Belt, Yellow Belt, Green Belt, Black Belt, and Master Black Belt. Each level represents a different degree of expertise and responsibility in leading improvement projects. Black Belts and Master Black Belts usually lead major projects and provide training to other team members.

The benefits of Six Sigma are significant. It improves product and service quality, reduces waste and rework, lowers production costs, increases efficiency, enhances customer satisfaction, and improves profitability. It also promotes a culture of continuous improvement and teamwork within the organization. However, the implementation of Six Sigma requires proper training, strong management support, and investment in time and resources. Without commitment from top management, the program may not succeed.

Six Sigma is a powerful quality improvement approach that focuses on reducing variation and eliminating defects through a systematic, data-driven methodology. By aligning processes with customer expectations and continuously improving performance, organizations can achieve operational excellence and gain a competitive advantage in the market.

Six Sigma Methodologies – Detailed Explanation

The success of Six Sigma largely depends on its structured methodologies, which provide a clear roadmap for solving problems and improving processes. The two major methodologies used in Six Sigma are **DMAIC** and **DMADV**. Each methodology is applied depending on whether the organization wants to improve an existing process or design a new one. These structured approaches ensure that improvements are systematic, measurable, and sustainable rather than temporary fixes.

1. DMAIC Methodology (For Improving Existing Processes)

DMAIC is the most widely used Six Sigma methodology. It is applied when a process already exists but is not performing efficiently or is producing defects. The purpose of DMAIC is to identify the root causes of problems and eliminate them permanently. The five stages of DMAIC are explained below in detail:

Define Phase

The Define phase is the starting point of the project. In this stage, the problem is clearly identified and defined in measurable terms. The project objectives, scope, timeline, and expected outcomes are determined. Customer requirements are carefully studied because Six Sigma strongly emphasizes meeting customer expectations. Tools such as project charters, SIPOC diagrams (Supplier, Input, Process, Output, Customer), and stakeholder analysis are often used. A well-defined problem statement ensures that the team focuses on the correct issue and avoids confusion later.

Measure Phase

In the Measure phase, data is collected to understand the current performance of the process. The goal is to establish a baseline measurement so that improvements can be compared later. The team identifies key performance indicators (KPIs) and critical-to-quality (CTQ) characteristics. Accurate and reliable data collection methods are essential in this stage. Tools such as data collection plans, process mapping, histograms, check sheets, and capability analysis are used. This phase answers the question: *How is the process currently performing?*

Analyze Phase

The Analyze phase focuses on identifying the root causes of defects and process variations. Instead of addressing symptoms, Six Sigma aims to find the fundamental reasons behind the problem. Statistical tools and analytical techniques are used to examine relationships between variables. Common tools include cause-and-effect (fishbone) diagrams, Pareto analysis, regression analysis, hypothesis testing, and failure mode and effects analysis (FMEA). By the end of this phase, the team clearly understands why the problem is occurring.

Improve Phase

In the Improve phase, solutions are developed and implemented to eliminate the root causes identified in the Analyze stage. Brainstorming sessions, pilot testing, and design of experiments (DOE) may be used to test potential improvements. The solutions must be practical, cost-effective, and sustainable. Once implemented, the team evaluates whether the improvements have significantly reduced defects and enhanced performance. This stage converts analysis into real action.

Control Phase

The Control phase ensures that the improvements achieved are maintained over time. Without proper control, processes may return to their old inefficient state. Standard operating procedures (SOPs), control charts, monitoring systems, and regular performance reviews are established to maintain consistency. Training employees and documenting changes are also important aspects of this phase. The Control stage guarantees long-term success and stability of the improved process.

2. DMADV Methodology (For Designing New Processes or Products)

DMADV is used when a new product or process needs to be developed, or when an existing process is so defective that incremental improvement is not sufficient. It is often associated with Design for Six Sigma (DFSS). The five stages are as follows:

Define Phase

Similar to DMAIC, the Define phase in DMADV focuses on identifying customer needs and project goals. Market research and voice-of-customer analysis are conducted to understand expectations clearly. This ensures that the new design aligns with customer requirements from the beginning.

Measure Phase

In this stage, critical quality factors and design specifications are determined. The team measures customer requirements and translates them into measurable technical specifications. Risk assessments and benchmarking studies may also be performed.

Analyze Phase

The Analyze phase involves developing different design alternatives and evaluating their feasibility. Statistical modeling and simulations may be used to predict performance outcomes. The best design option is selected based on data and analysis.

Design Phase

In the Design stage, the selected solution is developed in detail. Prototypes may be created, and process parameters are finalized. The design must meet performance standards and quality expectations.

Verify Phase

The final phase involves testing and validating the new design under real operating conditions. Pilot runs, customer feedback, and performance testing ensure that the design meets all requirements before full-scale implementation. Only after verification is the new process officially launched.

Comparison of DMAIC and DMADV

DMAIC is primarily used for improving existing processes, while DMADV is used for creating new processes or products. DMAIC focuses on correcting problems, whereas DMADV focuses on designing processes correctly from the beginning. Both methodologies rely heavily on data, statistical analysis, and customer-focused thinking.

Conclusion

The methodologies of Six Sigma provide a disciplined and systematic framework for problem-solving and process improvement. Whether improving an existing process through DMAIC or designing a new one through DMADV, the structured approach ensures reduced variation, minimized defects, and enhanced customer satisfaction. These methodologies form the backbone of Six Sigma and are essential for achieving operational excellence.

Advantages of Six Sigma	Disadvantages of Six Sigma
Improves product and service quality by reducing defects and errors.	Implementation cost is high due to training and consultancy expenses.
Reduces process variation and increases consistency in output.	Requires extensive data collection and statistical analysis, which may be complex.
Increases customer satisfaction by meeting quality expectations.	Time-consuming implementation process.
Decreases operational costs by reducing waste, rework, and scrap.	Strong dependence on top management support; failure if leadership commitment is weak.
Promotes data-driven decision making instead of guesswork.	May face employee resistance to change.

Enhances productivity and process efficiency.	Not suitable for very small organizations with limited resources.
Encourages teamwork and continuous improvement culture.	Overemphasis on statistics may ignore human and creative aspects.
Provides structured problem-solving methodology (DMAIC/DMADV).	Benefits may take time to become visible.

UNIT – IV

MATERIALS MANAGEMENT AND INVENTORY CONTROL

INTEGRATED MATERIALS MANAGEMENT

- ✓ As mentioned earlier, the main activity of production system is to convert *raw materials into useful products* by value addition process.
- ✓ If we closely examine the various elements of *prime cost, materials cost would dominate other costs.*
- ✓ The materials, which are required for the production purposes are normally, *procure and stored* in raw materials warehouses and then they are shifted to manufacturing plants if an organization has a number of plants.
- ✓ The raw materials are to be *purchased in advance and stocked stores mainly to smoothen the production process.*
- ✓ Each functional head of materials department will try to optimize the operation of his own function.
- ✓ But, all of them should aim for a common goal of providing materials with minimum total cost (cost of carrying, ordering cost, purchase cost, etc.) for better functioning of the organization.

For example, let us assume that the purchasing function plans to buy huge quantity of raw materials, just to exploit seasonal availability of the material. If the rent paid on the storage is abnormal in a place like Mumbai, then the purchasing function and the stores function will have conflicting objectives. This can be resolved if a proper trade-off analysis is done by taking the objectives together. This is possible if these two functions are integrated together. This is only a small example involving two functions. In reality, all the functions of materials management are to be integrated.

The different functions of materials management are:

- Materials planning
- Purchasing
- Receiving
- Stores
- Inventory control
- Scrap and Surplus disposal.

If these systems are designed to function independently, there won't be close coordination among them. But we need complete integration of these functions for better operation of the system.

The integrated materials management will result in the following advantages:

- Better accountability.
- Better coordination.
- Better performance.
- Adaptability to computerized systems.

COMPONENTS OF INTEGRATED MATERIALS MANAGEMENT

The components of the integrated materials management can be classified into the following modules.

1. Materials planning
2. Inventory Control
3. Purchase Management
4. Stores Management

1. Materials Planning

Sales forecasting and aggregate planning are the basic inputs for materials planning. The different tasks under planning are listed below:

- Estimating the individual requirements of parts
- Preparing materials budget
- Forecasting the levels of inventories
- Scheduling the orders and
- Monitoring the performance in relation to production and sales.

2. Inventory Control

This includes the following:

- ABC analysis
- Fixing economical order quantity
- Lead time analysis
- Setting safety stock and reorder level

3. Purchase Management

The tasks under purchasing are listed below:

- Evaluating and rating suppliers
- Selection of suppliers
- Finalization of terms of purchase
- Placement of purchase orders.
- Follow-up.
- Approval of payments to suppliers.

4. Stores Management

The different tasks under stores are listed below:

- Physical control of materials
- Preservation of obsolescence and damage through handling
- Disposal and efficient handling
- Maintenance of stores records
- Proper location and stocking of materials
- Reconciling the materials with book figures.

INVENTORY CONTROL

Inventory is essential to provide flexibility in operating a system. The inventory can be classified into:

Raw materials inventory remove dependency between suppliers and plants.

In-process inventory remove dependency between machines of a product line.

Finished goods inventory remove dependency between plant and its customers/market.

The main functions of inventory are summarized below.

- Smoothing out irregularities in supply
- Minimizing the production cost
- Allowing organizations to cope with perishable materials

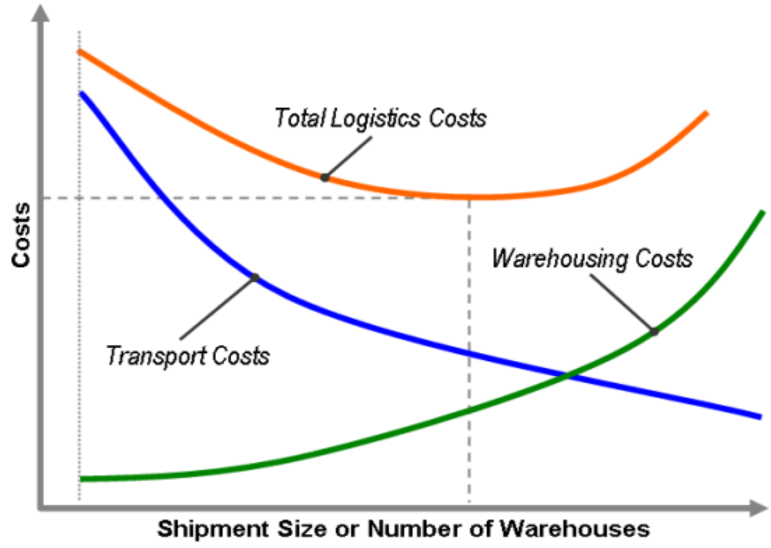
Inventory Decisions

Managers generally take the following two basic inventory decisions.

1. When to replenish the inventory of that item.
2. How much of an item to order when the inventory of that item is to be replenished.

Costs Trade-off

If the order quantity is less, the cost of order will be more, but the inventory carrying cost will be less. On the other hand, if the order quantity is more, the ordering cost will be less, but the carrying cost will be more.



Total cost curve represents the sum of ordering cost and carrying cost for each order size. The order size at which the total cost is minimum, called Economic Order Quantity (EOQ) or Q^* (optimal order size).

MODELS OF INVENTORY

There are different models of inventory.

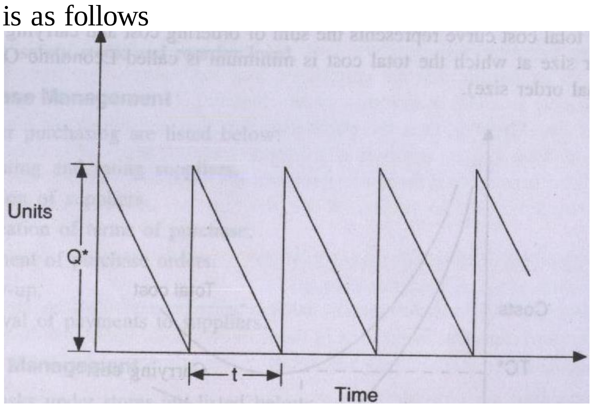
- Purchase model with instantaneous replenishment and without shortages
- Manufacturing model without shortages.
- Purchase model with instantaneous replenishment and with shortages
- Manufacturing model with shortages.

1. Purchase Model with Instantaneous Replenishment and without Shortages

In this model of inventory, orders of equal size are placed at periodical intervals. The items against an order are replenished instantaneously and the items are consumed at a constant rate. The purchase price per unit is the same irrespective of order size.

Let, D = the annual demand in units. C_0 = the ordering cost/order
C_c = the carrying cost/unit/year P = the purchase price per unit
Q = the order size

Then, the corresponding model is as follows



Purchase Model Without Shortages

Therefore,

$$\text{The number of orders/year} = \frac{D}{Q}$$

$$\text{Average inventory} = \frac{Q}{2}$$

$$\text{Cost of ordering/year} = \frac{D}{Q} \times Co$$

$$\text{Cost of carrying/year} = \frac{Q}{2} \times Cc$$

$$\text{Purchase cost/year} = D \times P$$

$$\text{The total inventory cost (TC)/year} = \frac{D}{Q} \times Co + \frac{Q}{2} \times Cc + D \times P$$

Differentiating w.r.t Q yields

$$\frac{d}{dQ}(TC) = \frac{-D}{Q2} Co + \frac{Cc}{2}$$

$$\text{The second derivative} = \frac{+2D}{Q3} Co$$

Since the second derivative is positive, we can equate the first derivative to zero to get the optimal value for Q.

$$\frac{-D}{Q2} Co + \frac{Cc}{2} = 0$$

$$Q2 = \frac{2CoD}{Cc}$$

$$Q^* = \sqrt{\frac{2CoD}{Cc}}$$

$$\text{Number of orders} = \frac{D}{Q^*}$$

$$\text{Time between orders} = \frac{Q^*}{D}$$

Problem 1: Alpha industry estimates that it will sell 12,000 units of its product for the forthcoming year. The ordering cost is Rs. 100 per order and the carrying cost per unit per year is 20% of the purchase price per unit. The purchase price per unit is Rs. 50.

Find, (a) Economic Order Quantity (EOQ)
(b) No. of orders per year
(c) Time between successive orders

Problem 2: Beta industry estimates that it will sell 15,000 units of its product for the forthcoming year. The ordering cost is Rs. 125 per order and the carrying cost per unit per year is 20% of the purchase price per unit. The purchase price per unit is Rs. 75.

Find, (a) Economic Order Quantity (EOQ)
(b) No. of orders per year
(c) Time between successive orders

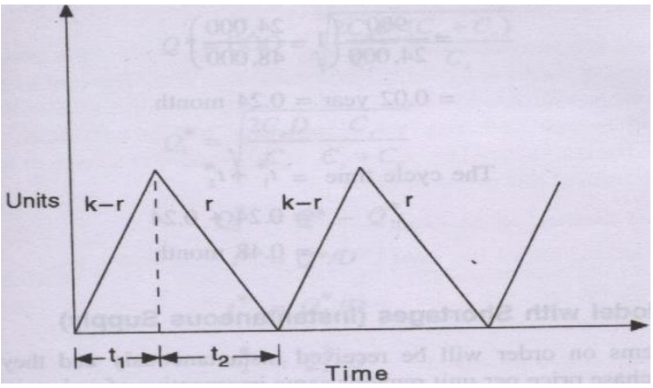
Problem 3: Ram Industry needs 5400 units/year of a bought out component, which will be used in its main product. The ordering cost is Rs. 250 per order and the carrying cost per unit per year is Rs. 30.

Find, (a) Economic Order Quantity (EOQ)
(b) No. of orders per year
(c) Time between successive orders

2. Manufacturing Model without Shortages

If a company manufactures its components which is required for its main product, then the corresponding model of inventory is called "***Manufacturing model***".
This model will be with shortages or without shortages. The rate of consumption of items is uniform throughout the year. The cost of production per unit is same irrespective of production lot size.

Let, r = the annual demand of an item; k = the production rate of the item
C_0 = the cost per set up; C_c = the carrying cost/unit/period
p = the cost of production per unit; EBQ = Economic Batch Quantity



Manufacturing Model Without Shortages

During the period t_1, the item is produced at the rate of k units per period and simultaneously it is consumed at the rate of r units per period. So, during this period, the inventory is built at the rate of k – r units per period. During the period t_2, the production of the item is discontinued but the consumption of that item is continued. Hence, the inventory is decreased at the rate of r units per period during this period. The operation of the manufacturing model without shortages is shown below.
The various formulas for this situation are given below:

$$EBQ = \sqrt{\frac{2C_o r}{C_c(1 - r/k)}}$$

$$t_1^* = Q^*/k$$
$$t_2^* = [Q^*(1 - r/k)]/r$$
$$\text{Cycle time} = t_1^* + t_2^*$$

Problem 1: If a product is to be manufactured within the company, the details are as follows:
R = 24,000 units/year; k = 48,000 units/year
C_o = Rs. 200 per set-up; C_c = Rs. 20/unit/year
Find the EBQ and cycle time.

Problem 2: An automobile factory manufactures a particular type of gear within the factory. This gear is used in the final assembly. The particulars of this gear are presented below:
Demand rate = 14,000 units/year; Production rate = 35,000 units/year
Set-up cost = Rs. 500 per set-up; Carrying cost = Rs. 15/unit/year
Find the EBQ and cycle time.

Problem 3: A product is to be manufactured within the company, the details of which are as follows:
r = 36,000 units/year; k = 72000 units/year
C_o = Rs. 250 per set-up; C_c = Rs. 25/unit/year

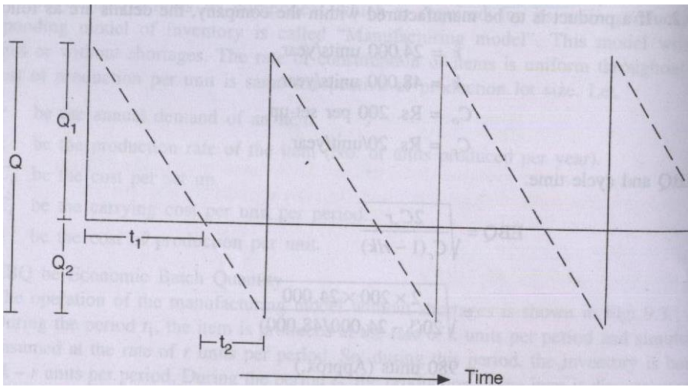
Find the EBQ and cycle time.

3. Purchase Model with Shortages (Instantaneous Supply)

In this model, the items on order will be received instantaneously and they are consumed at a constant rate. The purchase price per unit remains same irrespective of order size. If there is no stock at the time of receiving a request for the items, it is assumed that it will be satisfied at a later date with a penalty. This is called backordering.

The variables which are used in this model are given below:

D = Demand/period
C_0 = Ordering cost/order
C_c = Carrying cost/unit/period
C_s = Shortage cost/unit/period



Purchase Model With Shortages

In the above model,
Q represents Economic order quantity,
Q_1, Maximum inventory, and
Q_2, Maximum stockout

$$EOQ = Q^* = \sqrt{\frac{2CoD}{Cc} X \frac{Cs + Cc}{Cs}}$$

$$Q_1^* = \sqrt{\frac{2CoD}{Cc} X \frac{Cs}{Cs + Cc}}$$

$Q_2^* = Q^* - Q_1^*$
$t^* = Q^*/D$
$t_1^* = Q_1^*/D$
$t_2^* = Q_2^*/D$

Problem 1: The annual demand for an automobile component is 24,000 units. The carrying cost is Re. 0.40/unit/year, the ordering cost is Rs. 20.00 per order and the shortage cost is Rs. 10.00/unit/year. Find the optimal values of the following:

1. Economic Ordering Quantity
2. Maximum inventory
3. Maximum shortage quantity
4. Cycle time
5. Inventory period *(t_1)*
6. Shortage period *(t_2)*

Problem 2: The annual demand for a component is 7200 units. The carrying cost is Rs. 500/unit/year, the ordering cost is Rs. 1500 per order and the shortage cost is Rs. 2000/unit/year. Find the optimal values of the following.

1. Economic Ordering Quantity
2. Maximum inventory
3. Maximum shortage quantity
4. Cycle time
5. Inventory period *(t_1)*
6. Shortage period *(t_2)*

Problem 3: The annual demand for an automobile component is 36,000 units. The carrying cost is Rs. 0.50/unit/year, the ordering cost is Rs. 25.00 per order and the shortage cost is Rs. 15.00/unit/year. Find the optimal values of the following.

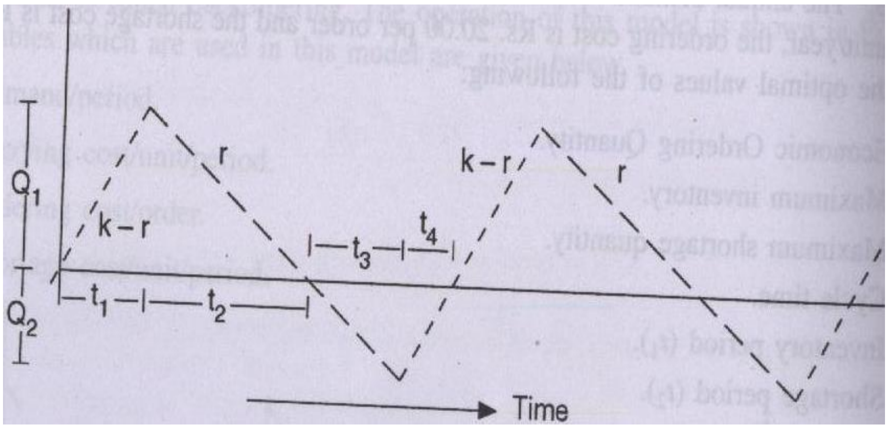
1. Economic Ordering Quantity
2. Maximum inventory
3. Maximum shortage quantity
4. Cycle time
5. Inventory period *(t_1)*
6. Shortage period *(t_2)*

4. <u>Manufacturing Model with Shortages</u>

In this model, the items are produced and consumed simultaneously for a portion of the cycle time. The rate of consumption of items is uniform throughout the year. The cost of production per unit is the same irrespective of production to lot size. In this model, stockout is permitted. It is assumed that the stockout units will be satisfied from the units which will be produced at a later date with a penalty. This is called backordering.

The variables which are used in this model are:

r = the annual demand of an item
C_0 = the cost/set up
C_s = the shortage cost/unit/period
EBQ = Economic Batch Quantity
k = the production rate of the item
C_c = the carrying cost/unit/period
p = the cost of production per unit



Manufacturing Model With Shortages

In the above model,

Q = Economic Batch Quantity
Q_1 = Maximum inventory
Q_2 = Maximum stockout

$$EBQ = Q^* = \sqrt{\frac{2Co}{Cc} X \frac{kr}{(k-r)} X \frac{Cc + Cs}{Cs}}$$

$$Q_1^* = \sqrt{\frac{2Co}{Cc} X \frac{Cs}{Cs + Cc} X \frac{r(k-r)}{k}}$$

$$Q_2^* = \sqrt{\frac{2CoCc}{Cs\,(Cc + Cs)} X \frac{r(k-r)}{k}}$$

$t^* = Q^*/r$ $t_1^* = Q_1^* / (k - r)$ $t_2^* = Q_1^*/r$ $t_3^* = Q_2^*/r$ $t_4^* = Q_2^* / (k - r)$

Problem 1: The demand for an item is 18000 per year. Its production rate is 3000 per month. The carrying cost is Re. 0.15/unit/month and the set-up cost is Rs. 500 per set-up. The shortage cost is Rs. 20 per unit per year. Find the various parameters of the inventory system.

Problem 2: The demand for an item is 6000 per year. Its production rate is 1000 per month. The carrying cost is Rs. 50/unit/year and the set-up cost is Rs. 2000 per set-up. The shortage cost is Rs. 1000 per unit per year. Find various parameters of the inventory system.

Problem 3: The demand for an item is 24,000 per year. Its production rate is 4000 per month. The carrying cost is Rs. 0.25/unit/year and the set-up cost is Rs. 800 per set-up. The shortage cost is Rs. 15 per unit per year. Find various parameters of the inventory system.

PURCHASING MANAGEMENT

The objective of the purchasing function is to ensure continuity of supply of raw materials, subcontracted items and spare parts and at the same time reduce the ultimate cost of the finished goods. The different parameters of purchasing are as listed below:

- Purchasing items with right price.
- Purchasing items with right quality.
- Purchasing items at right time so that the items are available when needed.
- Purchasing items from right source. Here, the dependability of the vendors is estimated using vendor rating. The location of vendors, nature of items, mode of transportation, vendor’s commitments to due dates, etc. should be taken into account.
- Purchasing items of right quantity. Generally, there is a trade-off between cost of ordering and cost of carrying inventory. Hence, orders should be placed with optimal quantity.

PURCHASE SYSTEMS

The purchase system may be classified into Pre-Purchase System, Ordering System and Post-Purchase System.

1. Pre-purchase system. This includes making requisitions, requirement programmes, selection of suppliers, obtain quotations and evaluating them.

2. Ordering system. Once the decision on supplier and the rates are finalized, the order is placed with the selected supplier. The next task is to place order. The details of order form are listed as

- Purchase order reference number.
- Description of the materials and detailed specifications.
- Quantity required and delivery schedule
- Price and discounts.
- Shipping instructions.

- Location where the materials are to be shipped.
- Signature of the materials manager.
- Detailed terms of conditions.

3. Post purchase system. The activities which are included under this system are follow-up procedure, receipt and checking invoices.

Whenever an order is placed, it should be continuously monitored. The whole system operates under probabilistic environment. Though orders are placed based on demand and lead time, these are subjected to variation.

SPECIAL PURCHASE SYSTEMS

The following are some special purchase systems.

1. ***Forward Buying:*** In Forward Buying, the purchasing decision for a period (say 1 year) will be taken in advance and the organization will commit accordingly in terms of order quantity, rate and delivery schedule, by taking into consideration the availability of funds and the requirements. Generally, this is used for public buying to avoid favoritism to a specific vendor.

2. ***Tender Buying:*** In Tender Buying the steps are: preparing bidder's list, advertising tenders, receiving bids, evaluating bids and placing order with the bidder with the lowest cost.

3. ***Blanket Order:*** In Blanket Ordering system, the organization will enter into an agreement with its supplies to receive items for a required quantity at a particular rate over a period of time.

4. ***Zero Stock:*** Zero Stock purchase system is in-line with using the just-in-time manufacturing system. The main idea of this system is to operate the plant with near zero inventories. If the suppliers are situated nearer to the company, they are more reliable in terms of making supply in time. The company can place orders with such suppliers.

5. ***Rate Contract:*** Rate Contract is very much used in public sectors and government departments. The suppliers are on 'rate contract' with DGS&D for a specific period. The organizations can place orders straightaway with such firms without going through the lengthy procedure of purchasing.

ASPECTS OF PURCHASE MANAGEMENT

The different aspects of purchasing management are as follows:

1. Price forecasting
2. Purchasing of capital equipments
3. International purchasing
4. Public buying

Price forecasting: Forecasting is nothing but prediction of a future event. In Materials Management, predicting the prices of materials is of utmost importance. The precise prediction of prices would help us in buying the materials in right time and of right quantity. The different methods which are used for price forecasting are as follows:

- ✓ Charting Method
- ✓ Moving Average Method
- ✓ Regression Method
- ✓ Exponential Smoothing Method

Purchasing of capital equipments: All machineries and equipments which are used in value addition process are termed as capital equipments. The frequency of purchase of these equipment is very less, may be once in five years or ten years. While comparing different alternatives, one can use any one of the following approaches to select the best alternative:

- ✓ Payback Period Method
- ✓ Rate of Return Method
- ✓ Present Worth Method
- ✓ Annual Equivalent Method
- ✓ Future worth Method

The various options to satisfy the demand for capital equipment are listed below:

- ✓ Purchase of new equipment
- ✓ Purchase of used equipment
- ✓ Leasing

For the purchase of new equipments, any one of the methods which are mentioned above may be used to judge each alternative. Then the best alternative is to be selected

International purchasing: In view of the growing global economy, many countries are importing major raw materials, sub assemblies which are available elsewhere at a cheaper rate at the same time the total cost of procurement is cheaper when compared to indigenous production/supply of the same.

Procedure in international purchasing: If a company is planning to import an item, first it should find out whether such item is allowed to be imported. This is done by contacting the Ministry of trade, foreign consulates and embassies, Indian consulates in foreign countries, etc. In this process, the importer will be using some special documents like, *bill of lading, invoices, and certificates of origin, weight certificates, insurance policy* and *markings of packages.*

Public buying: Many organizations are duplicating the same task of purchasing even though the specifications of the materials are the same. Whenever, an order is to be placed, there is a minimum lead time involved to get the items in addition to the minimum time required to source a supplier. These will certainly introduce delay in the purchase of materials and also adds a significant cost to the total cost of purchasing. Hence, a centralized buying concept was promoted to satisfy the demand of the following organizations through Directorate General of Supplies and Disposals (DGS&D) which is the central purchasing organization of Government of India.

- Defence organizations
- Railway departments
- Post and Telegraph departments
- State governments
- Public sector enterprises
- Quasi-public bodies

Any proposal for the purchase of materials from abroad is to be scrutinized by the DGS&D. The other activities of the DGS&D are as follows:

1. It inspects stores purchased by government departments and other bodies if they need its services.
2. It performs laboratory testing and analysis of stores on behalf of government departments.
3. It makes arrangement for shipment of stores exported and clearance of stores imported.
4. It undertakes the responsibility of disposal of surpluses declared by the central government departments and the state government departments.

STORES MANAGEMENT

The purchased materials are to be stored in stores/warehouses and issued for production as and when they are required. As already stated, store contains inventory mainly to provide uninterrupted supply of materials to the production divisions. So, stores play a vital role in the operation of any production system. The functions of stores are as follows:

1. It receives raw materials, tools, equipments and other necessary materials and accounts them.
2. It makes arrangement to store and preserve the items in good conditions for later use.
3. It maintains a proper account on issue of items on demand from shop floor/production division.
4. It maintains a classification and codification system to minimize obsolescence, surplus and scrap of items.
5. It provides information reports to support purchase activities to take place at right times.

An efficient store layout would assist proper stocking of raw materials and items and also quick retrieval of items at the time of issue. Nowadays, the stocking of items and issue of items in stores are done by 'pick and place' robot. They even take the items from the store and deliver them in the demanding work stations of the factory. It is also highly essential to follow all safety measures in the stores mainly to avoid accident.

Once the items are cleared from the receiving section, a Provisional Goods Inward Notes (PGI) is prepared and it is sent along with the materials to the Inspection Section. The different systems in stores are as listed below.

- Receipt system
- Stocking system
- Issue system.

At the time of receiving the items at the stores, necessary arrangement should be made to check the quality, quantity and weight of the items before they are accepted for stocking in the stores. There should be a proper system for maintaining accounts of issues made to internal divisions or external divisions.

STORES ACCOUNTING

The product cost consists of materials costs, labour costs and machine hour costs. Stores accounting is very much useful in determining the materials cost of a product. The different elements of cost of the material received are material price, freight charges, insurance and taxes.

The issues of the stores are accounted using any one of the following methods:
1. First in First Out (FIFO) method
2. Last in First Out (LIFO) method
3. Average Cost method
4. Standard Cost method
5. Market Price method

1. ***First in First Out (FIFO) method:*** The assumption is that the old stock is depleted first. This means that the rate pertaining to that will be applied while accounting issues.
2. ***Last in First Out (LIFO) method:*** The assumption is that the most recent receipts are issued first.
3. ***Average Cost method:*** The issues to the production department are divided into equal batches from each shipment at stock.
4. ***Standard Cost method:*** A standard rate for the material is fixed based on the detailed analysis of market prices. This cost would be used for a fixed period, say six months or above.
5. ***Market Price method:*** The prevailing market rate of the material is applied for costing the material at the time of issue.

OBSOLETE SURPLUS AND SCRAP MANAGEMENT

The materials and parts which are used in industries for carrying out production activity become obsolete because of so many reasons. This in turn results in surplus and scrap. The following are the main reasons for accumulation of obsolete, surplus and scrap items:

1. Change in product design;
2. Rationalization of raw materials so as to minimize variety and simplify procurement procedure;
3. Cannibalization: This is due to the usage of components of failed machineries which are not in operation for a long time, in order to rectify some of the similar machineries which are actively used in production process. This will make the old machineries obsolete after some time because of missing components.
4. Faulty planning, over estimation of demand and wrong indenting are some of the main reasons.
5. Faulty purchase procedure, just to avail quantity discount, seasonal availability, some industry will make bulk purchase. But, this will introduce surplus and scrap.

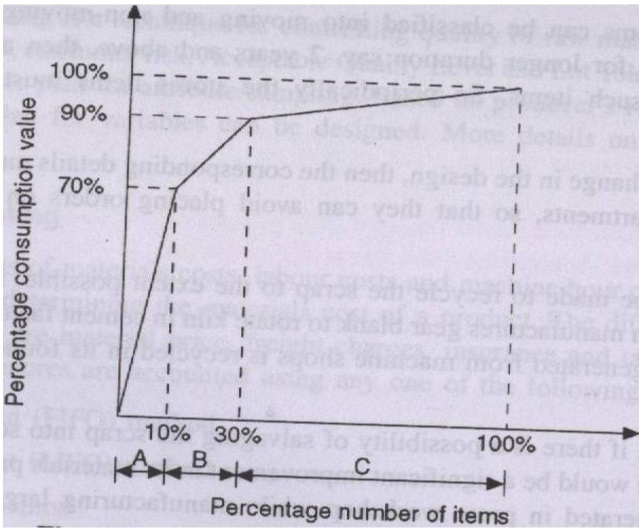
We can avoid such accumulation of obsolete, surplus and scrap items by using the following measures

1. Periodically, items can be classified into moving and non-moving items.
2. If there is any change in the design, then the corresponding details must be circulated among concerned departments.
3. Effort should be made to recycle the scrap to the extent possible.
4. In some cases, if there is a possibility of salvaging the scrap into some useful components/ products, there would be a significant improvement in its materials productivity.
5. It is possible to generate substantial amount of money by way of disposing scrap by using optimal methods.

ABC ANALYSIS

- ABC analysis is a technique which is used to classify the items in store based on the demand of the stock.
- There may be variety of items that need to be purchased and stocked in advance for issuing the same to various production departments.
- If the Stock on hand of a particular item becomes less than or equal to its reorder level, immediately an order is to be placed for its economical quantity.
- It is highly essential to classify the items of the stores into different categories.

ABC analysis is one such technique which classifies the items into A, B and C class items. It is clear that 10% of the items accounts for 70% of the annual consumption value of the items. 20% of the items accounts for 20% of the annual consumption value of the items and 70% of the items accounts for 10% of the annual consumption value of the items. The percentages on the annual consumption of items will be used as a criterion for classifying the items into A, B and C classes.



Cumulative Curve of ABC Analysis

PROCEDURE FOR ABC ANALYSIS

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 *Step 3.*

Problem 1: The store of an oil engine repair shop has 10 items whose details are shown in the following table. Apply ABC analysis to the store.

Details of Store

Component Code	Description	Price/Unit (Rs.)	Units/Year
C01	Packing thread	100	100
C02	Tower bolt	200	300
C03	Hexagonal nut	50	700
C04	Bush	300	400
C05	Coupling	500	1000
C06	Bearings (Big)	3000	30
C07	Bearings (Small)	1000	100
C08	Fuel pump	7000	500
C09	Fixture	5000	105
C10	Drill bit	60	1000

Solution: The preliminary working for ABC analysis with the annual consumption for various items is summarized in below table.

Preliminary Workings

Component Code	Description	Price/Unit (Rs.)	Units/Year	Annual Consumption Rs./Year
C01	Packing thread	100	100	10000
C02	Tower bolt	200	300	60000
C03	Hexagonal nut	50	700	35000
C04	Bush	300	400	120000
C05	Coupling	500	1000	500000
C06	Bearings (Big)	3000	30	90000
C07	Bearings (Small)	1000	100	100000
C08	Fuel pump	7000	500	3500000
C09	Fixture	5000	105	525000
C10	Drill bit	60	1000	60000

Rearrange the rows of the above table as per the decreasing order of annual consumption (Rs./Year) and compute the cumulative annual values as shown in below table.

Final Workings of ABC Analysis

Component Code	Price/Unit (Rs.)	Units/Year (Rs.)	Annual Consumption Rs./Year	Cumulative Value of Annual Consumption (Rs.)	Class
C08	7000	500	3500000	3500000	A
C09	5000	105	525000	4025000	B
C05	500	1000	500000	4525000	
C04	300	400	120000	4645000	C
C07	1000	100	100000	4745000	
C06	3000	30	90000	4835000	
C02	200	300	60000	4895000	
C10	60	1000	60000	4955000	
C03	50	700	35000	4990000	
C01	100	100	10000	5000000	

From the above table the summary of ABC classification as per 70%:20%:10% of the total consumption value is presented in below table.

Summary of A, B and C Items

Class	Items Code	Description
A	C08	Fuel Pump
B	C09	Fixture
	C05	Coupling
C	C04	Bush
	C07	Bearing (Small)
	C06	Bearing (Big)
	C02	Tower bolt
	C10	Drill bit
	C03	Hexagonal nut
	C01	Packing thread

Problem 2: An engine manufacturing company stocks the items as shown in the following table in its stores. The unit price, annual consumption quantity in terms of units/year is also given in the same table. Classify the items into A, B and C categories.

Component Code	Description	Price/Unit (Rs.)	Units/Year
C001	Connecting rod	500	600
C002	Crank case	4000	600
C003	Cylinder	2000	600
C004	Cylinder head	3000	600
C005	Crank Shaft	4000	600
C006	Cam	500	1200
C007	Nozzle	500	600
C008	Valve set	1000	1200
C009	Fuel injection pump	1500	600
C010	Exhaust pipe	500	600

Problem 3: The stores of a repair shop have 10 items whose details are shown in the following table. Apply ABC analysis to the stores and indentify A Class, B Class and C Class items.

Component Code	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10
Price/unit (Rs.)	110	3000	225	60	310	7000	500	1000	7000	800
Unit/year	125	40	310	720	425	525	900	90	510	600

Production Planning and Control (PPC) Processes

Production Planning and Control is the process of navigating the transformation of raw materials into finished goods by managing people, machines, and materials. It is generally divided into three main stages: **Planning**, **Action**, and **Monitoring/Control**.

1. The Planning Phase (Pre-Production)

This stage involves establishing the roadmap for production before any physical work begins.

A. Demand Forecasting

Estimating the quantity of products customers will purchase in the future. This serves as the foundation for all subsequent planning.

B. Aggregate Planning

Creating a high-level production plan for the medium term (typically 3 to 18 months). It balances production rates, workforce levels, and inventory to meet forecasted demand at minimum cost.

C. Master Production Schedule (MPS)

The "Disaggregation" of the aggregate plan. It specifies exactly which end items will be produced and when.

- **Input:** Customer orders and forecasts.
- **Output:** A weekly or daily production requirement list.

D. Routing

Determining the precise path (sequence of operations) a product must take through the factory.

- Defines which machines will be used.
- Establishes the standard time for each operation.
- Sets the quality checkpoints.

E. Loading

Assigning specific work to specific machines or work centers.

- **Infinite Loading:** Assigning work without regard to capacity (used to see where bottlenecks appear).
- **Finite Loading:** Assigning work only up to the actual capacity of the work center.

F. Scheduling

The final step of planning that assigns start and end times to every operation.

- **Forward Scheduling:** Starting a job as soon as requirements are known.
- **Backward Scheduling:** Starting from the due date and working backward to determine the latest possible start date.

2. The Action Phase (Execution)

This phase bridges the gap between the "paper plan" and the shop floor.

A. Dispatching

The transition from planning to execution. It involves issuing formal orders to:

- Release raw materials from the warehouse.
- Authorize the start of work on specific machines.
- Provide technical drawings and instruction sheets to operators.

3. The Control Phase (Post-Execution)

This stage ensures that the actual production matches the planned production.

A. Progress Reporting (Follow-up)

Monitoring the actual progress of work on the floor. It identifies deviations from the schedule.

B. Expediting

Taking action to clear bottlenecks or speed up "behind-schedule" jobs. This might involve authorizing overtime, shifting workers, or changing machine priorities.

C. Inspection

Verifying that the output meets the quality standards set during the planning phase.

D. Corrective Action & Evaluation

Analyzing why gaps occurred between the plan and the actual performance.

- **Feedback Loop:** If a machine consistently underperforms, the "Routing" and "Loading" data must be updated for future cycles to ensure plans remain realistic.

Summary of the PPC Cycle

1. **Plan:** What, How, Where, and When?
2. **Execute:** Authorize and Start.
3. **Control:** Monitor, Compare, and Adjust.

Job Shop Production System

A **Job Shop** is a manufacturing process in which small batches of a variety of custom products are made. In this system, each "job" or order typically requires a unique sequence of operations and a specific set of instructions, making it the most flexible yet most complex production environment to manage.

1. Core Characteristics

- **High Variety, Low Volume:** The primary differentiator. It handles a vast range of products in very small quantities (often "one-off" items).
- **General-Purpose Machines:** Unlike mass production lines, job shops use versatile machines (e.g., CNC mills, lathes, 3D printers) that can perform multiple types of tasks.
- **Highly Skilled Workforce:** Operators must be versatile enough to interpret different technical drawings and set up machines for varied tasks.
- **Functional Layout:** Equipment is grouped by function (e.g., all welding machines in one area, all grinding machines in another) rather than by the sequence of a specific product.
- **Jumbled Flow:** Materials move in non-linear paths across the shop floor depending on their specific routing requirements.

2. The Job Shop Workflow

The lifecycle of a job in this system follows a non-standardized path:

1. **Quotation:** Since every job is different, the process starts with a cost estimate based on customer designs.
2. **Routing:** Engineers determine the specific sequence of departments the product must visit.
3. **Scheduling:** This is the most difficult step. Planners must decide when each job will hit each machine, often dealing with competing priorities from other jobs.
4. **Execution:** The job moves through functional departments. Work-in-Progress (WIP) levels are typically high because parts "wait" for machines to become available.
5. **Quality Control:** Every unique product requires individual inspection against its specific blueprints.

3. Advantages & Disadvantages

Advantages	Disadvantages

Flexibility: Can handle almost any custom request.	**High Costs:** Higher labor costs and no economies of scale.
Lower Initial Investment: General-purpose machines are often cheaper than specialized automated lines.	**Complex Planning:** Scheduling is a constant "puzzle" due to varying job paths.
Worker Satisfaction: Highly varied work keeps skilled operators engaged.	**Long Lead Times:** Jobs often spend 80-90% of their time waiting in queues.
Innovation: Ideal for prototyping and new product development.	**High WIP:** Lots of unfinished inventory cluttering the shop floor.

4. Key Examples

- **Custom Machine Shops:** Creating specialized components for aerospace or medical industries.
- **Commercial Printing:** Handling unique orders for books, brochures, and posters.
- **Bespoke Furniture:** Handcrafting tables or cabinets to specific customer dimensions.
- **Tool & Die Shops:** Manufacturing the molds and tools used by *other* factories.

5. PPC Challenges in Job Shops

In Production Planning and Control (PPC), job shops are notorious for **bottlenecks**. Because different jobs might all require the same "key" machine at the same time, queues form rapidly.

- **Loading:** Managers must carefully balance the "load" across departments to prevent some machines from being overwhelmed while others sit idle.
- **Expediting:** Frequently requires "hot jobs" to be moved to the front of the line, which disrupts the existing schedule.

Job Sequencing and Priority Rules

Job sequencing is the process of determining the order in which a set of tasks or jobs should be processed through one or more work centers. The goal is to optimize specific performance metrics such as minimizing lateness, reducing work-in-process (WIP) inventory, or maximizing machine utilization.

1. Common Priority Sequencing Rules

These rules are typically used in single-machine environments or at individual work centers

Rule	Description	Best For...
FCFS (First-Come, First-Served)	Jobs are processed in the order they arrive at the work center.	Perceived "fairness" to customers; simplicity.
SPT (Shortest Processing Time)	The job with the shortest processing time is done first.	Minimizing average flow time and WIP; high throughput.
EDD (Earliest Due Date)	The job with the earliest due date is processed first.	Minimizing maximum lateness and meeting deadlines.
LPT (Longest Processing Time)	The job with the longest processing time is done first.	Often used in multiple-machine settings to "get the big ones out of the way."
STR (Slack Time Remaining)	Slack Time = (Due Date − Current Time) − Remaining Processing Time the smallest slack time	Identifying jobs that are most at risk of being late.
CR (Critical Ratio)	Critical Ratio = (Due Date − Current Time) ÷ Remaining Processing Time The smallest ratio goes first	Dynamic environments where priorities change based on time.

2. Advanced Sequencing Algorithms

Johnson's Rule (jobs on 2 machines)

Used to minimize the total elapsed time (makespan) for a group of jobs that must pass through two machines in the same order (Machine A Machine B).

The Algorithm:

1. List all jobs and their processing times for both machines.
2. Find the smallest processing time among all remaining jobs on either machine.
3. **Rule:**
   - If the smallest time is on **Machine 1**, place that job as **early** as possible in the sequence.
   - If the smallest time is on **Machine 2**, place that job as **late** as possible in the sequence.
4. Remove the job from the list and repeat until all jobs are sequenced.

Job Sequencing with Deadlines (Greedy Algorithm)

Used when jobs have specific deadlines and varying profits. The goal is to maximize total profit by completing as many high-value jobs as possible within their deadlines.

3. Performance Metrics

To decide which rule is "best," managers evaluate the results using these formulas:

1. **Mean Flow Time:**
2. **Average Number of Jobs in System:**
3. **Average Lateness:**
4. **Utilization:**

4. Summary Comparison

- **SPT** is generally the best for reducing the number of jobs waiting in the shop and minimizing average flow time. However, it can cause long jobs to be delayed indefinitely ("starvation").
- **EDD** is the industry standard when the primary concern is customer satisfaction and meeting delivery dates.
- **FCFS** is common in service industries (like banks or retail) because it is easy to explain to customers, though it is often inefficient for manufacturing.

Johnson's Rule

Johnson's Rule is used for sequencing jobs through two machines (Machine 1 Machine 2). All jobs must follow the same processing order.

The Logic (Step-by-Step)

1. **Identify the Minimums:** Look at the processing times for all jobs on both machines. Find the absolute smallest value.
2. **Placement Rule:**
   - If the minimum time is on **Machine 1**, place that job at the **beginning** (the leftmost available slot) of the sequence.
   - If the minimum time is on **Machine 2**, place that job at the **end** (the rightmost available slot) of the sequence.
3. **Eliminate and Repeat:** Once a job is placed, cross it off your list. Repeat the process for the remaining jobs until the sequence is full.

Detailed Example (Problem 3 Breakdown)

Given the data from Problem 3:

Job	Machine 1 (Grinding)	Machine 2 (Painting)
1	5	2
2	3	6

3	8	4
4	10	7
5	7	12

Iteration 1

- **Smallest Value:** 2 (Job 1, Machine 2).
- **Action:** Since it is on Machine 2, Job 1 goes **LAST**.
- **Sequence:** [ ] - [ ] - [ ] - [ ] - [1]

Iteration 2

- **Smallest Value remaining:** 3 (Job 2, Machine 1).
- **Action:** Since it is on Machine 1, Job 2 goes **FIRST**.
- **Sequence:** [2] - [ ] - [ ] - [ ] - [1]

Iteration 3

- **Smallest Value remaining:** 4 (Job 3, Machine 2).
- **Action:** Since it is on Machine 2, Job 3 goes as **LATE** as possible (in the last available slot before Job 1).
- **Sequence:** [2] - [ ] - [ ] - [3] - [1]

Iteration 4

- **Smallest Value remaining:** 7. This appears twice: Job 4 (Machine 2) and Job 5 (Machine 1).
- **Action for Job 5:** It's on Machine 1, so it goes as **EARLY** as possible (after Job 2).
- **Action for Job 4:** It's on Machine 2, so it goes as **LATE** as possible (before Job 3).
- **Final Sequence:** [2] - [5] - [4] - [3] - [1]

Why does it work?

Johnson's Rule works by:

1. **Loading Machine 1 quickly:** By putting jobs with short M1 times at the start, Machine 2 can start working as soon as possible (minimizing initial idle time).
2. **Emptying Machine 2 slowly:** By putting jobs with short M2 times at the end, we ensure Machine 2 remains productive for as long as possible while Machine 1 finishes its final tasks.

Limitations

- It only works for **two machines**. (For three machines, you can sometimes use a "virtual two-machine" conversion, but it is not always optimal).
- It assumes the **order** of machines is fixed (M1 then M2).

The Six Sigma Approach

Six Sigma is a disciplined, data-driven methodology for eliminating defects and reducing variability in any process—from manufacturing to transactional and from product to service.

1. What is "Six Sigma"?

Statistically, Six Sigma refers to a process in which **99.99966%** of all opportunities to produce some feature are expected to be free of defects. This equates to no more than **3.4 defects per million opportunities (DPMO)**.

Sigma Level	Yield (Percent)	Defects per Million (DPMO)
2 sigma	69.1%	308,538

4sigma	99.38%	6,210
6sigma	**99.99966%**	**3.4**

2. Core Methodologies

DMAIC (For Improving Existing Processes)

This is the most common Six Sigma roadmap.

1. **Define:** Identify the problem, the project goals, and the customer (internal or external) requirements (CTQ - Critical to Quality).
2. **Measure:** Quantify the current process performance. Establish a baseline.
3. **Analyze:** Use data analysis to find the root cause of defects and identify sources of variation.
4. **Improve:** Implement and verify the solution. Optimize the process based on analysis.
5. **Control:** Maintain the gains by documenting standard operating procedures and monitoring the process with Control Charts.

DMADV (For Creating New Processes)

Also known as **DFSS** (Design for Six Sigma).

- **Define** goals.
- **Measure** and identify CTQs.
- **Analyze** design alternatives.
- **Design** the process/product.
- **Verify** the design performance.

3. Key Six Sigma Tools

Six Sigma integrates various statistical and management tools:

- **SIPOC Diagram:** (Supplier, Input, Process, Output, Customer) to map the high-level process.
- **Fishbone (Ishikawa) Diagram:** For root cause analysis.
- **Pareto Chart:** To identify the "Vital Few" problems (80/20 rule).
- **FMEA:** (Failure Mode and Effects Analysis) to predict and prevent potential failures.
- **SPC Charts:** (X-R, NP, C charts) to monitor process stability.

4. The Belt Hierarchy

Six Sigma projects are led by trained professionals organized into "Belts":

- **White Belt:** Understands basic concepts; supports local problem-solving.
- **Yellow Belt:** Participates as a project team member; reviews process improvements.
- **Green Belt:** Leads smaller projects; assists Black Belts with data collection and analysis.
- **Black Belt:** Leads complex projects full-time; mentors Green Belts; high-level statistical mastery.
- **Master Black Belt:** Strategic level; trains Black and Green Belts; manages the Six Sigma program across the organization.

5. Lean Six Sigma

Modern organizations often combine **Lean** (which focuses on eliminating waste and increasing speed) with **Six Sigma** (which focuses on reducing variation and improving quality). Together, they create a highly efficient, high-quality production environment.

Six Sigma Approach

Six Sigma is a comprehensive and disciplined approach to quality management that focuses on improving processes by reducing defects and minimizing variation. It is a data-driven methodology that uses statistical tools and systematic problem-solving techniques to achieve high levels of process performance and customer satisfaction. The concept was developed in the 1980s by Motorola when the company faced serious quality issues and needed a structured approach to reduce manufacturing defects. Later, it gained worldwide recognition when General Electric adopted it under the leadership of Jack Welch and achieved remarkable improvements in quality and profitability.

The term “Six Sigma” refers to a statistical measure of process capability. In statistics, sigma (σ) represents standard deviation, which indicates variation in a process. Achieving Six Sigma level means that the process produces only 3.4 defects per million opportunities (DPMO), which is considered near-perfect performance. The main aim of Six Sigma is not only to reduce defects but also to eliminate the root causes of errors and improve overall efficiency.

Six Sigma is based on a strong focus on customer requirements. It begins with understanding what the customer defines as quality and then aligns business processes to meet those expectations. It emphasizes fact-based decision-making rather than assumptions. Data collection and statistical analysis play a crucial role in identifying process weaknesses and measuring improvements.

The most commonly used methodology in Six Sigma is DMAIC, which is applied to improve existing processes. DMAIC stands for Define, Measure, Analyze, Improve, and Control. In the Define phase, the problem is clearly identified, project goals are established, and customer requirements are understood. In the Measure phase, relevant data is collected to determine the current performance level of the process. In the Analyze phase, statistical tools are used to identify the root causes of defects and process variations. In the Improve phase, solutions are developed and implemented to eliminate the causes of defects. Finally, in the Control phase, monitoring systems are established to ensure that improvements are maintained and the process does not return to its previous state.

For designing new products or processes, Six Sigma uses another methodology called DMADV, which stands for Define, Measure, Analyze, Design, and Verify. This approach is mainly used when an existing process is not capable of meeting customer requirements and a completely new design is required.

Six Sigma also introduces a structured hierarchy of trained professionals known as “belts,” similar to martial arts ranking. These include White Belt, Yellow Belt, Green Belt, Black Belt, and Master Black Belt. Each level represents a different degree of expertise and responsibility in leading improvement projects. Black Belts and Master Black Belts usually lead major projects and provide training to other team members.

The benefits of Six Sigma are significant. It improves product and service quality, reduces waste and rework, lowers production costs, increases efficiency, enhances customer satisfaction, and improves profitability. It also promotes a culture of continuous improvement and teamwork within the organization. However, the implementation of Six Sigma requires proper training, strong management support, and investment in time and resources. Without commitment from top management, the program may not succeed.

Six Sigma is a powerful quality improvement approach that focuses on reducing variation and eliminating defects through a systematic, data-driven methodology. By aligning processes with customer expectations and continuously improving performance, organizations can achieve operational excellence and gain a competitive advantage in the market.

Six Sigma Methodologies – Detailed Explanation

The success of Six Sigma largely depends on its structured methodologies, which provide a clear roadmap for solving problems and improving processes. The two major methodologies used in Six Sigma are **DMAIC** and **DMADV**. Each methodology is applied depending on whether the organization wants to improve an existing process or design a new one. These structured approaches ensure that improvements are systematic, measurable, and sustainable rather than temporary fixes.

1. DMAIC Methodology (For Improving Existing Processes)

DMAIC is the most widely used Six Sigma methodology. It is applied when a process already exists but is not performing efficiently or is producing defects. The purpose of DMAIC is to identify the root causes of problems and eliminate them permanently. The five stages of DMAIC are explained below in detail:

Define Phase

The Define phase is the starting point of the project. In this stage, the problem is clearly identified and defined in measurable terms. The project objectives, scope, timeline, and expected outcomes are determined. Customer requirements are carefully studied because Six Sigma strongly emphasizes meeting customer expectations. Tools such as project charters, SIPOC diagrams (Supplier, Input, Process, Output, Customer), and stakeholder analysis are often used. A well-defined problem statement ensures that the team focuses on the correct issue and avoids confusion later.

Measure Phase

In the Measure phase, data is collected to understand the current performance of the process. The goal is to establish a baseline measurement so that improvements can be compared later. The team identifies key performance indicators (KPIs) and critical-to-quality (CTQ) characteristics. Accurate and reliable data collection methods are essential in this stage. Tools such as data collection plans, process mapping, histograms, check sheets, and capability analysis are used. This phase answers the question: *How is the process currently performing?*

Analyze Phase

The Analyze phase focuses on identifying the root causes of defects and process variations. Instead of addressing symptoms, Six Sigma aims to find the fundamental reasons behind the problem. Statistical tools and analytical techniques are used to examine relationships between variables. Common tools include cause-and-effect (fishbone) diagrams, Pareto analysis, regression analysis, hypothesis testing, and failure mode and effects analysis (FMEA). By the end of this phase, the team clearly understands why the problem is occurring.

Improve Phase

In the Improve phase, solutions are developed and implemented to eliminate the root causes identified in the Analyze stage. Brainstorming sessions, pilot testing, and design of experiments (DOE) may be used to test potential improvements. The solutions must be practical, cost-effective, and sustainable. Once implemented, the team evaluates whether the improvements have significantly reduced defects and enhanced performance. This stage converts analysis into real action.

Control Phase

The Control phase ensures that the improvements achieved are maintained over time. Without proper control, processes may return to their old inefficient state. Standard operating procedures (SOPs), control charts, monitoring systems, and regular performance reviews are established to maintain consistency. Training employees and documenting changes are also important aspects of this phase. The Control stage guarantees long-term success and stability of the improved process.

2. DMADV Methodology (For Designing New Processes or Products)

DMADV is used when a new product or process needs to be developed, or when an existing process is so defective that incremental improvement is not sufficient. It is often associated with Design for Six Sigma (DFSS). The five stages are as follows:

Define Phase

Similar to DMAIC, the Define phase in DMADV focuses on identifying customer needs and project goals. Market research and voice-of-customer analysis are conducted to understand expectations clearly. This ensures that the new design aligns with customer requirements from the beginning.

Measure Phase

In this stage, critical quality factors and design specifications are determined. The team measures customer requirements and translates them into measurable technical specifications. Risk assessments and benchmarking studies may also be performed.

Analyze Phase

The Analyze phase involves developing different design alternatives and evaluating their feasibility. Statistical modeling and simulations may be used to predict performance outcomes. The best design option is selected based on data and analysis.

Design Phase

In the Design stage, the selected solution is developed in detail. Prototypes may be created, and process parameters are finalized. The design must meet performance standards and quality expectations.

Verify Phase

The final phase involves testing and validating the new design under real operating conditions. Pilot runs, customer feedback, and performance testing ensure that the design meets all requirements before full-scale implementation. Only after verification is the new process officially launched.

Comparison of DMAIC and DMADV

DMAIC is primarily used for improving existing processes, while DMADV is used for creating new processes or products. DMAIC focuses on correcting problems, whereas DMADV focuses on designing processes correctly from the beginning. Both methodologies rely heavily on data, statistical analysis, and customer-focused thinking.

Conclusion

The methodologies of Six Sigma provide a disciplined and systematic framework for problem-solving and process improvement. Whether improving an existing process through DMAIC or designing a new one through DMADV, the structured approach ensures reduced variation, minimized defects, and enhanced customer satisfaction. These methodologies form the backbone of Six Sigma and are essential for achieving operational excellence.

Advantages of Six Sigma	Disadvantages of Six Sigma
Improves product and service quality by reducing defects and errors.	Implementation cost is high due to training and consultancy expenses.
Reduces process variation and increases consistency in output.	Requires extensive data collection and statistical analysis, which may be complex.
Increases customer satisfaction by meeting quality expectations.	Time-consuming implementation process.
Decreases operational costs by reducing waste, rework, and scrap.	Strong dependence on top management support; failure if leadership commitment is weak.
Promotes data-driven decision making instead of guesswork.	May face employee resistance to change.

Enhances productivity and process efficiency.	Not suitable for very small organizations with limited resources.
Encourages teamwork and continuous improvement culture.	Overemphasis on statistics may ignore human and creative aspects.
Provides structured problem-solving methodology (DMAIC/DMADV).	Benefits may take time to become visible.

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Project Management

Project Management is the process of planning, organizing, directing, and controlling resources to achieve specific objectives within a defined time, cost, and scope. A project is a temporary activity undertaken to create a unique product, service, or result. Unlike routine operations, projects have a definite beginning and ending.

Project Management Essentials

Project Management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements.

1. The Project Life Cycle (PLC)

Most projects follow a five-phase process defined by the PMBOK (Project Management Body of Knowledge):

1. **Initiation:** Defining the project at a broad level. Developing the Project Charter and identifying stakeholders.
2. **Planning:** Creating a roadmap. This includes the Work Breakdown Structure (WBS), schedule, budget, and risk management plan.
3. **Execution:** Putting the plan into action. Resources are allocated and the actual work begins.
4. **Monitoring & Control:** Tracking progress against the plan. Managing scope creep and quality control using tools like KPI dashboards.
5. **Closing:** Finalizing all activities. Handing over the deliverable and conducting a "Post-Mortem" or Lessons Learned session.

2. Key Methodologies

Methodology	Best For...	Characteristics
Waterfall	Fixed scope, clear requirements.	Linear, sequential phases. Hard to change once started.
Agile	Software, creative, or high-uncertainty projects.	Iterative "Sprints," continuous feedback, highly flexible.
Scrum	Teams of 5-9 people.	A subset of Agile featuring Daily Stand-ups, Product Backlogs, and Scrum Masters.
Lean	Manufacturing and efficiency-focused projects.	Focuses on maximizing value by minimizing waste (Muda).

3. Critical Scheduling Tools

Work Breakdown Structure (WBS)

A hierarchical decomposition of the total scope of work. It breaks large deliverables down into manageable "work packages."

Gantt Charts

A visual timeline showing start and end dates of tasks, as well as **dependencies** (e.g., Task B cannot start until Task A is finished).

Critical Path Method (CPM)

The sequence of stages determining the minimum time needed for an operation.

- **Critical Path:** The longest path through the network; it has **zero slack**. Any delay here delays the whole project.
- **Slack/Float:** The amount of time a task can be delayed without affecting the project completion date.

4. The Triple Constraint (The Iron Triangle)

Every project is constrained by three factors:

- **Scope:** What work is being done?
- **Time:** How long will it take?
- **Cost:** What is the budget?
- *Note: If you change one, at least one other must be adjusted.*

Key Characteristics of a Project

A project is a unique and temporary endeavor undertaken to achieve a specific objective within a defined time frame and budget. Unlike routine operations, projects have distinct features that differentiate them from regular organizational activities. The key characteristics of a project are explained below in detail:

1. Definite Objective

Every project is undertaken with a clear and specific goal. The objective defines what is to be achieved at the end of the project. It may involve constructing a building, developing a software application, launching a new product, or organizing an event. The objective gives direction to all planning and execution activities and acts as a basis for measuring project success.

2. Temporary Nature

A project has a definite beginning and a definite end. It is not a continuous process. Once the project objective is achieved, the project is terminated. The temporary nature distinguishes a project from routine business operations, which are ongoing and repetitive.

3. Unique Activity

Each project is unique in terms of scope, resources, location, or objectives. Even if two projects appear similar, there will always be differences in design, conditions, stakeholders, or execution methods. This uniqueness creates uncertainty and requires special planning.

4. Defined Time Frame

A project must be completed within a specified period. Time is a critical constraint in project management. Delays can lead to cost overruns and loss of reputation. Therefore, scheduling and time control are essential elements of every project.

5. Limited Resources

Projects operate under constraints of limited resources such as money, manpower, materials, and equipment. Efficient allocation and utilization of these resources are necessary to complete the project successfully.

6. Interdependent Activities

A project consists of several activities that are interconnected. The completion of one activity may depend on the completion of another. Proper sequencing and coordination of these activities are required to ensure smooth progress.

7. Involves Risk and Uncertainty

Since projects are unique and temporary, they involve uncertainties related to time, cost, technology, and external factors. Risk management is therefore an important aspect of project management.

8. Cross-Functional Involvement

Projects often require collaboration between different departments such as finance, production, marketing, and human resources. Effective communication and coordination among these departments are essential for project success.

The key characteristics of a project—such as defined objectives, temporary nature, uniqueness, limited resources, interdependence of activities, and inherent risks—make project management a specialized field. Understanding these characteristics helps in planning, executing, and controlling projects effectively.

Objectives of Project Management

The primary objective of project management is to complete a project successfully by achieving its goals within the given constraints of time, cost, and quality. Every project is undertaken to fulfill a specific purpose, and project management ensures that this purpose is achieved efficiently and effectively. The main objectives are explained below:

1. Completion Within Scheduled Time

One of the most important objectives of project management is to complete the project within the specified time frame. Delays in project completion can increase costs, affect customer satisfaction, and damage the organization’s reputation. Proper scheduling techniques such as network analysis (CPM and PERT) are used to monitor and control time.

2. Completion Within Budgeted Cost

Projects are carried out under financial constraints. Controlling costs and avoiding cost overruns is a major objective of project management. Efficient planning, budgeting, and monitoring ensure that the project is completed within the allocated funds.

3. Achievement of Desired Quality

Quality is a critical factor in determining project success. The output of the project must meet the required standards and specifications. Delivering poor quality may lead to rework, increased costs, and dissatisfaction among stakeholders. Therefore, maintaining quality standards is a key objective.

4. Optimum Utilization of Resources

Projects require resources such as manpower, materials, machines, and money. Effective project management ensures proper allocation and utilization of these limited resources to avoid wastage and improve efficiency.

5. Minimization of Risks

Projects involve uncertainties and risks related to time, cost, technology, and external factors. Identifying potential risks in advance and taking preventive measures help reduce negative impacts on project performance.

6. Effective Coordination and Communication

Projects often involve multiple departments and stakeholders. Ensuring smooth coordination and clear communication among team members is essential for achieving project objectives.

7. Customer Satisfaction

The ultimate objective of any project is to satisfy the client or end user. Delivering the project as per agreed specifications, within time and cost limits, ensures customer satisfaction and enhances organizational reputation.

Phases of Project Management

Project management is carried out through a systematic process divided into different phases. These phases provide a structured framework for planning, executing, and completing a project successfully. Each phase has specific objectives and activities that contribute to overall project success. The main phases of project management are explained below:

1. Project Initiation Phase

The initiation phase is the starting point of the project. In this phase, the need for the project is identified and clearly defined. The project objectives, scope, feasibility, and expected benefits are analyzed. A feasibility study may be conducted to determine whether the project is technically, financially, and economically viable.

Key activities in this phase include:

- Defining project goals and objectives
- Identifying stakeholders
- Conducting feasibility analysis
- Preparing the project proposal or project charter

This phase ends with formal approval to proceed with the project.

2. Project Planning Phase

The planning phase is the most important stage in project management. Detailed plans are prepared regarding time, cost, resources, quality, and risk management. A clear roadmap is created to guide the project team.

Key activities include:

- Developing Work Breakdown Structure (WBS)
- Scheduling activities using tools like CPM or PERT
- Estimating costs and preparing budgets
- Resource planning and allocation
- Risk identification and mitigation planning

Effective planning reduces uncertainties and increases the chances of project success.

3. Project Execution Phase

In the execution phase, the project plan is implemented. Resources are mobilized, tasks are performed, and deliverables are produced according to the schedule.

Key activities include:

- Assigning tasks to team members
- Coordinating resources
- Ensuring quality standards
- Maintaining communication among stakeholders

This phase requires strong leadership, coordination, and teamwork to achieve planned objectives.

4. Project Monitoring and Control Phase

This phase runs parallel to the execution phase. It involves tracking project performance and comparing actual progress with the planned schedule and budget. Any deviations are identified and corrective actions are taken.

Key activities include:

- Monitoring time and cost performance
- Controlling scope changes
- Managing risks
- Ensuring quality control

The main objective of this phase is to ensure the project stays on track.

5. Project Closure Phase

The closure phase marks the completion of the project. All activities are finalized, and the final product or service is handed over to the client.

Key activities include:

- Final inspection and approval
- Documentation and reporting
- Settlement of payments
- Evaluation of project performance
- Release of resources

This phase ensures that the project is formally completed and lessons learned are documented for future projects.

Conclusion

The phases of project management—Initiation, Planning, Execution, Monitoring and Control, and Closure—provide a structured approach to managing projects effectively. Following these phases systematically helps organizations complete projects successfully within time, cost, and quality constraints.

Project Networks: The Roadmap of Work

A Project Network is essentially a flow chart that shows the "who, what, and when" of a project. It maps out how tasks connect to each other.

1. The Building Blocks

Think of a network like a train map:

- **The Activity (The Track):** A specific task that takes time and effort (e.g., "Paint the room").
- **The Event/Node (The Station):** A point in time marking the start or finish of a task. It doesn't take time itself; it's just a milestone.
- **Precedence (The Rules):** The logic that says "You can't do Task B until Task A is finished."

2. Two Ways to Draw it

There are two main styles used in project management:

Activity on Node (AON) - The Modern Standard

- **The Look:** Boxes connected by arrows.
- **The Logic:** The **Box** is the task. The **Arrow** just shows the direction of the flow.
- *Why use it?* It's easier to read and used by almost all software (like MS Project).

Activity on Arrow (AOA)

- **The Look:** Arrows connected by circles.
- **The Logic:** The **Arrow** is the task. The **Circle** is the event (start/finish).
- *Why use it?* It's the traditional way, helpful for seeing milestones (events) clearly.

3. What the Network Tells You

Once you draw the map, you can find three "Holy Grail" pieces of information:

1. **The Critical Path:** The longest "path" of tasks from start to finish. If any task on this path is late by 1 day, the **whole project** is late by 1 day.
2. **Slack (or Float):** "Wiggle room." It's the amount of time a task can be delayed without making the whole project late. (Critical Path tasks have **zero** slack).
3. **Earliest & Latest Times:** * **Earliest Start (ES):** The soonest you can possibly start a task.
   - **Latest Start (LS):** The absolute last second you can start a task before you ruin the project schedule.

4. Simple Example

Project: Making a Sandwich

- Task A: Get Bread (2 mins)
- Task B: Get Filling (1 min)
- Task C: Assemble (1 min)

Network Logic: You need A AND B before you can do C.

Critical Path: Task A Task C (Total 3 mins). Task B has 1 minute of "Slack."

AOA vs. AON: Project Networks

To understand the difference between **Activity on Arrow (AOA)** and **Activity on Node (AON)**, let's look at one simple project through two different lenses.

The Example Project: Building a Garden Shed

- **Task A:** Level the Ground (2 days)
- **Task B:** Build the Floor (1 day) — *Must do A first*
- **Task C:** Buy Materials (1 day) — *Can do anytime*
- **Task D:** Assemble Walls (2 days) — *Must do B and C first*

1. Activity on Node (AON)

The Modern Standard. In this style, the **Node (Box)** is the activity itself. Arrows only show the "pathway" or dependency.

- **Pros:** Very easy to draw and read. You can put all the data (Start, Finish, Slack) inside the box.
- **Software:** This is what Microsoft Project and Primavera use.

2. Activity on Arrow (AOA)

The Traditional Style. In this style, the **Arrow** is the activity. The **Node (Circle)** is just a point in time (an event like "Ground Leveled").

- **Pros:** Clearly emphasizes **Milestones** (the circles).
- **Cons:** Sometimes requires **"Dummy Activities"** (dashed arrows with zero time) to maintain logic if two tasks share the same start and end nodes.

3. Side-by-Side Summary

Feature	AON (Activity on Node)	AOA (Activity on Arrow)
Node represents...	The Task itself	An Event (Start/End)
Arrow represents...	Dependency/Sequence	The Task itself
Dummy Activities?	Never needed	Sometimes needed
Ease of use	High (Intuitive)	Medium (Complex logic)
Best for...	Project Management Software	Visualizing Milestones

4. Analysis of our Shed Project

Using either method, we find the same results:

- **Critical Path:** A B D (Total 5 days).
- **Slack:** Task C has 2 days of slack (it only takes 1 day, but Tasks A+B take 3 days before D can start).

Basis	Event	Activity
Meaning	Oka particular point in time	Oka work / task
Nature	Start or finish point	Work process
Time	Time consume cheyyadu	Time consume chesthundi
Resources	Resources avasaram ledu	Resources avasaram untayi

Representation (AOA)	Circle / Node	Arrow
Example	“Foundation complete”	“Lay foundation (2 days)”

CPM (Critical Path Method)

Critical Path Method (CPM) is a deterministic network technique used for planning and controlling projects where activity durations are known and fixed.

Features of CPM

- Suitable for construction and production projects
- Uses single time estimates
- Focuses on time-cost optimization

Critical Path

The critical path is the longest path in the network. It determines the minimum time required to complete the project. Activities on the critical path have zero slack.

Advantages of CPM

- Identifies critical activities
- Helps in project scheduling and control
- Assists in time-cost trade-off analysis

Critical Path Method (CPM):

The **Critical Path Method (CPM)** is a step-by-step project management technique used to identify tasks that are "critical" to finishing a project on time.

1. What is the "Critical Path"?

Imagine you are baking a cake and decorating it.

- **Path A:** Preheat oven (10 mins) -> Bake cake (30 mins) -> Cool cake (20 mins).
- **Path B:** Buy decorations (5 mins) -> Make icing (10 mins).

Even though you have two sets of tasks, the **Baking Path (60 mins)** is much longer than the **Decorating Path (15 mins)**. The Baking Path is your **Critical Path**. If the oven takes 5 extra minutes to preheat, the whole cake is delayed. If buying decorations takes 5 extra minutes, it doesn't matter because the cake is still in the oven!

Key Definitions:

- **Critical Path:** The longest sequence of dependent tasks in a project.
- **Float (or Slack):** The amount of time a task can be delayed *without* delaying the entire project. Tasks on the critical path have **Zero Float**.

2. The 6 Steps of CPM

1. **List All Activities:** Use a Work Breakdown Structure (WBS) to list every task needed.
2. **Identify Dependencies:** Determine which tasks must be finished before others can start (e.g., you can't paint a wall before building it).

3. **Draw the Network Diagram:** Create a flowchart using boxes (nodes) for tasks and arrows to show the order.
4. **Estimate Durations:** Decide how many days/hours each task will take.
5. **Identify the Critical Path:** Add up the durations for every possible "path" from start to finish. The longest one is your critical path.
6. **Update as You Go:** As the project moves, the critical path can change if a non-critical task is delayed so much that it becomes the new longest path.

3. CPM vs. PERT

Here is the easiest way to remember the difference:

Feature	CPM (Critical Path Method)	PERT (Program Evaluation & Review Technique)
Focus	Focuses on **Cost & Time** trade-offs.	Focuses on **Time** uncertainty.
Time Estimates	One fixed estimate (Deterministic).	Three estimates (Optimistic, Likely, Pessimistic).
Used For	Predictable, repetitive projects (e.g., Construction).	Unpredictable, new projects (e.g., Research & Development).
Model	Activity-oriented.	Event-oriented.

4. Why Use CPM?

- **Prioritization:** You know exactly which tasks need the most attention.
- **Scheduling:** You can give stakeholders a realistic completion date.
- **Resource Allocation:** If you have extra workers, you put them on the "Critical Path" tasks to speed things up.

PERT (Program Evaluation and Review Technique)

PERT is a project management tool used to estimate the time required to complete a project when there is a lot of **uncertainty**.

Unlike CPM (which assumes we know exactly how long a task takes), PERT is **probabilistic**—it assumes things might go better or worse than planned.

1. The Three-Point Estimation

In PERT, you don't just give one time estimate. You give three:

1. **Optimistic Time (or):** The "perfect world" scenario. Everything goes right.
2. **Pessimistic Time (or):** The "Murphy's Law" scenario. Everything goes wrong (but not a total disaster).
3. **Most Likely Time (or):** The realistic, "normal" scenario.

The PERT Formula (Expected Time)

To find the final estimated time () for a task, we use a weighted average that gives more importance to the "Most Likely" time:

2. Example: Developing a New App

Let's say you are estimating how long it will take to code a login screen:

- **Optimistic ():** 2 days (if the code works first try).
- **Most Likely ():** 5 days (normal debugging needed).

- **Pessimistic ():** 14 days (if major bugs appear).

Calculation:

Even though 5 days was "most likely," the high risk of the 14-day delay pulls the average up to 6 days.

3. PERT vs. CPM: The Key Differences

Feature	PERT	CPM
Nature	Probabilistic (Uncertainty)	Deterministic (Fixed)
Focus	Time-focused (Meeting deadlines)	Time-Cost Trade-off
Estimates	3 Time Estimates ()	1 Fixed Estimate
Orientation	Event-oriented (Milestones)	Activity-oriented (Tasks)
Best For	New, non-repetitive projects (R&D)	Repetitive, routine projects (Construction)

4. Advantages & Disadvantages

Advantages:

- **Handles Uncertainty:** Great for projects that have never been done before.
- **Realistic:** Accounts for risks rather than just "guessing" one number.
- **Critical Path:** Like CPM, it helps identify which tasks will delay the whole project.

Disadvantages:

- **Subjective:** The estimates are still based on human judgment, which can be biased.
- **Complex:** It takes more time to gather three estimates for every single task.
- **No Cost Focus:** It doesn't look at how much money you're spending as much as CPM does.

Project Management

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2. Key Methodologies

Methodology	Best For...	Characteristics
Waterfall	Fixed scope, clear requirements.	Linear, sequential phases. Hard to change once started.
Agile	Software, creative, or high-uncertainty projects.	Iterative "Sprints," continuous feedback, highly flexible.
Scrum	Teams of 5-9 people.	A subset of Agile featuring Daily Stand-ups, Product Backlogs, and Scrum Masters.
Lean	Manufacturing and efficiency-focused projects.	Focuses on maximizing value by minimizing waste (Muda).

3. Critical Scheduling Tools

Work Breakdown Structure (WBS)

A hierarchical decomposition of the total scope of work. It breaks large deliverables down into manageable "work packages."

Gantt Charts

A visual timeline showing start and end dates of tasks, as well as **dependencies** (e.g., Task B cannot start until Task A is finished).

Critical Path Method (CPM)

The sequence of stages determining the minimum time needed for an operation.

- **Critical Path:** The longest path through the network; it has **zero slack**. Any delay here delays the whole project.
- **Slack/Float:** The amount of time a task can be delayed without affecting the project completion date.

4. The Triple Constraint (The Iron Triangle)

Every project is constrained by three factors:

- **Scope:** What work is being done?
- **Time:** How long will it take?
- **Cost:** What is the budget?
- *Note: If you change one, at least one other must be adjusted.*

Key Characteristics of a Project

A project is a unique and temporary endeavor undertaken to achieve a specific objective within a defined time frame and budget. Unlike routine operations, projects have distinct features that differentiate them from regular organizational activities. The key characteristics of a project are explained below in detail:

1. Definite Objective

Every project is undertaken with a clear and specific goal. The objective defines what is to be achieved at the end of the project. It may involve constructing a building, developing a software application, launching a new product, or organizing an event. The objective gives direction to all planning and execution activities and acts as a basis for measuring project success.

2. Temporary Nature

A project has a definite beginning and a definite end. It is not a continuous process. Once the project objective is achieved, the project is terminated. The temporary nature distinguishes a project from routine business operations, which are ongoing and repetitive.

3. Unique Activity

Each project is unique in terms of scope, resources, location, or objectives. Even if two projects appear similar, there will always be differences in design, conditions, stakeholders, or execution methods. This uniqueness creates uncertainty and requires special planning.

4. Defined Time Frame

A project must be completed within a specified period. Time is a critical constraint in project management. Delays can lead to cost overruns and loss of reputation. Therefore, scheduling and time control are essential elements of every project.

5. Limited Resources

Projects operate under constraints of limited resources such as money, manpower, materials, and equipment. Efficient allocation and utilization of these resources are necessary to complete the project successfully.

6. Interdependent Activities

A project consists of several activities that are interconnected. The completion of one activity may depend on the completion of another. Proper sequencing and coordination of these activities are required to ensure smooth progress.

7. Involves Risk and Uncertainty

Since projects are unique and temporary, they involve uncertainties related to time, cost, technology, and external factors. Risk management is therefore an important aspect of project management.

8. Cross-Functional Involvement

Projects often require collaboration between different departments such as finance, production, marketing, and human resources. Effective communication and coordination among these departments are essential for project success.

The key characteristics of a project—such as defined objectives, temporary nature, uniqueness, limited resources, interdependence of activities, and inherent risks—make project management a specialized field. Understanding these characteristics helps in planning, executing, and controlling projects effectively.

Objectives of Project Management

The primary objective of project management is to complete a project successfully by achieving its goals within the given constraints of time, cost, and quality. Every project is undertaken to fulfill a specific purpose, and project management ensures that this purpose is achieved efficiently and effectively. The main objectives are explained below:

1. Completion Within Scheduled Time

One of the most important objectives of project management is to complete the project within the specified time frame. Delays in project completion can increase costs, affect customer satisfaction, and damage the organization's reputation. Proper scheduling techniques such as network analysis (CPM and PERT) are used to monitor and control time.

2. Completion Within Budgeted Cost

Projects are carried out under financial constraints. Controlling costs and avoiding cost overruns is a major objective of project management. Efficient planning, budgeting, and monitoring ensure that the project is completed within the allocated funds.

3. Achievement of Desired Quality

Quality is a critical factor in determining project success. The output of the project must meet the required standards and specifications. Delivering poor quality may lead to rework, increased costs, and dissatisfaction among stakeholders. Therefore, maintaining quality standards is a key objective.

4. Optimum Utilization of Resources

Projects require resources such as manpower, materials, machines, and money. Effective project management ensures proper allocation and utilization of these limited resources to avoid wastage and improve efficiency.

5. Minimization of Risks

Projects involve uncertainties and risks related to time, cost, technology, and external factors. Identifying potential risks in advance and taking preventive measures help reduce negative impacts on project performance.

6. Effective Coordination and Communication

Projects often involve multiple departments and stakeholders. Ensuring smooth coordination and clear communication among team members is essential for achieving project objectives.

7. Customer Satisfaction

The ultimate objective of any project is to satisfy the client or end user. Delivering the project as per agreed specifications, within time and cost limits, ensures customer satisfaction and enhances organizational reputation.

Phases of Project Management

Project management is carried out through a systematic process divided into different phases. These phases provide a structured framework for planning, executing, and completing a project successfully. Each phase has specific objectives and activities that contribute to overall project success. The main phases of project management are explained below:

1. Project Initiation Phase

The initiation phase is the starting point of the project. In this phase, the need for the project is identified and clearly defined. The project objectives, scope, feasibility, and expected benefits are analyzed. A feasibility study may be conducted to determine whether the project is technically, financially, and economically viable.

Key activities in this phase include:

- Defining project goals and objectives
- Identifying stakeholders
- Conducting feasibility analysis
- Preparing the project proposal or project charter

This phase ends with formal approval to proceed with the project.

2. Project Planning Phase

The planning phase is the most important stage in project management. Detailed plans are prepared regarding time, cost, resources, quality, and risk management. A clear roadmap is created to guide the project team.

Key activities include:

- Developing Work Breakdown Structure (WBS)
- Scheduling activities using tools like CPM or PERT
- Estimating costs and preparing budgets
- Resource planning and allocation
- Risk identification and mitigation planning

Effective planning reduces uncertainties and increases the chances of project success.

3. Project Execution Phase

In the execution phase, the project plan is implemented. Resources are mobilized, tasks are performed, and deliverables are produced according to the schedule.

Key activities include:

- Assigning tasks to team members
- Coordinating resources
- Ensuring quality standards
- Maintaining communication among stakeholders

This phase requires strong leadership, coordination, and teamwork to achieve planned objectives.

4. Project Monitoring and Control Phase

This phase runs parallel to the execution phase. It involves tracking project performance and comparing actual progress with the planned schedule and budget. Any deviations are identified and corrective actions are taken.

Key activities include:

- Monitoring time and cost performance
- Controlling scope changes
- Managing risks
- Ensuring quality control

The main objective of this phase is to ensure the project stays on track.

5. Project Closure Phase

The closure phase marks the completion of the project. All activities are finalized, and the final product or service is handed over to the client.

Key activities include:

- Final inspection and approval
- Documentation and reporting
- Settlement of payments
- Evaluation of project performance
- Release of resources

This phase ensures that the project is formally completed and lessons learned are documented for future projects.

Conclusion

The phases of project management—Initiation, Planning, Execution, Monitoring and Control, and Closure—provide a structured approach to managing projects effectively. Following these phases systematically helps organizations complete projects successfully within time, cost, and quality constraints.

Project Networks: The Roadmap of Work

A Project Network is essentially a flow chart that shows the "who, what, and when" of a project. It maps out how tasks connect to each other.

1. The Building Blocks

Think of a network like a train map:

- **The Activity (The Track):** A specific task that takes time and effort (e.g., "Paint the room").
- **The Event/Node (The Station):** A point in time marking the start or finish of a task. It doesn't take time itself; it’s just a milestone.
- **Precedence (The Rules):** The logic that says "You can't do Task B until Task A is finished."

2. Two Ways to Draw it

There are two main styles used in project management:

Activity on Node (AON) - The Modern Standard

- **The Look:** Boxes connected by arrows.
- **The Logic:** The **Box** is the task. The **Arrow** just shows the direction of the flow.
- *Why use it?* It's easier to read and used by almost all software (like MS Project).

Activity on Arrow (AOA)

- **The Look:** Arrows connected by circles.
- **The Logic:** The **Arrow** is the task. The **Circle** is the event (start/finish).
- *Why use it?* It's the traditional way, helpful for seeing milestones (events) clearly.

3. What the Network Tells You

Once you draw the map, you can find three "Holy Grail" pieces of information:

1. **The Critical Path:** The longest "path" of tasks from start to finish. If any task on this path is late by 1 day, the **whole project** is late by 1 day.
2. **Slack (or Float):** "Wiggle room." It's the amount of time a task can be delayed without making the whole project late. (Critical Path tasks have **zero** slack).
3. **Earliest & Latest Times:** * **Earliest Start (ES):** The soonest you can possibly start a task.
   - **Latest Start (LS):** The absolute last second you can start a task before you ruin the project schedule.

4. Simple Example

Project: Making a Sandwich

- Task A: Get Bread (2 mins)
- Task B: Get Filling (1 min)
- Task C: Assemble (1 min)

Network Logic: You need A AND B before you can do C.

Critical Path: Task A Task C (Total 3 mins). Task B has 1 minute of "Slack."

AOA vs. AON: Project Networks

To understand the difference between **Activity on Arrow (AOA)** and **Activity on Node (AON)**, let's look at one simple project through two different lenses.

The Example Project: Building a Garden Shed

- **Task A:** Level the Ground (2 days)
- **Task B:** Build the Floor (1 day) — *Must do A first*
- **Task C:** Buy Materials (1 day) — *Can do anytime*
- **Task D:** Assemble Walls (2 days) — *Must do B and C first*

1. Activity on Node (AON)

The Modern Standard. In this style, the **Node (Box)** is the activity itself. Arrows only show the "pathway" or dependency.

- **Pros:** Very easy to draw and read. You can put all the data (Start, Finish, Slack) inside the box.
- **Software:** This is what Microsoft Project and Primavera use.

2. Activity on Arrow (AOA)

The Traditional Style. In this style, the **Arrow** is the activity. The **Node (Circle)** is just a point in time (an event like "Ground Leveled").

- **Pros:** Clearly emphasizes **Milestones** (the circles).

- **Cons:** Sometimes requires **"Dummy Activities"** (dashed arrows with zero time) to maintain logic if two tasks share the same start and end nodes.

3. Side-by-Side Summary

Feature	AON (Activity on Node)	AOA (Activity on Arrow)
Node represents...	The Task itself	An Event (Start/End)
Arrow represents...	Dependency/Sequence	The Task itself
Dummy Activities?	Never needed	Sometimes needed
Ease of use	High (Intuitive)	Medium (Complex logic)
Best for...	Project Management Software	Visualizing Milestones

4. Analysis of our Shed Project

Using either method, we find the same results:

- **Critical Path:** A B D (Total 5 days).
- **Slack:** Task C has 2 days of slack (it only takes 1 day, but Tasks A+B take 3 days before D can start).

Basis	Event	Activity
Meaning	Oka particular point in time	Oka work / task
Nature	Start or finish point	Work process
Time	Time consume cheyyadu	Time consume chesthundi
Resources	Resources avasaram ledu	Resources avasaram untayi
Representation (AOA)	Circle / Node	Arrow
Example	“Foundation complete”	“Lay foundation (2 days)”

CPM (Critical Path Method)

Critical Path Method (CPM) is a deterministic network technique used for planning and controlling projects where activity durations are known and fixed.

Features of CPM

- Suitable for construction and production projects
- Uses single time estimates
- Focuses on time-cost optimization

Critical Path

The critical path is the longest path in the network. It determines the minimum time required to complete the project. Activities on the critical path have zero slack.

Advantages of CPM

- Identifies critical activities
- Helps in project scheduling and control
- Assists in time-cost trade-off analysis

Critical Path Method (CPM):

The **Critical Path Method (CPM)** is a step-by-step project management technique used to identify tasks that are "critical" to finishing a project on time.

1. What is the "Critical Path"?

Imagine you are baking a cake and decorating it.

- **Path A:** Preheat oven (10 mins) -> Bake cake (30 mins) -> Cool cake (20 mins).
- **Path B:** Buy decorations (5 mins) -> Make icing (10 mins).

Even though you have two sets of tasks, the **Baking Path (60 mins)** is much longer than the **Decorating Path (15 mins)**. The Baking Path is your **Critical Path**. If the oven takes 5 extra minutes to preheat, the whole cake is delayed. If buying decorations takes 5 extra minutes, it doesn't matter because the cake is still in the oven!

Key Definitions:

- **Critical Path:** The longest sequence of dependent tasks in a project.
- **Float (or Slack):** The amount of time a task can be delayed *without* delaying the entire project. Tasks on the critical path have **Zero Float**.

2. The 6 Steps of CPM

1. **List All Activities:** Use a Work Breakdown Structure (WBS) to list every task needed.
2. **Identify Dependencies:** Determine which tasks must be finished before others can start (e.g., you can't paint a wall before building it).
3. **Draw the Network Diagram:** Create a flowchart using boxes (nodes) for tasks and arrows to show the order.
4. **Estimate Durations:** Decide how many days/hours each task will take.
5. **Identify the Critical Path:** Add up the durations for every possible "path" from start to finish. The longest one is your critical path.
6. **Update as You Go:** As the project moves, the critical path can change if a non-critical task is delayed so much that it becomes the new longest path.

3. CPM vs. PERT

Here is the easiest way to remember the difference:

Feature	**CPM (Critical Path Method)**	**PERT (Program Evaluation & Review Technique)**
Focus	Focuses on **Cost & Time** trade-offs.	Focuses on **Time** uncertainty.
Time Estimates	One fixed estimate (Deterministic).	Three estimates (Optimistic, Likely, Pessimistic).
Used For	Predictable, repetitive projects (e.g., Construction).	Unpredictable, new projects (e.g., Research & Development).

Model	Activity-oriented.	Event-oriented.

4. Why Use CPM?

- **Prioritization:** You know exactly which tasks need the most attention.
- **Scheduling:** You can give stakeholders a realistic completion date.
- **Resource Allocation:** If you have extra workers, you put them on the "Critical Path" tasks to speed things up.

PERT (Program Evaluation and Review Technique)

PERT is a project management tool used to estimate the time required to complete a project when there is a lot of **uncertainty**.

Unlike CPM (which assumes we know exactly how long a task takes), PERT is **probabilistic**—it assumes things might go better or worse than planned.

1. The Three-Point Estimation

In PERT, you don't just give one time estimate. You give three:

1. **Optimistic Time (or):** The "perfect world" scenario. Everything goes right.
2. **Pessimistic Time (or):** The "Murphy's Law" scenario. Everything goes wrong (but not a total disaster).
3. **Most Likely Time (or):** The realistic, "normal" scenario.

The PERT Formula (Expected Time)

To find the final estimated time () for a task, we use a weighted average that gives more importance to the "Most Likely" time:

2. Example: Developing a New App

Let's say you are estimating how long it will take to code a login screen:

- **Optimistic ():** 2 days (if the code works first try).
- **Most Likely ():** 5 days (normal debugging needed).
- **Pessimistic ():** 14 days (if major bugs appear).

Calculation:

Even though 5 days was "most likely," the high risk of the 14-day delay pulls the average up to 6 days.

3. PERT vs. CPM: The Key Differences

Feature	PERT	CPM
Nature	Probabilistic (Uncertainty)	Deterministic (Fixed)
Focus	Time-focused (Meeting deadlines)	Time-Cost Trade-off
Estimates	3 Time Estimates ()	1 Fixed Estimate
Orientation	Event-oriented (Milestones)	Activity-oriented (Tasks)
Best For	New, non-repetitive projects (R&D)	Repetitive, routine projects (Construction)

4. Advantages & Disadvantages

Advantages:

- **Handles Uncertainty:** Great for projects that have never been done before.
- **Realistic:** Accounts for risks rather than just "guessing" one number.
- **Critical Path:** Like CPM, it helps identify which tasks will delay the whole project.

Disadvantages:

- **Subjective:** The estimates are still based on human judgment, which can be biased.
- **Complex:** It takes more time to gather three estimates for every single task.
- **No Cost Focus:** It doesn't look at how much money you're spending as much as CPM does.

Project Crashing and Cost Analysis

Project Crashing is the technique of shortening (compressing) the project duration by adding extra resources. The goal is to reduce the project time with the **minimum increase in cost**.

1. The Two Types of Costs

To understand crashing, you must distinguish between these two costs:

- **Direct Costs:** Costs directly tied to tasks (Labor, materials, equipment).
  - *Rule:* If you crash a project (speed it up), **Direct Costs go UP** because you are paying for overtime or extra machines.
- **Indirect Costs:** Overhead costs that continue as long as the project is active (Rent, insurance, administrative salaries).
  - *Rule:* If you crash a project (shorten it), **Indirect Costs go DOWN** because the project finishes sooner.

Total Project Cost = Direct Costs + Indirect Costs

2. Key Terms in Crashing

For every task, you need four pieces of information:

1. **Normal Time:** The standard time to complete a task.
2. **Normal Cost:** The cost associated with normal time.
3. **Crash Time:** The shortest possible time the task can be completed in.
4. **Crash Cost:** The higher cost associated with the crash time.

The Cost Slope Formula

To decide *which* task to crash first, you calculate the **Cost Slope**. This tells you how much it costs to save one day of time for that specific task.

Lower slope = Cheaper to crash.

3. The Step-by-Step Crashing Process

1. **Find the Critical Path:** You only crash tasks on the **Critical Path**. Crashing a non-critical task is a waste of money because it won't shorten the project finish date.
2. **Calculate Cost Slope:** Find the cost per day of crashing for all critical tasks.
3. **Crash the Cheapest Task:** Select the task on the critical path with the **lowest cost slope**.
4. **Check for New Critical Paths:** When you shorten one path, another parallel path might become "critical." If you now have two critical paths, you must crash tasks on both simultaneously.
5. **Stop when:**
   - You reach the "Crash Limit" (tasks can't be shortened further).

- The increase in Direct Cost is higher than the savings in Indirect Cost.

4. Total Cost Trade-off (The Curve)

In an exam, you might be asked about the relationship between time and cost.

- As you shorten the project, the **Direct Cost Curve** goes **Up**.
- As you shorten the project, the **Indirect Cost Curve** goes **Down**.
- The **Total Cost Curve** is U-shaped. The "Optimal Point" is the duration where the total cost is at its absolute minimum.

Action	Direct Cost	Indirect Cost	Total Cost
Normal Schedule	Low	High	Medium
Optimal Crashing	Medium	Medium	**Lowest**
Max Crashing	Very High	Low	High

Applications of Network Techniques (CPM & PERT) – Detailed Study Material

Network techniques such as **CPM (Critical Path Method)** and **PERT (Program Evaluation and Review Technique)** are widely used in planning, scheduling, and controlling projects. These techniques are especially useful when a project consists of many interrelated activities and requires systematic coordination.

Unlike simple scheduling methods, network techniques show **logical relationships between activities**, help determine the **minimum completion time**, and identify **critical activities** that cannot be delayed without affecting the whole project.

Below is a detailed explanation of their major applications:

1 Construction Projects

Construction projects are one of the most common areas where network techniques are applied. These projects involve a large number of sequential and parallel activities such as site preparation, foundation work, structural construction, electrical installation, plumbing, finishing, etc.

In such projects:

- Each activity depends on the completion of previous activities.
- Delay in one major activity can delay the entire project.
- Resources like labor, machinery, and materials must be properly scheduled.

Using **CPM**, project managers can identify the *critical path*, which represents the longest sequence of dependent activities. Any delay in critical activities directly increases the project duration.

Using **PERT**, uncertain activities (such as weather-dependent tasks) can be estimated using three time estimates (optimistic, pessimistic, and most likely).

Example:
While constructing a bridge, foundation must be completed before pillars are built. If foundation work is delayed, the entire project is delayed. Network techniques help in preventing such risks by proper planning.

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2 Manufacturing and Production Projects

In manufacturing industries, network techniques are used for:

- New product development
- Installation of new machinery
- Plant expansion projects
- Maintenance shutdown scheduling

Manufacturing projects involve coordination between different departments like procurement, production, quality control, and logistics.

Network techniques help:

- Reduce idle time of machines
- Avoid material shortages
- Coordinate multiple operations
- Ensure timely product launch

Example:
In automobile manufacturing, design must be completed before prototype testing. Prototype testing must be completed before mass production. Network analysis ensures smooth transition between stages.

3 Research and Development (R&D) Projects

R&D projects are highly uncertain in nature. Activities like testing, experimentation, and innovation cannot be predicted accurately.

PERT is particularly useful here because:

- It considers uncertainty in activity duration
- It calculates expected completion time
- It estimates probability of completing the project within a given deadline

In fields like pharmaceuticals, aerospace, and technology development, delays are costly. Network techniques improve planning accuracy and risk management.

Example:
In drug development, clinical trial phases may take uncertain time. PERT helps estimate the overall project duration more realistically.

4 Defense and Space Projects

Network techniques were originally developed for defense projects. Large-scale government projects require strict time control and coordination of multiple agencies.

Applications include:

- Missile development

- Satellite launches
- Military equipment production
- Strategic infrastructure projects

These projects involve thousands of activities and huge investments. A small delay can cause massive financial loss.

Network techniques help:

- Identify bottlenecks
- Allocate high-cost resources efficiently
- Monitor progress continuously

5 Information Technology (IT) Projects

In IT projects such as software development, ERP implementation, or website creation, many activities are interdependent.

For example:

- Requirement analysis must be completed before system design.
- Coding must be completed before testing.
- Testing must be completed before deployment.

Network techniques help IT managers:

- Schedule development cycles
- Identify critical modules
- Avoid project overruns
- Manage deadlines efficiently

6 Event Management

Even small projects like events can benefit from network techniques.

Event planning includes:

- Venue booking
- Invitation distribution
- Catering arrangements
- Decoration
- Logistics coordination

Proper sequencing is essential. For example, venue must be confirmed before invitations are sent.

Network techniques reduce confusion and ensure everything is completed on time.

Overall Importance of Network Techniques

Network techniques are not limited to one industry. They are applicable wherever:

- The project has multiple activities
- Activities are interdependent
- Time and cost control are important

- Delays can cause serious consequences

They help managers to:

- Determine minimum project completion time
- Identify critical activities
- Calculate slack/float time
- Perform time–cost trade-off analysis
- Improve coordination and control

Network techniques like CPM and PERT are powerful scientific tools used for planning and controlling complex projects. They transform complicated projects into structured network diagrams, making it easier to visualize relationships between activities.

By identifying critical paths and managing resources efficiently, these techniques reduce uncertainty, control costs, and ensure timely project completion.

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Project Management:

A project consist of inter related, activities which are to be executed in a ~~cert~~ certain orders before the entire task is completed.

→ The activities are inter related in a logical seauence which is known as ~~proceeded~~ prodecessor seauence.

* The project is represented in the form of Nlws for the purpose of analytical treatment to get solutions for scheduling & controlling it's activites.

Techniques:

1) CPM: (critical path method) (longest path.

2) PERT: (project evolution review techinque)

Phases of project managment:

→ Planning

→ Scheduling

→ controlling

CPM (critical path method):-

1) consider the details of a project as shown in the table?

→ consider the details of a project as shown in the table

Activity	Immediate predecessor(s)	duration (months)
A	-	2
B	-	5
C	-	4
D	B	5
E	A	7
F	A	3
G	B	3
H	C, D	6
I	C, D	2
J	E	5
K	F, G, H	4
L	F, G, H	3
M	I	12
N	J, K	8

a) construct cpm N/W

b) Determine the critical path & project completion time.

c) compute total floats & free floats for non-critical activities.

Basic concept
→ Project managment
→ Phases of project Managment
→ Guidelines for N/w construction
→ Critical path

precedence.
→ one project has
5 activities
A → complete
B to B
& relation
D

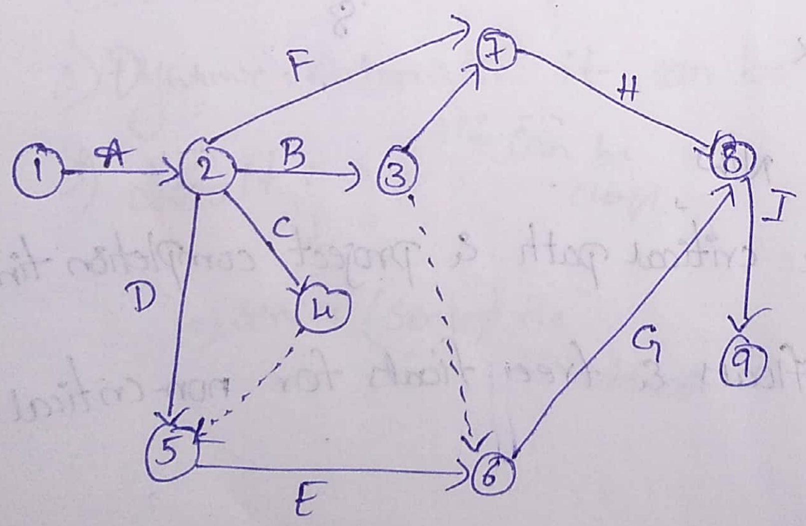
* A project consists of interrelated activities which are to be executed in a certain order before the entire task is completed.

* The activites are interrelated in a logical sequence which is known as precedence Relationship.

* Project is represented in the form of a N/w for the Purpose of analytical treatment to get solutions for Scheduling & controlling its activities.

Techniqes

cpm → critical Path method
PERT → project evaluation & Review technique.



→ Guidelines for N/w construction

1) ① ② ... ⑨ nodes
2) A,B.. - I activity

3) starting event & ending event of an activity are called
tail " " head.

$1 \longrightarrow 2$

tail head

4) each & every activity has a unique tail event (starting)

5) " " " " " " head " (ending)

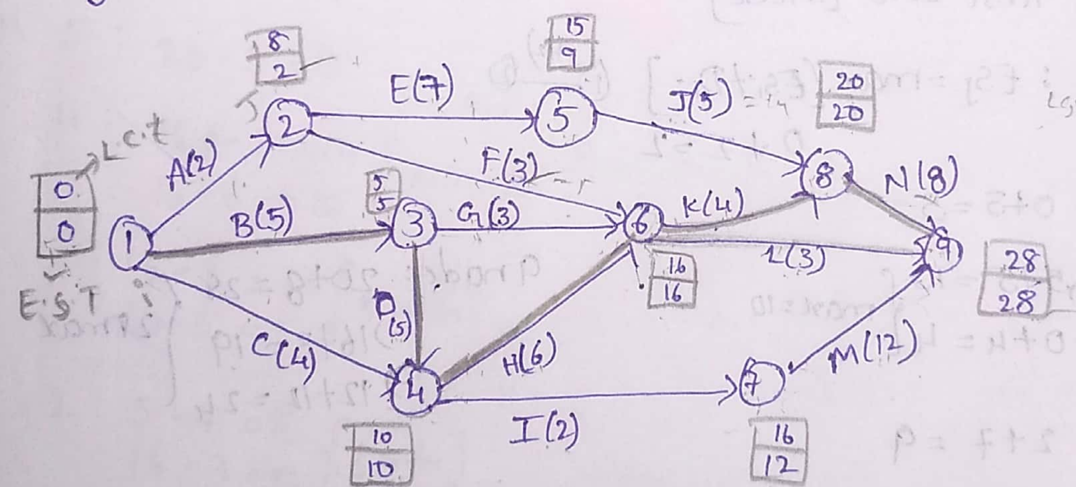
~~6) Each activity has two nodes, there will be~~

6) No activity should be represented by more than one arc (activity) in the N/w.

7) No two activities should have the same starting node and the same ending node.

8) Dummy activity is an imaginary activity indicating precedence relationship only. Duration of a dummy activity is zero.

a)



→ critical path

1) The project N/w is the longest path in the N/w.

2) ~~we have follow~~ This can be sastified by simply out all the possible paths from the start node of the project to the end node of the project & then selecting the path with the maximum sum of activity forms on that path.

Two phases

→ Determine earliest start time [ES] of all the nodes. [called as forward pass]

→ Determine latest completion ~~forms~~ times [LC] of various nodes [called as backward pass]

find E.S.T & L.C.T of each & every node:-

1) EST [Earliest start time]

formula : $ES_j = \max_i [ES_i + D_{ij}]$

j = ending activity

i = starting activity

ES_j = Earliest start time of ending activity

D = duration.

EST:

1) always first zero. [1 node]

2) 2 node : $ES_j = \max_i [ES_i + D_{ij}]$ $1 \xrightarrow{A(2)} 2$

start end

0 + 2 = 2

3 node: 0+5 = 5

4 node: 5+5 = 10
→ 0+4 = 4
max = 10

5 node: 2+7 = 9

6 node : 2+3 = 5
→ 5+3 = 8
→ 10+6 = 16
16 max

7 node : 10+2 = 12

8 node : 9+5 = 14
→ 16+4 = 20
20 max

9 node: 20+8 = 28
→ 16+3 = 19
→ 12+12 = 24
28 max

Laatest completion time: [backward]

starting → this process starts with node 9

Determination of LCT [formula]

$$LC_i = \min (LC_j - D_{ij})$$

latest completion starting node = LC_i

" " ending node = LC_j

LCT

node : 9 = 28

node 8 : $LC_j - D_{ij}$

$LC_9 - D_{89}$

$\Rightarrow 28 - 8 = 20$

node 7 :

$LC_j - D_{ij}$

$28 - 12 = 16$

node 6 : $\left.\begin{array}{l} 28 - 3 = 25 \\ 20 - 4 = 16 \end{array}\right\}$ [min = 16]

" 5 : $20 - 5 = 15$

4 : $\left.\begin{array}{l} 16 - 2 = 14 \\ 16 - 6 = 10 \end{array}\right\}$ min = 10]

3 : $\left.\begin{array}{l} 16 - 3 = 13 \\ 10 - 5 = 5 \end{array}\right\}$ [5 min]

2 : $\left.\begin{array}{l} 15 - 7 = 8 \\ 16 - 3 = 13 \end{array}\right\}$ [8 min]

1 : $\left.\begin{array}{l} 8 - 2 = 6 \\ 5 - 5 = 0 \\ 10 - 4 = 6 \end{array}\right\}$ 0 min

Condition for criticalpath:-

$ES_i = LC_i$

$ES_j = LC_j$

$ES_j - ES_i = LC_j - LC_i = D_{ij}$

$\Rightarrow$ 1-3-4-6-8-9

critical path B-D-H-K-N

duration:

5+5+6+4+8 = 28

c) Now we calculating total floats & free floats of NON-critical path.

Total floats: It is the amt of time that the completion time of an activity can be ~~displayed~~ delayed without affecting the project completion time.

formula: $TF_{ij} = LC_j - ES_i - D_{ij}$

Activity ~~2~~ 1-2 (A)

$\Rightarrow 8 - 0 - 2 = 6$

(B) $\Rightarrow 5 - 0 - 5 = 0$

(C) $\Rightarrow 10 - 0 - 4 = 6$

(D) $\Rightarrow 10 - 5 - 5 = 0$

(E) $\Rightarrow 15 - 2 - 7 = 6$

(F) $\Rightarrow 16 - 2 - 3 = 11$

(G) $\Rightarrow$ ~~16-2-3~~ $16 - 5 - 3 = 8$

(H) $\Rightarrow 16 - 10 - 6 = 0$

(I) $\Rightarrow 16 - 10 - 2 = 4$

(J) $\rightarrow 20 - 9 - 5 = 6$

(K) $\rightarrow 20 - 16 - 4 = 0$

(L) $\rightarrow 28 - 16 - 3 = 9$

(M) $\rightarrow 28 - 12 - 12 = 4$

(N) $\rightarrow 28 - 20 - 8 = 0$

Summary of total floats & free floats

Activity (i,j)	Duration (D_{ij})	Total float (TF_{ij})	free float (FF_{ij})
A 1-2	2	6	0
B 1-3	5	0	0
C 1-4	4	6	6
D 3-4	5	0	0
E 2-5	7	6	0
F 2-6	3	11	11
G 3-6	3	8	8
H 4-6	6	0	0
I 4-7	2	4	0
J 5-8	5	6	6
K 6-8	4	0	0
L 6-9	3	9	9
M 7-9	12	4	4
N 8-9	(8) 8	0	0

Free floats

$FF_{ij} = ES_j - ES_i - D_{ij}$

activity A 1-2

$\Rightarrow 2-0-2=0$

∴ Here T.F & FF values are zero. This property we can determine critial activities

(B) $\Rightarrow 5-0-5=0$

(C) $\Rightarrow 10-0-4=6$

(D) $\Rightarrow 10-5-5=0$

(E) $\Rightarrow 9-2-7=0$

(F) $\Rightarrow 16-2-3=11$

(G) $\Rightarrow 16-5-3=8$

(H) $16-10-6=0$

(I) $\Rightarrow 12-10-2=0$

(J) $20-9-5=6$

(K) $20-16-4=0$

(L) $28-16-3=9$

(M) $28-12-12=4$

(N) $28-20-8=0$

28-8-20

2) consider the details of a project as shown in below.

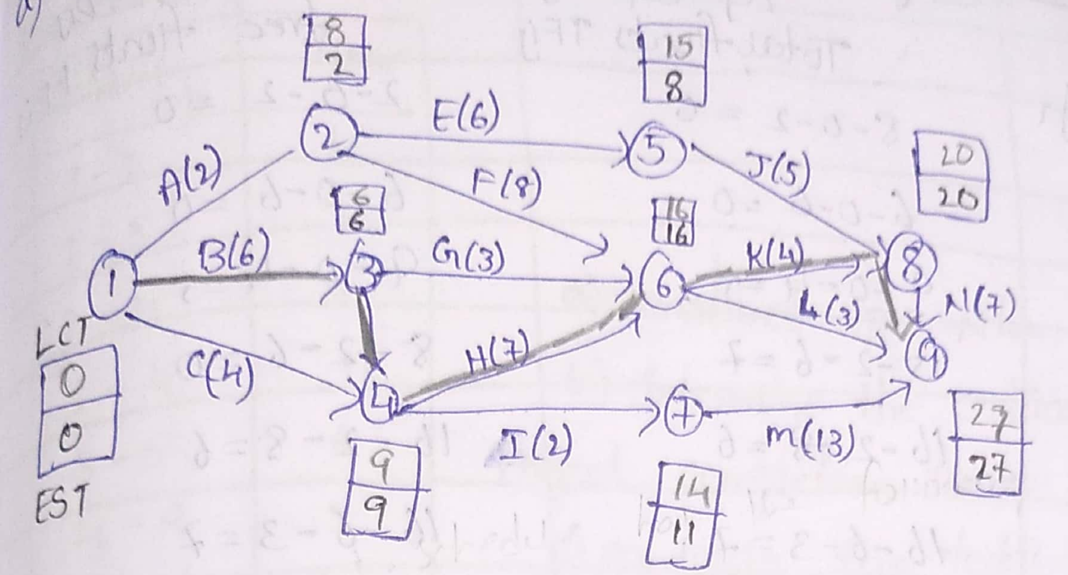
Activity	Immediate Predecessor(s)	duration
A	-	2
B	-	6
C	-	4
D	B	3
E	A	6
F	A	8
G	B	3
H	CD	7
I	CD	2
J	E	5
K	FGH	4
L	FGH	3
M	I	13
N	JK	7

a) construct cpm n/w.

b) determine the critical path & project completion time

c) compute total floats & free floats for non-critical activities.

a) construct CPM N/W



b) Earliest ~~com~~ starting time : [forward] [→] [1 to 9]

formula: $ES_j = \max_i (ES_i + D_{ij})$

Node 1: 0

2 : 0+2=2

3 : 0+6=6

4 : 0+4=4, 6+3=9 } max=9

5 : 2+6=8

6 : 2+8=10, 6+3=9, 9+7=16 } max=16

7 : 9+2=11

8 : 16+4=20, 8+5=13 } max=20

9 : 11+13=24, 20+7=27, 16+3=19 } max=24

Latest completion time:

[Backward] [⇐] [9 to 1]

formula: $LC_j = \min_j (LC_j - D_{ij})$

Node 9 : 27

8 : 27-7=20

7 : 27-13=14

6 : 20-4=16, 27-3=24 } min=16

5 : 20-5=15

4 : 14-2=12, 16-7=9 } min=9

3 : 16-3=13, 9-3=6 } min=6

2 : 15-6=9, 16-8=8 } min=8

1 : 8-2=6, 6-6=0, 9-4=5 } min=0

Summarizing the total floats & free floats.

Activity	Total floats TF_{ij} ($LC_j - ES_i - D_{ij}$)	free floats FF_{ij} ($ES_j - ES_i - D_{ij}$)
1-2	8-0-2 = 6	2-6-2 = 0
1-3	6-0-6 = 0	6-0-6 = 0
1-4	9-0-4 = 5	9-0-4 = 5
2-5	15-2-6 = 7	8-2-6 = 0
2-6	16-2-8 = 6	16-2-8 = 6
3-6	16-6-3 = 7	16-6-3 = 7
3-4	9-6-3 = 0	9-6-3 = 0
4-6	16-9-7 = 0	16-9-7 = 0
4-7	14-9-2 = 3	11-9-2 = 0
5-8	20-8-5 = 7	20-8-5 = 7
6-8	20-16-4 = 0	20-16-4 = 0
6-9	27-16-3 = 8	27-16-3 = 8
7-9	27-11-13 = 3	27-11-13 = 3
8-9	27-20-7 = 0	27-20-7 = 0

∴ The critical path: [longest path]

1-3-4-6-8-9

Consider the details of a project as shown in the below.

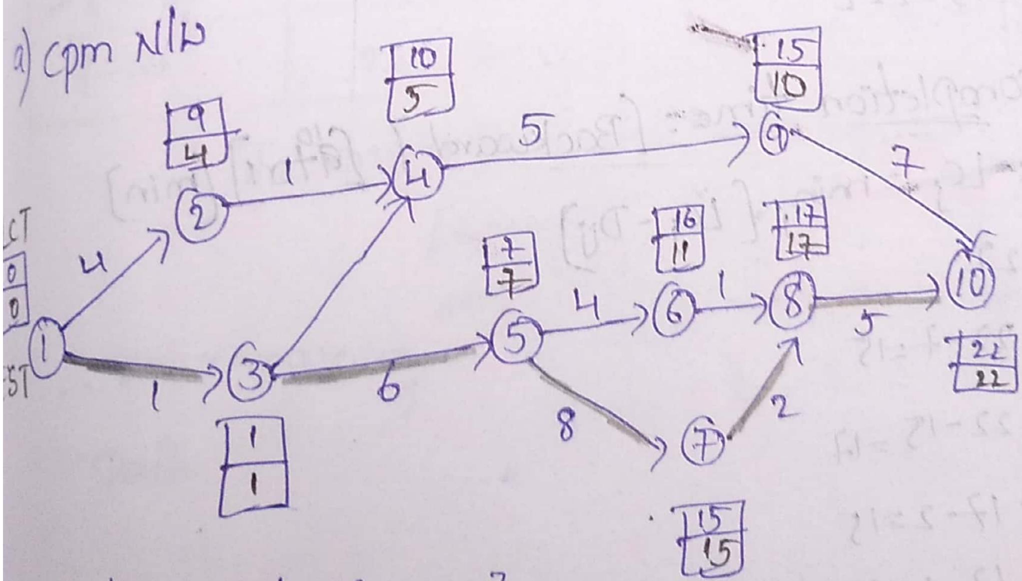
Activity	time
1-2	4
1-3	1
2-4	1
3-4	1
3-5	6
4-9	5
5-6	4
5-7	8
6-8	1
7-8	2
8-10	5
9-10	7

a) construct cpm N/w.

b) determine the critical path & project completion time.

c) compute the total floats & free floats for non-critical activities.

a) cpm N/w



critical path : [longest]

1-3-5-7-8-10

EST [Earliest starting time [forward] [→] [1 to 10]]

formula: $ES_j = \max_i (ES_i + D_{ij})$

node1 : 0

2 : 0+4=4

3 : 0+1=1

4 : 4+1=5, 1+1=2 { 5 max

5 : 1+6=7

6 : 7+4=11, 7+1=8 { 11 max

7 : 7+8=15

8 : 15+2=17, 8+1=9 { max 17

9 : 5+5=10

10 : 10+7=17, 17+5=22 { 22 max

Latest completion time : [Backward] [10 to 1] [min]

formula: $LC_i = \min_j [LC_j - D_{ij}]$

Node 10: 22

9 : 22-7=15

8 = 22-15 = 17

7 : 17-2=15

6 : 17-1=16

5 : 16-4=12, 15-8=7 { min 7

4 : 15-5=10

3 : 10-1=9, 7-6=1 { min 1

node 2 : 10-1=9

node 1 : 9-4=5, 1-1=0 { 0 min

Summarizing the total floats & free floats

Activity	$LC_j - ES_i - D_{ij}$ Total float TF_{ij}	$ES_j - ES_i - D_{ij}$ free floats FF_{ij}
1-2	9-0-4=5	4-0-4=0
1-3	1-0-1=0	1-0-1=0
2-4	10-4-1=5	5-4-1=0
3-4	10-1-1=8	5-1-1=3
3-5	7-1-6=0	7-1-6=0
4-9	15-5-5=5	10-5-5=0
5-6	16-7-4=5	11-7-4=0
5-7	15-7-8=0	15-7-8=0
6-8	17-11-1=5	17-11-1=5
7-8	17-15-2=0	17-15-2=0
8-10	22-17-5=0	22-17-5=0
9-10	22-10-7=5	22-10-7=5

∴ The critical Path : 1-3-5-7-8-10
[longest]

∴ All remaining activities are the non-critical longest path.

PERT : (project Evoluation Review Technique)

→ project Managment
1) CPM
2) PERT

cpm: The activities timing are deterministic in nature.

PERT: each activity will have 3 time estimates.

1) optmistic time
2) most likely time
3) Pessmistic time.

1) consider the following table summarizing the details of a project.

Activity	predecessors	duration (weeks) O	M	P
A	-	5	6	7
B	-	1	3	5
C	-	1	4	7
D	A	1	2	3
E	B	1	2	9
F	C	1	5	9
G	C	2	2	8
H	EF	4	4	10
I	D	2	5	8
J	HG	2	2	8

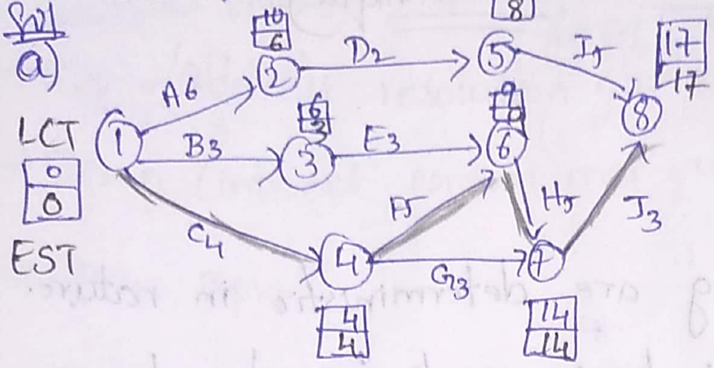
a) construct the project n/w

b) find the expected duration & variance of each activity

c) find the critical path & expected project completion time

d) what is the ~~propa~~ probability of completely project on or before 22 weeks

Sol
a)



b) calculation of the expected duration & variance of each activities

Activity	duration o	m	p	mean duration	variance
A	5	6	7	6	0.11
B	1	3	5	3	0.44
C	1	4	7	4	1
D	1	2	3	2	0.11
E	1	2	9	3	1.78
F	1	5	9	5	1.78
G	2	2	8	3	1
H	4	4	10	5	1
I	2	5	8	5	1
J	2	2	8	3	1

$\therefore$ critical path

$\Rightarrow$ 1-4-6-7-8

$\Rightarrow$ C-F-H-J

$\Rightarrow 4+5+5+3 = 17$ weeks

Mean duration formula (m): $\frac{t_o + 4t_m + t_p}{6}$

$$\Rightarrow \frac{5+4(6)+7}{6} = \frac{5+24+7}{6} = \frac{36}{6} = 6$$

$$\Rightarrow \frac{1+4(3)+5}{6} = \frac{1+12+5}{6} = \frac{18}{6} = 3$$

Variance formula:

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

$$\Rightarrow \left[\frac{7-5}{6}\right]^2 = \left[\frac{2}{6}\right]^2 = 0.11$$

$$\Rightarrow \left[\frac{5-1}{6}\right]^2 = \left[\frac{4}{6}\right]^2 = 0.44$$

(c) Earliest starting time ⇒ forward

node 1 = 0
2 = 0+6 = 6
3 = 0+3 = 3
4 = 0+4 = 4
5 = 6+2 = 8
6 = ~~3~~+3 = ~~9~~6 } 9 max
4+5 = 9
7 = 4+3 = 7 } max = 14
9+5 = 14
8 = 8+5 = 13 } (17) max
14+3 = 17

Latest completion time ⇒ (←) Backward

node 8 = 17
node 7 = 17−3 = 14
6 = 14−5 = 9
5 = 17−5 = 12
4 = 9−5 = 4 } 4 min
14−3 = 11
3 = 9−3 = 6
2 = 12−2 = 10
1 = 10−6 = 4 } 0 min
6−3 = 3
4−4 = 0

(d) wt is the probability completing the project on or before 22 weeks

Activity	mean duration	Variance
C	4	1.78
F	5	1
H	5	1
J	3	1
	$u = 17$	$\sigma^2 = 4.78$

$\therefore \sigma = \sqrt{4.78} = 2.189$

$P(x \leq 22)$

formula:

$P\left[\frac{x-\mu}{\sigma}\right]$

$= \frac{22-17}{2.19} = \cancel{\frac{5}{2.19}} = 2.28$

$\Rightarrow \sigma^2 = 4.78$

$\sigma = \sqrt{4.78}$

$= 2.18$

$P\left[\frac{x-\mu}{\sigma}\right] \leq \left[\frac{22-17}{2.18}\right]$

$= \frac{5}{2.18}$

$= 2.2936$

$\therefore P[x \leq 22] = 0.9887$

2) consider the data of a project summarized in table.

Activity	Immediate predecessor(s)	duration (weeks)		
		o(a)	m	p(b)
A	–	4	4	10
B	–	1	2	9
C	–	2	5	14
D	A	1	4	7
E	A	1	2	3
F	A	1	5	9
G	B, C	1	2	9
H	C	4	4	4
I	D	2	2	8
J	E, G	6	7	8

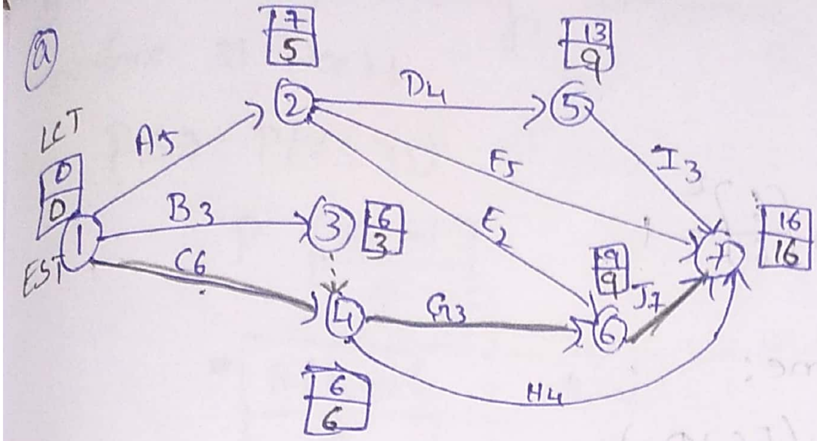
a) construct a project N/w.

b) find the expected duration & variance of each activity

c) find the critical path & expected completion time.

d) wt is the probability completing the project on or before 35 weeks.

(a)



critical path

1-4-6-7

C-G-J

= 6+3+7=16 week

(b) calculating the expected duration & variance of each activity.

Activity	duration ~~From~~			mean duration	variance.
	o(a)	m	p(b)		
A	4	4	10	5	1
B	1	2	9	3	1.78
C	2	5	14	6	4
D	1	4	7	4	1
E	1	2	3	2	0.11
F	1	5	9	5	1.78
G	1	2	9	3	1.78
H	4	4	4	4	0
I	2	2	8	3	1
J	6	7	8	7	0.11

meanduration:

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

$$= \frac{4+4(4)+10}{6} = \frac{4+16+10}{6} = \left(\frac{30}{6}\right) = 5$$

Variance

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

$$= \left[\frac{10-4}{6}\right]^2 \Rightarrow \left[\frac{6}{6}\right]^2 = 1$$

c) Earliest starting time:

formula: $ES_j = \max_i (ES_i + D_{ij})$

node 1 : 0

node 2 : $0+5=5$

3 : $0+3=3$

4 : $0+6=6$

5 : $5+4=9$

6 : $6+3=9$; $5+2=7$ — max : 9

7 : $9+3=12$; $5+5=10$; $9+7=16$; $6+4=10$ — max : 16

Latest completion time,

$LC_i = \min_j [LC_j - D_{ij}]$

node : 7 = 16

6 : $16-7=9$

5 : $16-3=13$

4 : $16-4=12$; $9-3=6$ — 6 min

3 : $6-0=6$

2 : $13-4=9$; $16-5=11$; $9-2=7$ — min 7

node 1 : $7-5=5$; $6-3=3$; $6-6=0$ — min 0

d) find the probability completing the project on or before 35 weeks

$P(x \leq 35)$

$P\left[\frac{x-\mu}{\sigma}\right]$

Activity	duration	variance
C	6	4
G	3	1.78
J	7	0.11
	$\mu=16$	5.89

$P(x \leq 35)$

$P\left[\frac{x-\mu}{\sigma}\right]$

$\sigma^2 = 16 \Rightarrow \sigma = \sqrt{16}$

$= 4$

$\boxed{\sigma = 4}$

$\left[\frac{35-16}{4}\right]$

$\left[\frac{19}{4}\right]$

$P(x \leq 35)$

$P\left(\frac{x-\mu}{\sigma}\right) \leq \frac{35-16}{2.42}$

$= \frac{19}{2.42}$

$= 7.85$

$\therefore P(x \leq 35) = 4.75$