LECTURER NOTES

ON

INDUSTRIAL ENGINEERING & MANAGEMENT

(Theory - 1)

6th Semester Mechanical Engineering
(As per SCTE&VT, Odisha Syllabus)

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INTRODUCTION

- The American Institute of Industrial Engineers (AIIE) has defined the Industrial Engineering as "Concerned with design, improvement and installation of integrated systems of people, materials, equipment and energy."
- Industrial Engineering is going to play a pivotal role in increasing the productivity. It is the engineering approach to the detailed analysis of the use and cost of the resources of an organization. The main resources are men, money, materials, equipment and machinery.
- The Industrial Engineer carries out such analysis in order to achieve the objectives (to increase productivity or profits etc.) and policies of the organization.

Productivity

- Production is transformation of inputs into the output of commodity in a specific period of time with the given technology.
- Production implies the creation of form, place and time utilities of different usable commodities and service.
- Productivity measures the efficiency of the production system. Or productivity may be defined as ratio between output and input.
- Output means the amount produced or the number of items produced.
- Input are the various sources employed like land. Building, equipment, machinery, material, labor, etc.

Main function of an Industrial Engineer

- Design of a system and management of that system
- Productivity Improvement

Productivity Improvement means:

- More efficient use of resources
- Less waste per unit of input supplied
- Higher levels of output for fixed levels of input supplied

The inputs are:

- Human efforts
- Energy
- Materials
- Invested capital

Present state of Industrial Engineering:

- Value engineering
- Operation research
- CPM and PERT
- Human Engineering (Ergonomics)
- System analysis
- Advances in Information Technology and Computer packages
- Mathematical and statistical tools

Activities of Industrial Engineering:

- Selection of processes and assembling methods
- Selection and design of tools and equipment
- Design of facilities including plant location layout of buildings, machines and equipments material handling system, raw materials and finished goods storage facilities.
- Design and improvement of planning and control system for production, inventory, quality and plant maintenance and distribution systems.
- Developing a cost control system such as budgetary control, cost analysis and standard costing.
- Development of time standard, costing and performance standards
- Development and installation of job evaluation system
- Installation of wage incentives schemes
- Design and installation of value engineering and analysis system
- Operation research including mathematical techniques and statistical analysis
- Performance evaluation
- Organization and methods
- Project feasibility studies
- Supplier selection and evaluation

Objective of Industrial Engineering:

- To establish methods for improving the operations and controlling the production costs
- To develop programs for reducing those costs

Technique of Industrial Engineering:

- Method study
- Time study
- Motion study
- Financial and non-financial incentives
- Value analysis
- Production, planning and control
- Inventory control
- Job evaluation
- Material handling analysis
- Ergonomics (Human engineering)
- System analysis
- Operation research techniques
- Other techniques

Applications of Industrial Engineering:

- In health services
- In government organizations
- In banking
- Others such as marketing, finance, purchasing, industrial relations etc.

CHAPTER - 1

Chapter 1

PLANT LOCATION AND LAYOUT

1.1.1 PLANT LOCATION

To start a new business, location is very important factor. Business location plays major role in growth of the business. Since every business wants to maximize the profit and minimize the cost. If the wrong site selection is done then it may lead to failure of the business.

Plant location refers to the choice of region and the selection of a particular site for setting up a business or factory.

1.1.2 NATURE OF LOCATION DECISION

Plant location depends on the nature of business and size of business.

Following various factors are to be considered for the location decision:

- Economic consideration
- Suppliers market availability
- Customer's reachability
- Manpower availability
- Government policies regarding the business
- Support of local communities

1.1.3 IMPORTANCE OF PLANT LOCATION

The selection of plant location site is important because of following reasons:

- The location of plant should be nearer to the customers as well as to the suppliers in order to reduce the transportation cost.
- Physical factor such as electric power, transportation facility, availability of labour, availability of water etc. must be considered.
- Climate conditions such as temperature, humidity, rainfall, probability of flood etc. are to be considered for site selection.
- Political influence and community factor may also affect the plant location.

1.1.4 DYNAMIC NATURE OF PLANT LOCATION

It is difficult to say that the selected location is permanent for the industry. The plant location may change due to many reasons.

- Expansion of the company.
- Shift of market away from location.
- Shifting of suppliers and interrelated industries to any other areas.
- Change in existing transportation facilities.
- Increase in transportation cost.
- Unavailable of labour force.
- Problems in availing basic facilities such as electricity, water and communication facility.
- Change in government regulations.
- Withdrawn of government facilities such as relaxation in taxes.

1.1.5 CHOICE OF SITE FOR SELECTION

i. **Land location and its cost**
The prime factor in deciding the site for the plant is availability of the land and its cost. If the land is available in the urban area, the cost will be high and available land will be less. On the other hand, in rural area, the sufficient land at comparatively cheaper rate will be available but the distance will increase the transportation cost.

ii. **Nearness to market**
Nearness to market, i.e. to customer is very important for any business. It reduces transportation cost as well as the chances of damaging of finished products. Additionally, when plant is near to the market, organization can give quick service to the customers. Moreover, ideas and needs of customers can be understood very easily and quickly.

iii. **Transportation facility**
Transportation can be reduced by nearness to the markets and nearness to the customers. So, appropriate transportation facility should be available from the plant location. The location of plant should be selected such that the transportation cost should be minimum as possible in order to reduce overall cost.

iv. **Availability of labour**
Labour is the power of any industry to transform raw material in to finished products using machines and other facilities. There is always a need of skilled and stable labour force in adequate number who works at reasonable rate.

v. **Availability of power, water and fuel**
Power and steam requirements are high in most industrial plants and fuel is ordinarily required to supply these utilities. Power, fuel and steam are required for running the various equipments like generators, motors, turbines, plant lightings and general use and thus be considered as one major factor is choice of plant site. Water is used for processing in the industry, used for drinking purpose, sanitary purpose and for many more purposes.

vi. **Availability of communication facility**
Since in today's world, internet, telephone, faxes and mobile is communication means of business. So, the location of plant should be such that all these facilities are easily accessible.

vii. **Availability of banking facility**
Banking facility is backbone for the industries. Without banking facilities all monetary functions will be stopped. Also, the facility of ATM is highly appreciable near the plant facility.

viii. **Government benefits**
Government is providing incentives such as subsidy, lower interest rates for loan, cheaper electrical supply, exemption in service tax etc. in certain specified localities.

ix. **Community attitude**
Success of an industry depends very much on the attitude of the local people and their support. So, attitude nearby community plays an important role in the growth of business.

x. **Hospital and school facility**
If the industry is providing the residential facilities to the employee, they should select site which is having hospital as well as school facility.

xi. **Future expansion**
The selected location should have future expansion availability.

1.1.6 COMPARISION OF LOCATION

Urban Area		Rural Area	
i.	Good transportation facility is available.	i.	Difficult to get good transportation facility.
ii.	Provide good customer market.	ii.	Customer market is away from site.
iii.	Right labour force is available.	iii.	Difficulty in getting skilled workers.
iv.	Sufficient power and water is easily available.	iv.	Less amount of power and water available.
v.	Good hospitals, schools, banking and commercial facility are available.	v.	Banking and other hospitalities are away from the site location.
vi.	Good educational and training facilities available.	vi.	Not to have training and facility aids.
vii.	Security are available.	vii.	No security is available.
viii.	Less amount of land is available.	viii.	Huge amount of land is available.
ix.	Cost of land is high.	ix.	Land is cheap.
x.	Union problems are more.	x.	Less union problems.

1.2 PLANT LAYOUT

Plant Layout is defined as a technique of locating machines, processes and plant services within the factory so as to achieve the right quantity and quality of output at the lowest possible cost of manufacturing.

Plant layout refers to the arrangement of physical facilities such as machinery, equipment, furniture etc. within the factory building in such a manner so as to have quickest flow of material at the lowest cost and with the least amount of handling in processing the product from the receipt of material to the shipment of the finished product.

1.3 OBJECTIVES OF GOOD PLANT LAYOUT

- Proper and efficient utilization of available floor space
- To ensure that work proceeds from one point to another point without any delay
- Provide enough production capacity.
- Reduce material handling costs
- Reduce hazards to personnel
- Utilise labour efficiently
- Increase employee morale
- Reduce accidents
- Provide for volume and product flexibility
- Provide ease of supervision and control
- Provide for employee safety and health
- Allow ease of maintenance
- Allow high machine or equipment utilization
- Improve productivity

PRINCIPLE OF GOOD PLANT LAYOUT

- **Principle of integration:** A good layout is one that integrates men, materials, machines and supporting services and others in order to get the optimum utilisation of resources and maximum effectiveness.
- **Principle of minimum distance travelling:** This principle is concerned with the minimum travel (or movement) of man and materials. The facilities should be arranged such that, the total distance travelled by the men and materials should be minimum and as far as possible straight-line movement should be preferred.
- **Principle of cubic space utilisation:** The good layout is one that utilise both horizontal and vertical space. It is not only enough if only the floor space is utilised optimally but the third dimension, i.e., the height is also to be utilised effectively.
- **Principle of minimum waiting time:** The waiting time of men at the machines for the raw materials should be minimum.
- **Principle of maximum flexibility:** The good layout is one that can be altered without much cost and time, i.e., future requirements should be taken into account while designing the present layout.
- **Principle of safety, security and satisfaction:** A good layout is one that gives due consideration to workers safety and satisfaction and safeguards the plant and machinery against fire, theft, etc.
- **Principle of minimum handling:** A good layout is one that reduces the material handling to the minimum.

1.4 TYPES OF PLANT LAYOUT

Following are different types of plant layout:

1. Product Layout
2. Process Layout
3. Combined Layout
4. Fixed position Layout

(1) Product Layout (Lint Layout)

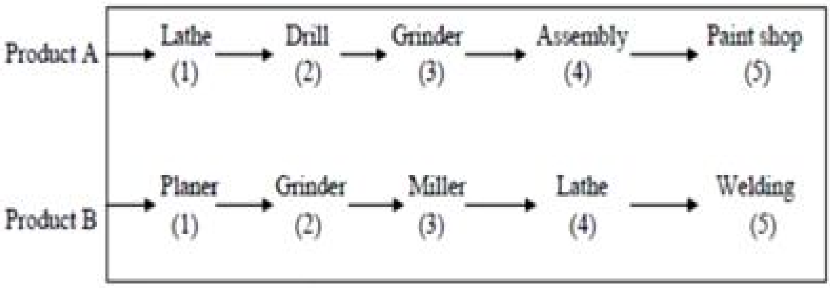


Fig 1.1 Product layout

- This kind of layout is designed according the operations required in manufacturing the product. The machines are arranged sequentially according to the process to be carried out on raw materials.
- This type of layout is used when the large amount of same product is to be manufactured.
- The materials move from one workstation to another sequentially without any backtracking or deviation. Under this, machines are grouped in one sequence.

Advantages:

- Low cost of material handling, due to straight and short route and absence of backtracking.
- Continuous flow of work.
- Optimum use of floor space.
- Shorter processing time or quicker output.
- Minimum material handling cost.
- Simplified production, planning and control systems are possible.
- Unskilled workers can learn and manage the production.
- The flow of product will be smooth and logical in flow lines.

Limitations:

- Breakdown of one machine will hamper the whole production process.
- A change in product design may require major alterations in the layout.
- Comparatively high investment in equipments is required.
- *Lack of flexibility.* A change in product may require the facility modification.

(2) Process Layout (Functional Layout)

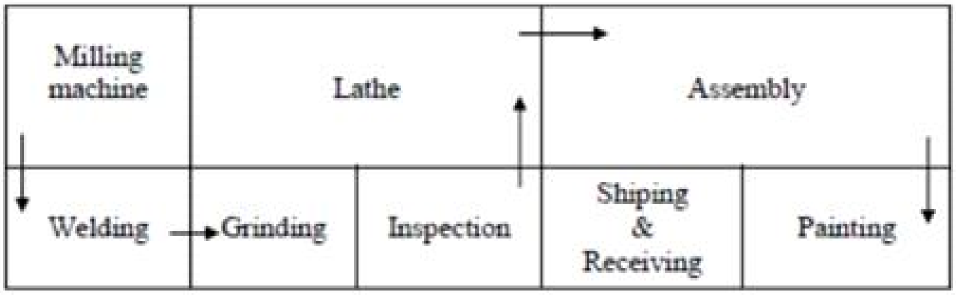


Fig. 1.2 Process Layout

- Process layout is recommended for batch production. All machines performing similar type of operations are grouped at one location in the process layout e.g., all lathes, milling machines, etc. are grouped in the shop will be clustered in like groups.
- Thus, in process layout the arrangement of facilities is grouped together according to their functions.

Advantages:

- The overhead costs are relatively low.
- Flexibility of equipment and personnel is possible in process layout.
- Breakdown of one machine does not result in complete work stoppage.
- Supervision can be more effective and specialized.
- There is a greater flexibility of scope for expansion.

Limitations:

- Material handling costs are high due to backtracking.
- More skilled labour is required resulting in higher cost.
- Time gap or lag in production is higher.

- Lowered productivity due to number of set-ups.
- Work in progress inventory is high needing greater storage space.

(3) Combined Layout

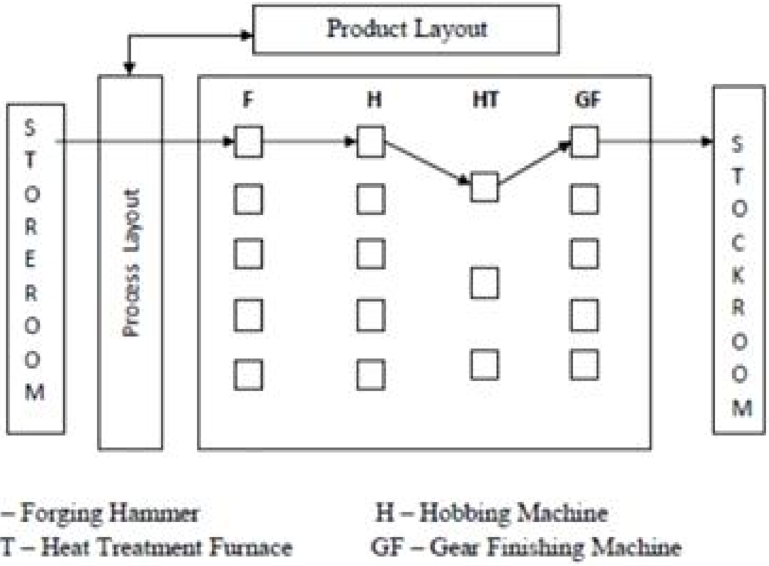


Fig 1.3 Combination layout

- A combination of process and product layouts combines the advantages of both types of layouts.
- A combination layout is possible where an item is being made in different types and sizes. Here machinery is arranged in a process layout but the process grouping is then arranged in a sequence to manufacture various types and sizes of products.
- Figure shows a combination type of layout for manufacturing different sized gears.

(4) Fixed Position Layout

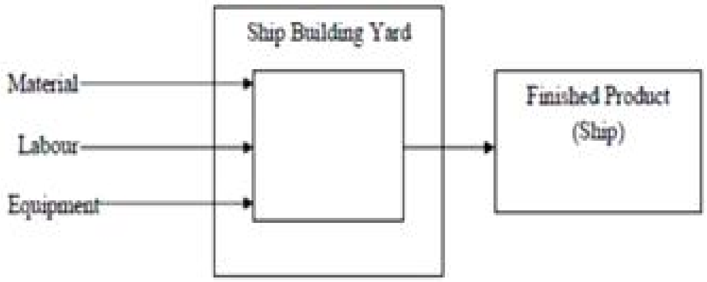


Fig 1.4 Fixed position layout

- This is also called the project type of layout. In this type of layout, the material, or major components remain in a fixed location and tools, machinery, men and other materials are brought to this location.

- This type of layout is suitable when one or a few pieces of identical heavy products are to be manufactured and when the assembly consists of large number of heavy parts, the cost of transportation of these parts is very high.

Advantages:

- Layout capital investment is lower.
- Greater flexibility with this type of layout.
- This involves minimum movements of materials. So, material handling cost is least.
- It is possible to assign one or more skilled workers to a project start to finish in have continuity of work.

Limitations:

- This kind of layout requires skilled labour.
- Movement of equipments and men take more time, so the time for completion of this project is more.

1.5 TECHNIQUES TO IMPROVE LAYOUT

Some of the important techniques of plant layout are:

(a) Process chart: It is a graph containing details regarding various activities and operations taking place in the organisation from start to the last stage of the work.

(b) Process flow diagram: This is an aid to process chart. This relates to details regarding position of machines, area covered by each machine, internal transportation and other operations pertaining to production. This model diagram is prepared on the paper.

(c) Templates: The area covered by a machine is cut to scale from a thick paper to form a template. Not only machines but space covered by furniture, equipment and other components can also form a template. These can be well arranged representing the actual plan of layout to be undertaken.

(d) Models: Three dimensional wooden models of machinery, equipment and other devices and components can be prepared. By seeing these models even, a layman can form an idea about the layout of the plant. But this technique is very costly and only big concern can afford to install such a measure.

(e) Drawings: Layout drawings can be got prepared by drafts men showing walls, stairways, machines and equipment etc.

(f) Machine data card: These cards are tied with different machines operating in the plant. These obtain valuable information regarding various salient features or characteristics of machines viz., efficiency, capacity space area covered by the machine and technique of operating the machine etc.

1.6 PRINCIPLES OF MATERIAL HANDLING EQUIPMENT

Material handling principles are as follows:

1. **Planning principle:** All handling activities should be planned.

2. **Systems principle:** Plan a system integrating as many handling activities as possible and co-ordinating the full scope of operations (receiving, storage, production, inspection, packing, warehousing, supply and transportation).

3. **Space utilization principle:** Make optimum use of cubic space.

4. **Unit load principle:** Increase quantity, size, weight of load handled.

5. **Gravity principle:** Utilise gravity to move a material wherever practicable.

6. **Material flow principle:** Plan an operation sequence and equipment arrangement to optimise material flow.

7. **Simplification principle:** Reduce combine or eliminate unnecessary movement and/or equipment.

8. **Safety principle:** Provide for safe handling methods and equipment.

9. **Mechanisation principle:** Use mechanical or automated material handling equipment.

10. **Standardisation principle:** Standardise method, types, size of material handling equipment.

11. **Flexibility principle:** Use methods and equipment that can perform a variety of task and applications.

12. **Equipment selection principle:** Consider all aspect of material, move and method to be utilised.

13. **Dead weight principle:** Reduce the ratio of dead weight to pay load in mobile equipment.

14. **Motion principle:** Equipment designed to transport material should be kept in motion.

15**. Idle time principle:** Reduce idle time/unproductive time of both MH equipment and man power.

16. **Maintenance principle:** Plan for preventive maintenance or scheduled repair of all handling equipment.

17. **Obsolescence principle:** Replace obsolete handling methods/equipment when more efficient method/equipment will improve operation.

18. **Capacity principle:** Use handling equipment to help achieve its full capacity.

19**. Control principle:** Use material handling equipment to improve production control, inventory control and other handling.

20. **Performance principle:** Determine efficiency of handling performance in terms of cost per unit handled which is the primary criterion.

1.7 PLANT MAINTENANCE

Maintenance is the process of keeping the machine and equipment in good working condition so that the efficiency of machine is retained and its life is increased.

Or

"Plant maintenance is a combination of actions carried out by an organization to replace, repair, service the machineries, components or their groups in a manufacturing plant, so that it will continue to operate satisfactorily"

Maintenance is a result of design and it includes servicing, removal and replacement, inspection, calibration, over haul and condition verification.

1.7.1 IMPORTANCE OF PLANT MAINTENANCE:

- To maintain a high level of equipment reliability and maintainability as contributes to production/operation.
- To maximize economy in equipment management for its entire life.
- To cultivate equipment related expertise and skills amongst maintenance personnel.
- To create vigorous and enthusiastic work environment.
- To maximize overall equipment effectiveness through total employee involvement
- To minimize the total production or operating costs directly attributed to equipment service and repair.
- To minimize the frequency of interruptions to production by reducing breakdowns.
- To enhance the safety of manpower.

TYPES OF MAINTENANCE

Maintenance may be classified into following categories:

a) Corrective or breakdown maintenance,
b) Scheduled maintenance,
c) Preventive maintenance, and

1.7.2 CORRECTIVE OR BREAKDOWN MAINTENANCE

- Corrective or breakdown maintenance implies that repairs are made after the equipment is out of order and it cannot perform its normal function any longer, e.g. an electric motor will not start, a belt is broken, etc.
- Under such conditions, production department calls on the maintenance department to rectify the defect. The maintenance department checks into the difficulty and makes the necessary repairs.
- After removing the fault, maintenance engineers do not attend the equipment again until another failure or breakdown occurs.
- Breakdown maintenance practice is economical for those (non-critical) equipments whose down-time and repair costs are less this way than with any other type of maintenance.
- Breakdown type of maintenance involves little administrative work, few records and a comparative small staff.

Advantages

1. Involves low cost investment for maintenance.

2. Less staff is required.

Disadvantages

1. Increased cost due to unplanned downtime of equipment.

2. Increased labour cost, especially if overtime is needed.

3. Cost involved with repair or replacement of equipment.

4. Possible secondary equipment or process damage from equipment failure.

5. Inefficient use of staff resources.

1.7.3 PREVENTIVE MAINTENANCE

- It is a method of maintenance aimed at avoiding or preventing breakdowns. The principle of preventive maintenance is 'Prevention is better than cure'
- Here some components are identified as weak spots in all machineries and equipments. These parts are inspected regularly. Minor repairs are carried out immediately as soon as there is necessity. This reduces the unanticipated breakdowns.

Advantages

1. Cost effective in many capital-intensive processes.
2. Flexibility allows for the adjustment of maintenance periodicity.
3. Increased component life cycle.
4. Energy savings.
5. Reduced equipment or process failure.
6. Estimated 12% to 18% cost savings over reactive maintenance program.

Disadvantages

1. Catastrophic failures still likely to occur.
2. Labour intensive.
3. Includes performance of unneeded maintenance.
4. Potential for incidental damage to components in conducting unneeded maintenance.

1.7.4 SCHEDULED MAINTENANCE

- Scheduled maintenance is a stich-in-time procedure aimed at avoiding breakdowns.
- Breakdowns can be dangerous to life and as far as possible should be minimized.
- Scheduled maintenance practice incorporates (in it), inspection, lubrication, repair and overhaul of certain equipments which if neglected can result in breakdown.
- Inspection, lubrication, servicing, etc., of these equipments are included in the predetermined schedule.
- Scheduled maintenance practice is generally followed for overhauling of machines, cleaning of water and other tanks, white-washing of buildings, etc.

CHAPTER - 2

CHAPTER 2

OPERATIONS RESEARCH

2.1.1 INTRODUCTION

Operation Research is a relatively new discipline. The contents and the boundaries of the OR are not yet fixed. Therefore, to give a formal definition of the term Operations Research is a difficult task. The OR starts when mathematical and quantitative techniques are used to substantiate the decision being taken. The main activity of a manager is the decision making. In our daily life we make the decisions even without noticing them. The decisions are taken simply by common sense, judgment and expertise without using any mathematical or any other model in simple situations. But the decision we are concerned here with are complex and heavily responsible. Examples are public transportation network planning in a city having its own layout of factories, residential blocks or finding the appropriate product mix when there exists a large number of products with different profit contributions and production requirement etc.

Operations Research tools are not from any one discipline. Operations Research takes tools from different discipline such as mathematics, statistics, economics, psychology, engineering etc. and combines these tools to make a new set of knowledge for decision making. Today, O.R. became a professional discipline which deals with the application of scientific methods for making decision, and especially to the allocation of scarce resources. The main purpose of O.R. is to provide a rational basis for decisions making in the absence of complete information, because the systems composed of human, machine, and procedures may do not have complete information.

Operations Research can also be treated as science in the sense it describing, understanding and predicting the systems behaviour, especially man-machine system. Thus O.R. specialists are involved in three classical aspect of science; they are as follows:

i. Determining the systems behaviour
ii. Analyzing the systems behaviour by developing appropriate models
iii. Predict the future behaviour using these models

The emphasis on analysis of operations as a whole distinguishes the O.R. from other research and engineering. O.R. is an interdisciplinary discipline which provided solutions to problems of military operations during World War II, and also successful in other operations. Today business applications are primarily concerned with O.R. analysis for the possible alternative actions. The business and industry befitted from O.R. in the areas of inventory, reorder policies, optimum location and size of warehouses, advertising policies, etc.

As stated earlier defining O.R. is a difficult task. The definitions stressed by various experts and Societies on the subject together enable us to know what O.R. is, and what it does. They are as follows:

1. According to the Operational Research Society of Great Britain (OPERATIONAL RESEARCH QUARTERLY, 13(3):282, 1962), Operational Research is the attack of modern science on complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defense. Its distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as change and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically.

2. Randy Robinson stresses that Operations Research is the application of scientific methods to improve the effectiveness of operations, decisions and management. By means such as analyzing data, creating mathematical models and proposing innovative approaches, Operations Research professionals develop scientifically based information that gives insight and guides decision making. They also develop related software, systems, services and products.

3. Morse and Kimball have stressed O.R. is a quantitative approach and described it as "a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control".

2.1.2 Stages of Development of Operations Research

The stages of development of O.R. are also known as phases and process of O.R, which has six important steps. These six steps are arranged in the following order:

Step I: Observe the problem environment

Step II: Analyze and define the problem

Step III: Develop a model

Step IV: Select appropriate data input

Step V: Provide a solution and test its reasonableness

Step VI: Implement the solution

2.1.3 O.R. Tools and Techniques

Operations Research uses any suitable tools or techniques available. The common frequently used tools/techniques are mathematical procedures, cost analysis, electronic computation. However, operations researchers given special importance to the development and the use of techniques like linear programming, game theory, decision theory, queuing theory, inventory models and simulation. In addition to the above techniques, some other common tools are non-linear programming, integer programming, dynamic programming, sequencing theory, Markov process, network scheduling (PERT/CPM), symbolic Model, information theory, and value theory. There is many other Operations Research tools/techniques also exists. The brief explanations of some of the above techniques/tools are as follows:

Linear Programming:

This is a constrained optimization technique, which optimize some criterion within some constraints. In Linear programming the objective function (profit, loss or return on investment) and constraints are linear. There are different methods available to solve linear programming.

Game Theory:

This is used for making decisions under conflicting situations where there are one or more players/opponents. In this the motive of the players are dichotomized. The success of one player tends to be at the cost of other players and hence they are in conflict.

Decision Theory:

Decision theory is concerned with making decisions under conditions of complete certainty about the future outcomes and under conditions such that we can make some probability about what will happen in future.

Queuing Theory:

This is used in situations where the queue is formed (for example customers waiting for service, aircrafts waiting for landing, jobs waiting for processing in the computer system, etc). The objective here is minimizing the cost of waiting without increasing the cost of servicing.

Inventory Models:

Inventory model make a decision that minimize total inventory cost. This model successfully reduces the total cost of purchasing, carrying, and out of stock inventory.

Simulation:

Simulation is a procedure that studies a problem by creating a model of the process involved in the problem and then through a series of organized trials and error solutions attempt to determine the best solution. Sometimes this is a difficult/time consuming procedure. Simulation is used when actual experimentation is not feasible or solution of model is not possible.

Non-linear Programming:

This is used when the objective function and the constraints are not linear in nature. Linear relationships may be applied to approximate non-linear constraints but limited to some range, because approximation becomes poorer as the range is extended. Thus, the non-linear programming is used to determine the approximation in which a solution lies and then the solution is obtained using linear methods.

Dynamic Programming:

Dynamic programming is a method of analyzing multistage decision processes. In this each elementary decision depends on those preceding decisions and as well as external factors.

Integer Programming:

If one or more variables of the problem take integral values only then dynamic programming method is used. For example, number or motor in an organization, number of passengers in an aircraft, number of generators in a power generating plant, etc.

Markov Process:

Markov process permits to predict changes over time information about the behavior of a system is known. This is used in decision making in situations where the various states are defined. The probability from one state to another state is known and depends on the current state and is independent of how we have arrived at that particular state.

Network Scheduling:

This technique is used extensively to plan, schedule, and monitor large projects (for example computer system installation, R & D design, construction, maintenance, etc.). The aim of this technique is minimized trouble spots (such as delays, interruption, production bottlenecks, etc.) by identifying the critical factors. The different activities and their relationships of the entire project are represented diagrammatically with the help of networks and arrows, which is used for identifying critical activities and path. There are two main types of technique in network scheduling, they are:

Program Evaluation and Review Technique (PERT) – is used when activities time is not known accurately/ only probabilistic estimate of time is available.

Critical Path Method (CPM) – is used when activities time is known accurately.

Information Theory:

This analytical process is transferred from the electrical communication field to O.R. field. The objective of this theory is to evaluate the effectiveness of flow of information with a given system. This is used mainly in communication networks but also has indirect influence in simulating the examination of business organizational structure with a view of enhancing flow of information.

2.1.4 Applications of Operations Research

Today, almost all fields of business and government utilizing the benefits of Operations Research. There are voluminous of applications of Operations Research. Although it is not feasible to cover all applications of O.R. in brief. The following are the abbreviated set of typical operations research applications to show how widely these techniques are used today:

Accounting:

- Assigning audit teams effectively
- Credit policy analysis
- Cash flow planning
- Developing standard costs
- Establishing costs for byproducts
- Planning of delinquent account strategy

Construction:

- Project scheduling, monitoring and control
- Determination of proper work force
- Deployment of work force
- Allocation of resources to projects

Facilities Planning:

- Factory location and size decision
- Estimation of number of facilities required
- Hospital planning
- International logistic system design
- Transportation loading and unloading
- Warehouse location decision

Finance:

- Building cash management models
- Allocating capital among various alternatives
- Building financial planning models
- Investment analysis

- Portfolio analysis
- Dividend policy making

Manufacturing:

- Inventory control
- Marketing balance projection
- Production scheduling
- Production smoothing

Marketing:

- Advertising budget allocation
- Product introduction timing
- Selection of Product mix
- Deciding most effective packaging alternative

Organizational Behavior / Human Resources:

- Personnel planning
- Recruitment of employees
- Skill balancing
- Training program scheduling
- Designing organizational structure more effectively

Purchasing:

- Optimal buying
- Optimal reordering
- Materials transfer

Research and Development:

- R & D Projects control
- R & D Budget allocation
- Planning of Product introduction

2.2 INTRODUCTION TO LINEAR PROGRAMMING

Linear programming is powerful mathematical technique for finding the best use of limited resources of a concern. It may be defined as a technique which allocates scarce available resources under conditions of certainty in an optimum manner to achieve the company objectives which may be maximum overall profit or minimum overall cost.

Thus, a Linear Programming Problem is one that is concerned with finding the optimal value (maximum or minimum value) of a linear function (called objective function) of several variables (say x and y), subject to the conditions that the variables are non-negative and satisfy a set of linear inequalities (called linear constraints). The term linear implies that all the mathematical relations used in the problem are linear relations while the term programming refers to the method of determining a particular programme or plan of action.

LP can be applied effectively only if

1. The objectives can be stated mathematically
2. Resources can be measured as quantities (no. weight etc.)
3. There are too many alternate solutions to be evaluated conveniently
4. The variables of the problem bear a linear relationship i.e. Doubling the units of resources will double the profit.

Problem solving is based upon the system of linear equation:

Standard form of linear programming problem:

Let $x_1, x_2, x_3 \ldots\ldots\ldots\ldots x_n$ are the decision variables.

Optimize (maximum or minimize)

$Z = c_1x_1 + c_2x_2 + \ldots\ldots\ldots\ldots\ldots\ldots + c_nx_n$ (Objective function)

Subject to constraints

$$
\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \ldots\ldots\ldots\ldots\ldots + a_{1n}x_n &\le b_1 \\
a_{21}x_1 + a_{22}x_2 + \ldots\ldots\ldots\ldots\ldots + a_{2n}x_n &\le b_2 \\
\vdots \\
a_{m1}x_1 + a_{m2}x_2 + \ldots\ldots\ldots\ldots\ldots + a_{mn}x_n &\le b_n
\end{aligned}
$$

$x_1, x_2, x_3 \ldots\ldots\ldots\ldots\ldots\ldots x_n \ge 0$ (non-negative restriction)

where $c_1, c_2, c_3 \ldots\ldots\ldots\ldots\ldots\ldots c_n \ge 0$ are cost or profit coefficients.

$a_{ij} (i = 1,2,3, \ldots\ldots\ldots n \text{ and } j=1,2,3, \ldots\ldots\ldots n)$

$b_1, b_2, b_3 \ldots\ldots\ldots\ldots\ldots\ldots b_n$ are called requirement or availability.

Objective function linear function Z=ax+by, where a, b are constants, which has to be maximized or minimized is called a ***linear objective function***.

The linear inequalities or equations or restrictions on the variables of the linear programming problem are called ***constraints***.

LPP can solved by two methods.

1. Graphical method: when two decision variables are involved. This is simple.
2. Simplex method: useful for any no. of decision variable in the problem and no. of constraints.

Formulation of LP problem:

1. From the given problem, identify the key decisions to be made.
2. Identify the decision variables, whose values give the solution to the problem.

3. Write the objective in the quantitative terms and express it as a function of linear variables.
4. Study the constraints and express them as a linear equation.

2.3 GRAPHICAL METHOD

Simple two-dimensional linear programming problems can be easily and rapidly solved by this technique. This method can be easily be applied up to 3 variables.

Procedure:

- Set up the objective function
- Set up the constraint equations
- Set up the non-negative restrictions
- Convert the constraint equations into intercept form $\frac{x_1}{a} + \frac{x_2}{b} = 1$
- Plot the constraint equations on the graphical solution space.
- Identify the feasible region
- Find the corner points of the feasible region
- Substitute corner points in the objective function to get a maximum or minimum value

Feasible region: The common region determined by all the constraints including non-negative constraints $x, y \geq 0$ of a linear programming problem is called the feasible region (or solution region) for the problem. The region other than feasible region is called an infeasible region.

Example 1 Solve the following linear programming problem graphically:

Maximize $Z = 4x + y$

subject to the constraints:

$x + y \leq 50$

$3x + y \leq 90$

$x \geq 0, y \geq 0$

Solution:

1st step:

Formulate the LPP

Max $Z = 4x+y$

Subjected to $x + y \leq 50$ (c1)

$3x + y \leq 90$ (c2)

$x\geq 0, y\geq 0$ (c3)

c1 is constrain no. 1 and so on.

2nd step:

2nd steps convert the constraint inequalities temporarily into intercept form $\frac{x}{a} + \frac{y}{b} = 1$

$\frac{x}{50}+\frac{y}{50}=1$..............eqn1

$\frac{x}{\frac{90}{3}}+\frac{y}{90}=1$ or $\frac{x}{30}+\frac{y}{90}=1$.......eqn 2

3rd steps: Axis are marked on the graph paper and labeled with variables x & y.

4th steps:

4th step is draw straight lines on the graph paper using constraint equations and to mark feasible solution on the graph paper.

Taking 1st constraint equation,

x + y=50

x = 0, y = 50

y = 0, x = 50

Mark the point of 50 at X axis and point 50 on Y axis. The straight line represents c1 equation.

Similarly, c2 can be plotted.

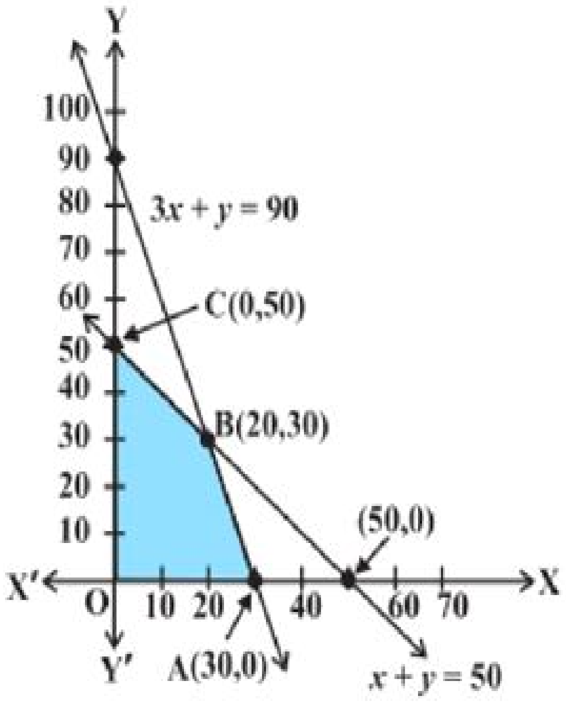


Fig.2.1

3x + y=90

x = 0, y = 90

y = 0, x = 30

According to constrain c3, x & y are greater than or equal to zero, hence the marked area between x = y = 0 and c1, c2 represents the feasible solution.

Note: If the constraint equations contain sign of ≤, then mark the **area toward the origin** otherwise **away the origin**.

Fig. 2.1 is the feasible region determined by the system of constraints. We observe that the feasible region OABC is bounded. So, we now use Corner Point Method to determine the maximum value of Z.

The coordinates of the corner points O, A, B and C are (0, 0), (30, 0), (20, 30) and (0, 50) respectively.

For point B, we need to solve two constraints equations as they intersect at B point. Now we evaluate Z at each corner point.

Corner Point	Corresponding value of Z	
(0, 0)	0	
(30, 0)	**120** ←	Maximum
(20, 30)	110	
(0, 50)	50	

As at pint B (30,0) we have Z_B=4(30) +0=120 is maximum so (30,0) is optimal solution and maximum value is 120.

Example 2 Solve by graphical method

$$\text{Max } Z = 3x_1 + 5x_2$$

Subject to

$$2x_1 + x_2 \geq 7$$

$$x_1 + x_2 \geq 6$$

$$x_1 + 3x_2 \geq 9$$

$$x_1 \geq 0, x_2 \geq 0$$

Solution:

The first constraint $2x_1 + x_2 \geq 7$, written in a form of equation

$2x_1 + x_2 = 7$

Put $x_1 = 0$,then $x_2 = 7$

Put $x_2 = 0$,then $x_1 = 3.5$

The coordinates are (0,7) and (3.5,0)

The second constraint $x_1 + x_2 \geq 6$, written in a form of equation $x_1 + x_2 = 6$

Put $x_1 = 0$,then $x_2 = 6$

Put $x_2 = 0$,then $x_1 = 6$

The coordinates are (0,6) and (6,0)

The third constraint $x_1 + 3x_2 \geq 9$, written in a form of equation $x_1 + 3x_2 = 9$

Put $x_1 = 0$,then $x_2 = 3$

Put $x_2 = 0$,then $x_1 = 9$

The coordinates are (0,3) and (9,0)

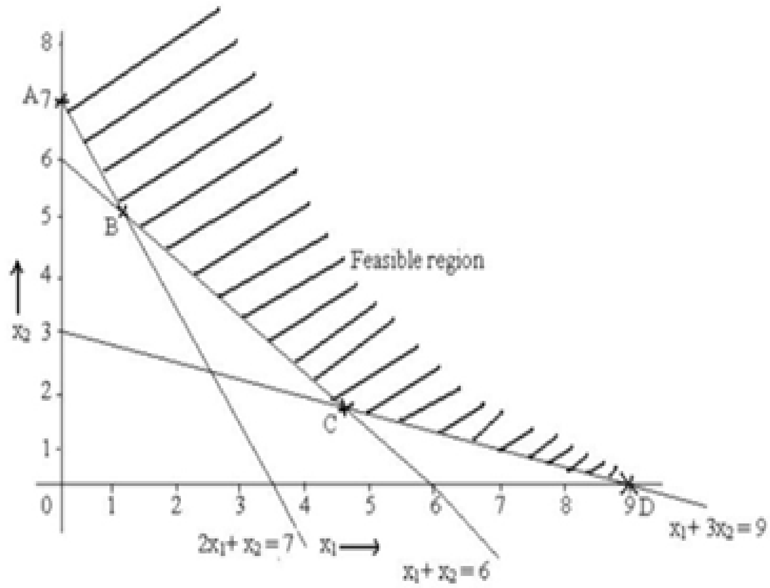


Fig. 2.2

The corner points of feasible region are A, B, C and D. So the coordinates for the corner points are A(0,7)

B (1,5) (Solve the two equations $2x_1 + x_2 \geq 7$ and $x_1 + x_2 \geq 6$ to get the coordinates)

C (4.5,1.5) (Solve the two equations $x_1 + x_2 \geq 6$ and $x_1 + 3x_2 \geq 9$ to get the coordinates)

D (9,0)

We know that Max $Z = 3x_1 + 5x_2$

At A (0,7), Z=3(0) +5(7) =35

At B (1,5), Z=3(1) +5(5) =28

At C (4.5,1.5), Z=3(4.5) +5(1.5) =21

At D (9,0), Z=3(9) +5(0) =27

The values of objective function at corner points are 35, 28, 21 and 27. But there exists infinite number of points in the feasible region which is unbounded. The value of objective function will be more than the value of these four corner points i.e. the maximum value of the objective function occurs at a point at ∞ . Hence the given problem has unbounded solution.

Example 3

Solve graphically

Max $Z = 3x_1 + 2x_2$

Subject to

$x_1 + x_2 \leq 1$

$x_1 + x_2 \geq 3$

$x_1 \geq 0, x_2 \geq 0$

Solution

The first constraint $x_1 + x_2 \leq 1$, written in a form of equation $x_1 + x_2 = 1$

Put $x_1 = 0$,then $x_2 = 1$

Put $x_2 = 0$,then $x_1 = 1$

The coordinates are (0. 1) and (1,0)

The first constraint $x_1 + x_2 \geq 3$, written in a form of equation $x_1 + x_2 = 3$

Put $x_1 = 0$,then $x_2 = 3$

Put $x_2 = 0$,then $x_1 = 3$

The coordinates are (0, 3) and (3,0)

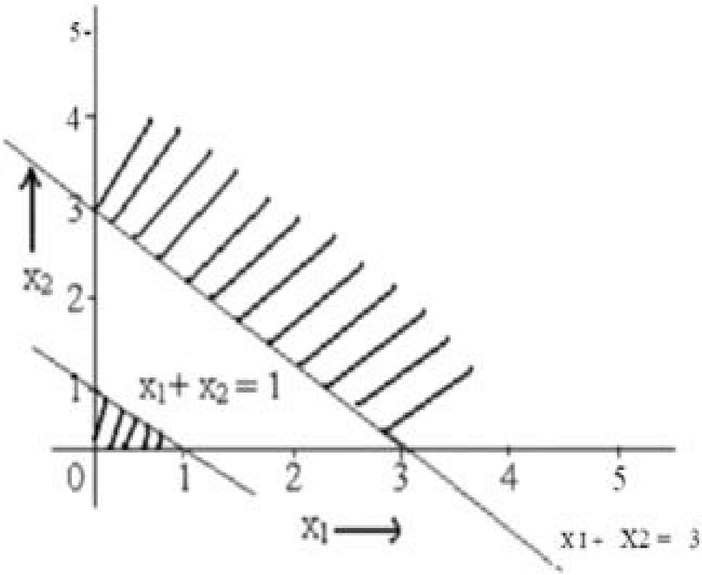


Fig. 2.3

There is no common feasible region generated by two constraints together i.e. we cannot identify even a single point satisfying the constraints. Hence there is no optimal solution.

2.4 PERT and CPM

2.4.1 Project

A project is an interrelated set of activities that has a definite starting and ending point and those results in a unique product. That means projects are not repetitive. Few examples of projects are:

1. Constructing a bridge, dam, highway or building.
2. Producing an airplane, missile or large machine.
3. Introducing a new product.
4. Installing a large computer system.
5. Redesigning the layout of plant or office.
6. Construction of a ship.
7. Fabrication of a steam boiler.
8. Maintenance of major equipments/Plants.
9. Commissioning of a power plant/factory.
10. Conducting National Election.

2.4.2 Basic steps in project management

Managing a project, regardless of its size and complexity, requires identifying every activity to be undertaken and planning when each activity must begin and end in order to complete the overall project on time. Typically, all projects involve the following steps:

1. Describe the project.
2. Develop a network model.
3. Insert time estimates.

4. Analyze the model.
5. Develop the project plan.
6. Periodically assess the progress of the project and repeat steps 2-6 as needed.

2.4.3 Terminologies used in Network diagram:

Network: A network is the graphical representation of the project activities arranged in a logical sequence and depicting all the interrelationships among them.

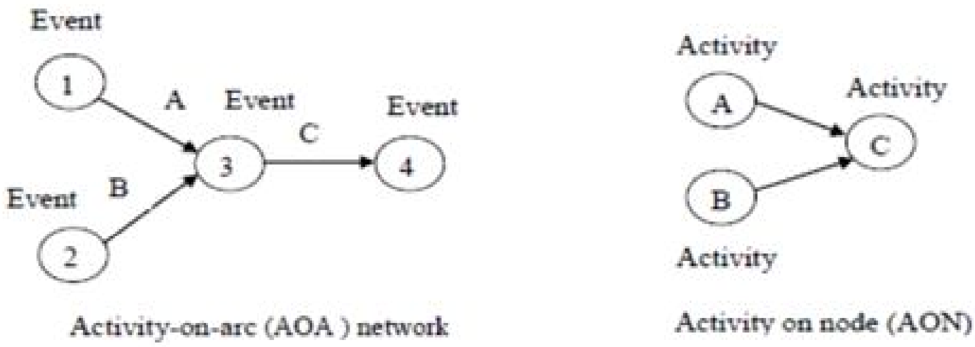
Activity: An activity means work/job. It is a time-consuming process. It is represented by an arrow in the network diagram (AOA system).

Activities are classified as:

1. Critical activities: In a network diagram, critical activities are those which if consume more than their estimated time the project will be delayed. An activity is called critical if its earliest start time plus the time taken by it is equal to the latest finishing time. A critical activity is marked either by a thick arrow or (//).

2. Non critical activities: Such activities have provision (slack or float) so that even if they consume a specified time over and above the estimated time, the project will not be delayed.

3.Dummy activity: An activity which depicts the dependency or relationship over the other but does not consume time or resources. It is used to maintain the logical sequence. It is used to maintain the logical sequence. It is indicated by a dotted line.



Event(node): An event is a specific instant of time marks the start and end of an activity. Event consumes neither time nor resources. It is represented by a circle and the event no. is written within the circle.

Critical path: It is the sequence of activities which decides the total project duration. It is formed by critical activities. A critical path consumes maximum resources. It is the longest path and consumes maximum time. It has zero float. The expected completion data cannot be met, if even one critical activity is delayed. A dummy activity joining two critical activities is also a critical activity.

Duration (d): Duration is the estimated or actual time required to complete a task or an activity.

Total project time: Time to complete the project. In other words, it is the duration of critical path.

Earliest start time (EST or E_i): It is the earliest possible time at which an activity can start. It is calculated by moving from 1st to last event in the network diagram.

Latest start time (LST or L_i): It is the latest possible time by which an activity can start.

LST=LFT-duration

Earliest finish time (EFT or E_j): It is the earliest possible time at which activity can finish. i.e. (EST+duration)

Latest finish time (L_j): It is the last event time of the head event. It is calculated by moving backward in the network diagram.

Float/Slack: Slack is with reference to an event and Float is with reference to an activity.

There are three type of float.

1.Total float: It is the additional time which a non-critical activity can consume without increasing the project duration. TF = LST – EST or LFT – EFT and it can be – ve.

2.Free float: If all the non-critical activities start as early as possible, the time is the free float. FF = TF-Head event slack or EST of tail event – EST of head event – activity duration

3.Independent float: It can be used to advantage. If one is interested to reduce the effort on a non-critical activity in order to apply the effort on a critical activity by reducing the project duration.

IF = FF-Tail event slack or EST of tail event – LFT of head event – activity duration.

If IF is negative, then taken as 0.

Head event slack=Latest time of head event-Earliest time of head event

Tail event slack= Latest time of tail event-Earliest time of Tail event

2.4.4 Numbering of events (Fulkerson's rule):

1. The initial event which has all outgoing arrows with no incoming arrow is numbered '1'.
2. Delete all arrows coming out from node 1. This will convert some more nodes into initial events number these events 2, 3 etc.
3. Delete all the arrows going out from these numbered events to create more initial events. Assign next number to these events.
4. Continue until the final or terminal node which has all arrows coming in, with no arrow going out is numbered.

2.4.5 Rules for Network Construction:

The following are the primary needs for constructing Activity on Arc (AOA) network diagram.

1. The starting event and ending event of an activity are called tail and head event respectively.
2. The network should have a unique starting node. (tail event)
3. The network should have a unique completion node. (head event)
4. No activity should be represented by more than one is (→) in the network.
5. No two activities should have the same starting node and same ending node.
6. Dummy activity is an imaginary activity indicating precedence relationship only. Duration of dummy activity is zero.
7. The length of the arrow bears no relationship to the activity time.
8. The arrow in a network identifies the logical condition of dependence.

9. The direction of arrow indicates the direction of workflow.
10. All networks are constructed logically or based on the principle of dependency.
11. No event can be reached in a project before the completion of precedence activity.
12. Every activity in the network should be completed to reach the objective.
13. No set of activities should form a circular loop.

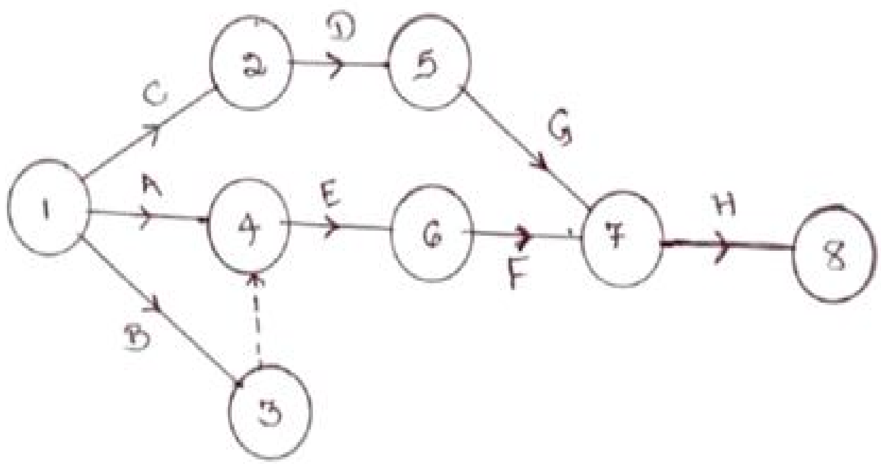
2.4.6 Network scheduling

The biggest advance in project scheduling since the development of the Gantt chart in 1917 was made between 1956-58. During this period, two new scheduling techniques were developed. These techniques are

i. Program evaluation and review technique (PERT)
ii. Critical path method (CPM)

Example 1. Construct the network from the information.

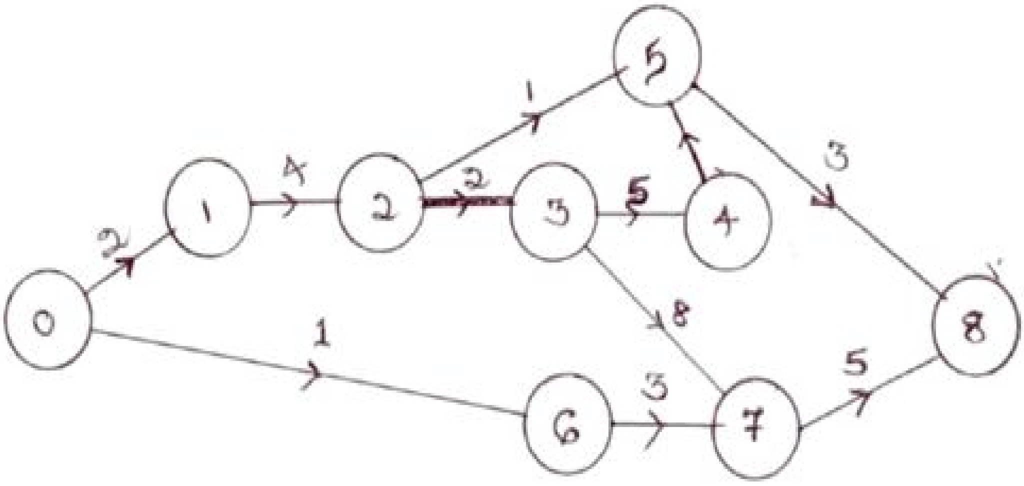
Activity	Immediate predecessor	Time
A	----	6
B	----	10
C	----	14
D	C	6
E	A, B	14
F	E, D	6
G	D	4
H	F, G	4



Example 2. Construct the network from the information.

Activity No.	Duration	Activity No.	Duration
0-1	2	0-6	1
1-2	4	3-7	8
2-3	2	6-7	3
3-4	5	5-8	3

2-5	1	7-8	5
4-5	1		



Critical Path Method:

In the critical path method, the activity times are known with certainty. For each activity EST and LST are computed. The path with the longest time sequence is called critical path. The length of the critical path determines the minimum time in which the entire project can be completed. The activities on the critical path are called critical activities.

Objective:

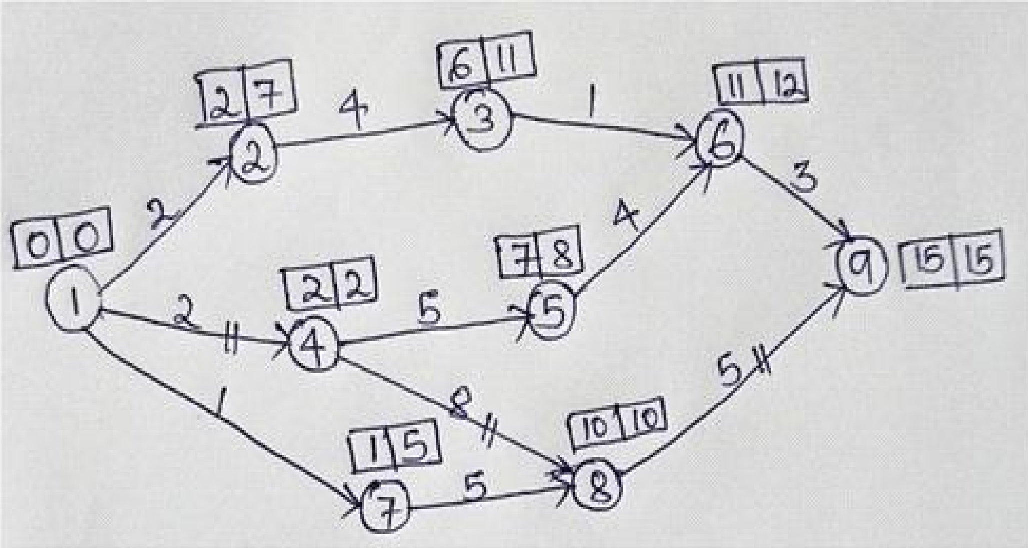
1. Determining the completion time for the project.
2. Earliest time when each activity can start.
3. Latest time when each activity can start without delaying the total project.
4. Determining the float for each activity.
5. Identification of the critical activities and critical path.

Example 3: A project schedule has the following characteristics

Activity	1-2	1-4	1-7	2-3	3-6	4-5	4-8	5-6	6-9	7-8	8-9
Duration, day	2	2	1	4	1	5	8	4	3	5	5

Construct the network and locate the critical path. Calculate the various time estimates and floats.

Solution:



Activity	Duration(d)	EST	LST=LFT-d	EFT=EST+d	LFT	Total float (TF)=LST-EST	Free float (FF)	Independent float (IF)
1-2	2	0	0	2	7	5	0	0
1-4	2	0	0	2	2	**0**	0	0
1-7	1	0	0	1	5	4	0	0
2-3	4	2	7	6	11	5	0	-5
3-6	1	6	11	11	12	5	4	-1
4-5	5	2	3	7	8	1	0	-1
4-8	8	2	3	10	10	**0**	0	-1
5-6	4	7	8	11	12	1	0	-1
6-9	3	11	12	15	15	1	1	0
7-8	5	1	5	10	10	4	4	0
8-9	5	10	10	15	15	**0**	0	0

As TF of activity (1-4), (4-8) and (8-9) is zero so critical path is 1-4-8-9.

FF=TF -Head event slack

FF for activity 1-2 =5-(7-2) =0, here head event is 2(as arrow head towards the event 2)

IF for activity 1-2=FF-Tail event slack=0-(0-0) =0 here tail event is 1

Similarly, TF, FF and IF can be calculated and given in the above table

Programme Evaluation Review Technique (PERT):

PERT takes into account the uncertainty of activity times. It is a probabilistic model with uncertainty in activity duration.

It makes use of three-time estimates.

I. Optimistic time (t_o)
II. Most likely time (t_m)

III. Pessimistic time (t_p)

I. Optimistic time (t_o):
   - It is the shortest possible time in which an activity can be completed if everything goes perfectly without any complications.
   - It is an estimate of minimum possible time to complete the activity under ideal condition.

II. Pessimistic time (t_p): It is the longest time in which an activity can be completed if everything goes wrong.

III. Most likely time(t_m): It is the time in which the activity is normally expected to complete under normal contingencies.

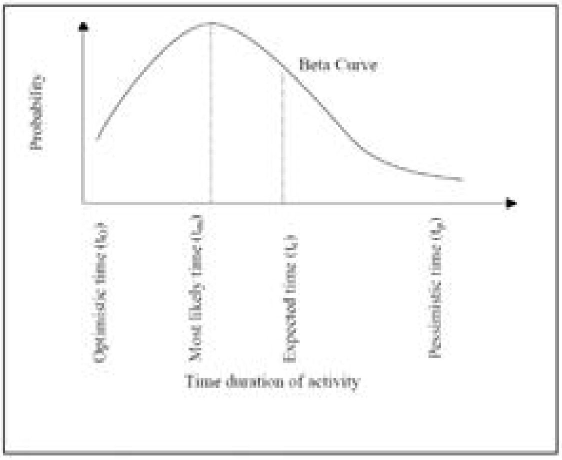


Fig. 2.4 Beta distribution curve

According to the β distribution curve

Expected time $t_e = \dfrac{t_0 + 4t_m + t_p}{6}$

The standard deviation of time required to complete each activity.

Standard deviation (σ) = $\dfrac{t_p - t_0}{6}$

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

Project completion time follows normal distribution curve

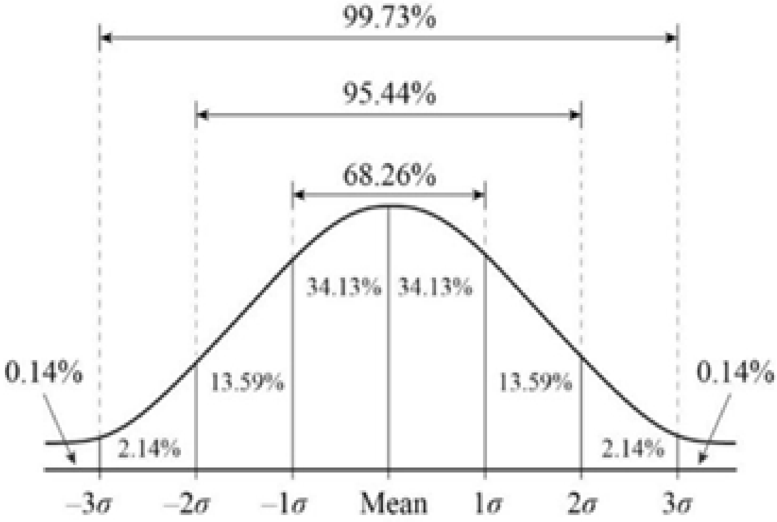


Fig. 2.5 Normal distribution curve

The probability of completing of a project is given by the formula

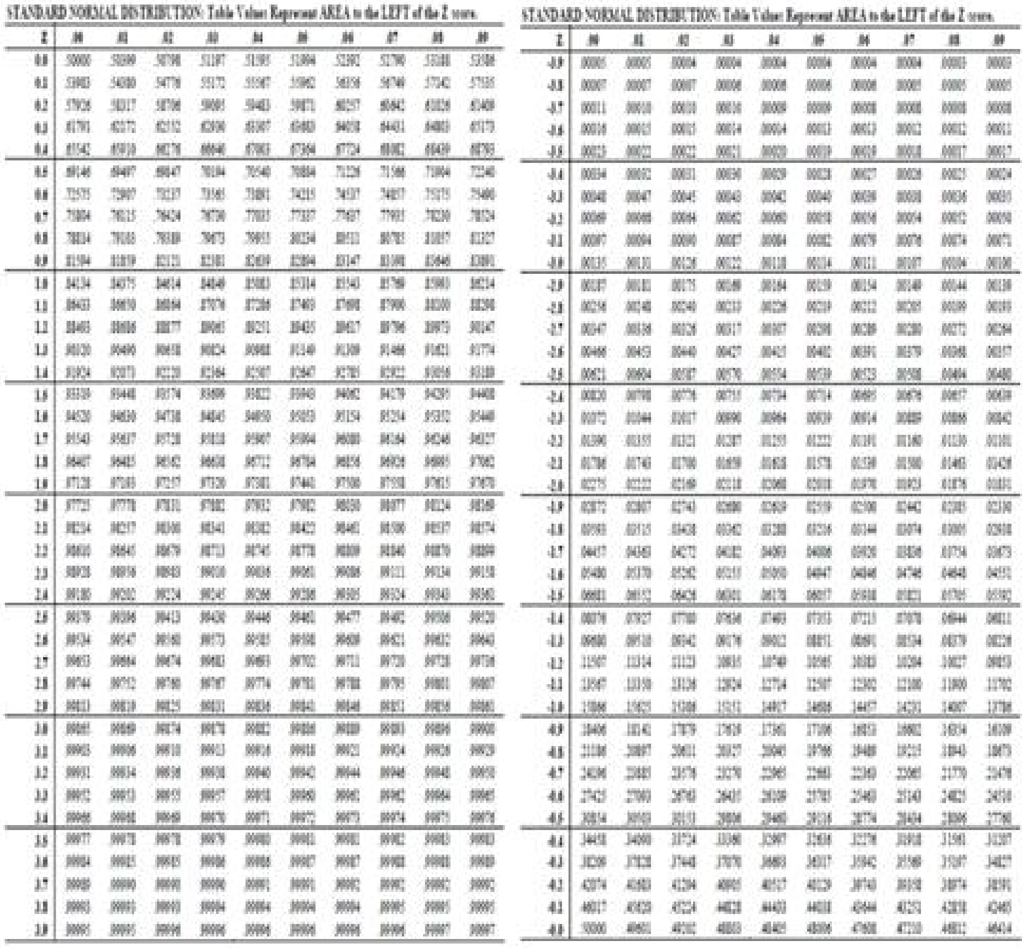
$$Z = \frac{D - t_e}{\sigma_{cp}}$$

Where D= Desired completion time

t_e=Critical path estimate time

σ_{cp} =Standard deviation of critical path

Z is a no. belonging to normal distribution curve.



STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.

Fig. 2.6 Normal distribution chart

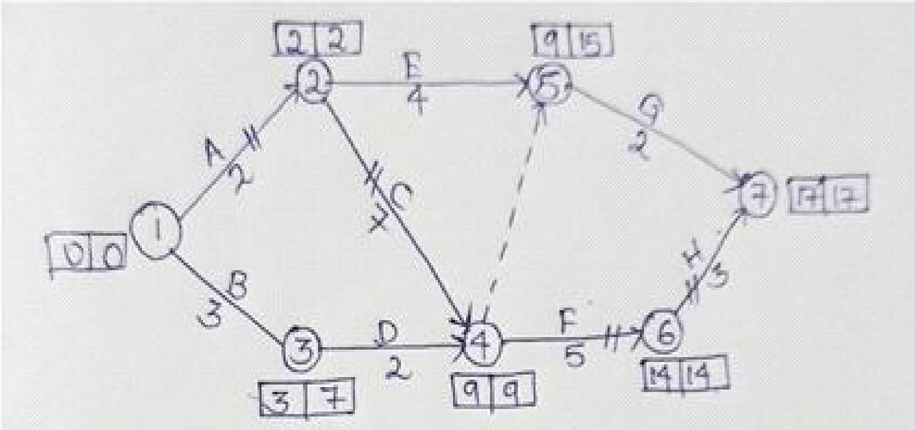
Example 4: Consider the following data of a project

Activity	predecessor	Duration (weeks)		
		Optimistic time (to)	Most likely time (tm)	Pessimistic time (tp)
A	-----	1	2	3
B	-----	2	2	8
C	A	6	7	8
D	B	1	2	3
E	A	1	4	7
F	C, D	1	5	9
G	C, D, E	1	2	3
H	F	1	2	9

a) Construct the project network
b) Find the expected duration and variance of each activity
c) Find the critical path and the expected project completion time
d) What is the probability of completing the project on or before 20 weeks?
e) If the probability of completing the project is 0.8, find the expected project completion time.

Solution:

a)



b)

Activity	Duration (weeks)			Expected time $t_e = \frac{t_0 + 4t_m + t_p}{6}$	Variance $\sigma^2 = \left(\frac{t_p - t_0}{6}\right)^2$
	to	tm	tp		
A	1	2	3	2	0.11
B	2	2	8	3	1.00
C	6	7	8	7	0.11
D	1	2	3	2	0.11
E	1	4	7	4	1.00
F	1	5	9	5	1.78
G	1	2	3	2	0.11
H	1	2	9	3	1.78

c)The critical path is A-C-F-H and the corresponding project completion time is 17 weeks.

d)The sum of the variances of all the activities on the critical path is

$0.11 + 0.11 + 1.78 + 1.78 = 3.78$ weeks. Therefore $\sigma = \sqrt{3.78} = 1.945$ weeks

$P(D \le 20) = P\left(\frac{D - t_e}{\sigma_{cp}} \le \frac{20-17}{1.945}\right) = P(Z \le 1.542) = 0.9382$ (value obtained from standard normal table)

Therefore, the probability of completing the project on or before 20 weeks is 0.9382.

e)

$$P(D \le C) = 0.8$$
$$P\left(Z \le \frac{C-17}{1.945}\right) = 0.8$$

From the standard normal table, the value of Z is 0.84 when the cumulative probability is 0.8. Therefore,

$$\left(\frac{C-17}{1.945}\right) = 0.84$$
$$\Rightarrow C = 0.84 \times 1.945 + 17 = 18.63 \text{ weeks} \approx 19 \text{ weeks}$$

Hence project will be completed in 18.63 weeks (approximately 19 weeks) if the probability of completing the project is 0.8.

2.5 Difference between PERT and CPM

Sl.No.	PERT	CPM
1	PERT is a probabilistic model with uncertainty in activity duration. Activity duration is calculated from t_0, t_p and t_m.	CPM is a deterministic model with well known activity duration.
2	It is an event-oriented approach.	It is an activity-oriented approach.
3	PERT terminology uses word like network diagram, event and slack.	CPM terminology employs word like arrow diagram, nodes and float.
4	The use of dummy activity is required for representing the proper sequencing.	No dummy activity required.
5	PERT basically does not demarcate between critical and non-critical activities.	CPM marks the critical activities.
6	PERT is applied in projects where resources are always made available.	CPM is applied to projects where minimum overall cost is the prime importance.
7	PERT is suitable in Defence project and R&D where activity time can't be readily predicted.	Suitable for plant maintenance, civil construction projects etc. where activity duration is known.

CHAPTER - 3

CHAPTER 3

INVENTORY CONTROL

Introduction:

- In majority of the organization, cost of the material is a main part of selling price of the product. The interval between the receiving the purchased parts and transforming them into final products varies from industries to industries depending upon cycle time of manufacture.
- Materials are procured and held in the form of inventories.
- It acts as a buffer between supply and demand for efficient operation of the system.
- Stocking of anything that is tangible in order to meet the future demand is called inventory theory.

Inventory:

- Inventory is a detailed list of those movable items which are necessary to manufacture a product and to maintain the equipment and machinery in good working order.
- It represents those items which are either stocked for sale or they are in the process of manufacturing or they are in the form of materials which are yet to be utilized.
- Ex – money kept in the shape of HSS bit MS rod milling

Inventory control:

It may be defined as the scientific method of finding out how much stock should be maintained in order to meet the production demands and be able to provide right type of material at right time in the right quantities and at competitive prices.

The objectives are

1. To minimize investment in inventory
2. To maximize the service levels to the firm's customers and its own operating department.

3.1.1 Types of inventories:

1.Raw inventories (raw materials):

- Raw materials and semi-finished products supplied by another firm which are raw items for present industry.
- Raw materials are those basic unfabricated materials which have not undergone any operation since they are received from the suppliers. Ex – round bars, angles, channels, pipes etc.

2.Work-in-progress inventories (WIP):

- Semi-finished products at various storages of manufacturing cycle
- The items or materials in partially completed condition of manufacturing

3.Finished inventories:

- They are the finished goods lying in stock rooms and waiting dispatch.

4.Indirect inventories:

- The inventories refer to those items which do not form the part or the final product but consumed in the production process. Example – machine spares, oil, grease, spare parts, lubricants

- For proper operation, repair and maintenance during manufacturing cycle.

3.1.2 Reasons for keeping inventories:

- To stabilize production
- To take advertise of price discount
- To meet the demand during replenishment period
- To prevent loss of orders
- To keep pace with changing market conditions

3.1.3 Inventory control:

- Keeping track of inventory
- It is a planned approach of determining what to order, when to order and how much to order and how much to stock so that costs associated with buying and storing are optimal without interrupting production and sales.
- When should an order placed?
- How much should be ordered order quantity

3.2 Objective of inventory control:

- Purchasing material at economical price at proper time and in sufficient quantity as not to run slow
- Providing a suitable and secure storage location
- To maintain timely record of inventories of all the items
- A definite inventory identification system
- Adequate and responsible store room staff
- Suitable requisition procedure
- To provide a reserve stock

3.3 and 3.4 Advantages or benefits or functions of inventory control

- One does not face shortage of materials
- Materials of good quality and procured in time minimized defect in finished goods.
- Delays in production schedules are avoided
- Production forgets are achieved
- Accurate delivery dates
- Economy in purchasing

3.5 Cost associated with inventory

Purchase (or production) cost: The value of an item is its unit purchasing or production cost.

Capital cost: The amount invested in an item is an amount of capital not available for other purchases.

Ordering cost: It is also known as procurement cost or replenishment cost or acquisition cost.

- Two type of costs- Fixed costs and variable costs.
- Fixed costs don't depend on the no. of orders whereas variable costs change w. r. t the no. of orders placed.

Ordering costs are in the form of

I. Purchasing: The clerical and administrative cost associated with the purchasing, the cost of requisition material, placing the order, follow up, receiving and evaluating quotations.
II. Inspection: The cost of checking material after they are received by the supplier for quantity and quality and maintaining records of the receipts.
III. Accounting: The cost of checking supply against a given level of hand and this cost vary in direct proportion to the amount of holding and period of holding the stock in stores. This includes storage costs (rent, heating, lighting etc.), handling costs (associated with moving the items. Such as labour cost, equipment for handling), depreciation, taxes and insurance, product deterioration and obsolescence, spoilage, breakage

3.6 Inventory control terminology:

1. Demand: It is the no. of items (products) required per unit of time. The demand may be either deterministic or probabilistic in nature.
2. Order cycle: The time period between two successive orders is called order cycle.
3. Lead time: The length of the time between placing an order and receipt of items is called lead time.
4. Safety stock: It is also called butter stock or minimum stock. It is the stock or inventory needed to account for delays in materials supply and to account for sudden increase in demand due to rush orders.
5. Inventory turnover: It the company maintains inventories equal to 3 months consumption it means that inventory turnover is 4 times a year i.e. the entire inventory is used up and replaced 4 times a year.
6. Reorder level: It is the point at which the replenishment action is initiated. When the stock level reaches ROL the order is placed for the item.
7. Reorder quantity: This is the quantity of material to be ordered at the reorder level. This quantity equals to the EOQ.

3.7 Basic EOQ model

EOQ = Economic Order Quantity.

EOQ represent the size of the order (or lot size) such that the sum of carrying cost (due to holding the inventory) and ordering cost is minimum. it is shown by figure 3.1.

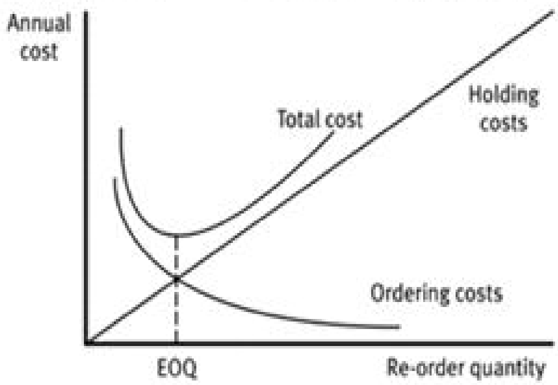


Fig. 3.1

As mentioned earlier, the two most important decisions related to inventory control are:

- When to place an order? &
- How much to order?

In 1913, F.W. Harris developed a rule for determining optimum number of units of an item to purchase based on some fundamental assumptions. This model is called Basic Economic Order Quantity model. it has broad applicability.

Economic order quantity with instantaneous stock replenishment (Basic Inventory Model)

Assumptions

The following assumptions are considered for the sake of simplicity of model.

1. Demand (D) is assumed to be uniform.
2. The purchase price per unit (P) is independent of quantity ordered.
3. The ordering cost per order (Co) is fixed irrespective of size of lot.
4. The carrying cost/holding cost (Cc) is proportional to the quantity stored.
5. Shortages are not permitted i.e., as soon as the level of inventory reaches zero, the inventory is replenished.
6. The lead time (LT) for deliveries (i.e., the time of ordering till the material is delivered) is constant and is known with certainty.

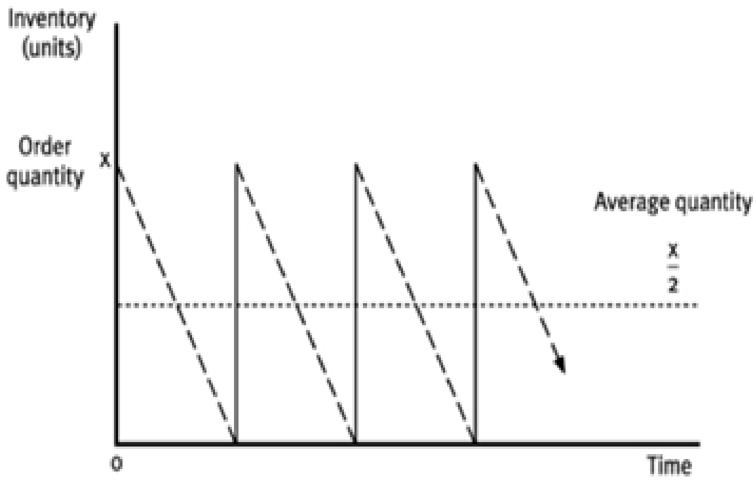


Fig. 3.2 Basic Inventory model

Let D be the annual demand (units per year)

Co = Ordering cost (Rs. /order)

Cc = Inventory carrying cost/holding cost

Q = order size

Q^* =Economic order quantity

N= Number of orders placed per annum

T_c=Total cost per annum

Therefore, the number orders/year $=N=\frac{D}{Q}$ ---------(1)

Average inventory level $= \frac{Q}{2}$

Annual Ordering cost per year = No. of order x Ordering cost/order$=\frac{D}{Q}\times C_o$ ------------(2)

Annual Inventory Carrying cost per year =Average Inventory level x inventory carrying cost

$$=\frac{Q}{2}\times C_c \text{ --------------(3)}$$

Now,

the total inventory cost per year = TC=Annual Ordering cost per year + Annual Inventory Carrying cost per year

$$=\frac{D}{Q}\times C_o+\frac{Q}{2}\times C_c \text{ -------(4)}$$

Differentiating Eq (4) w.r.t. Q it becomes:

$$\frac{d(TC)}{dQ}=\frac{-D}{Q^2}C_o+\frac{C_C}{2} \text{ ------------(5)}$$

The 2nd derivative $= \frac{2D}{Q^3}C_o$ ----(6)

Since the 2nd derivative is +ve, we can equate the value of first derivative to zero to get the optimum value of Q. i.e.,

$$\frac{-D}{Q^2}C_o+\frac{C_C}{2}=0$$

$$\Rightarrow \frac{C_C}{2}=\frac{D}{Q^2}C_o$$

$$\Rightarrow Q^2=\frac{2DC_o}{C_c}$$

$$\Rightarrow Q^*=\sqrt{\frac{2DC_o}{C_c}} \text{ -----------(7)}$$

So, optimum EOQ$=Q^*=\sqrt{\frac{2DC_o}{C_c}}$

Note: If the inventory carrying cost is expressed as a percentage of annual average inventory investment,

then $Q^*=\sqrt{\frac{2DC_o}{C_pI}}$,where it is expressed as a percentage of annual inventory investment.

The optimal number of orders placed per annum, $N^* = \frac{D}{Q^*}$

Minimum total yearly inventory cost is given by $T_{cm} = \frac{DC_o}{Q^*} + \frac{Q^*C_c}{2}$ ------(8)

Substituting for Q^* from equation (7)

$$T_{cm} = \frac{DC_o}{\sqrt{\frac{2DC_o}{C_c}}} + \sqrt{\frac{2DC_o}{C_c}} \times \frac{C_c}{2}$$

$$T_{cm} = \sqrt{2DC_oC_c}$$

Example 1: ABC company estimates that it will sell 12000 units of its product for the forthcoming year. the ordering cost is Rs 100/- per order and the carrying cost per year is 20% of the purchase price per unit. The purchase price per unit is Rs 50/-.Find

i. Economic Order Quantity
ii. No. of orders/year
iii. Time between successive order.

Solution:

Given D = 12000 units/yr., Co = Rs 100/year

Cc = Rs 50×0.2 = Rs 10/- per unit/year

Therefore

i. $EOQ = \sqrt{\frac{2DC_o}{C_c}} = \sqrt{\frac{2 \times 12000 \times 100}{10}} = 489.89 \simeq 490$ units

ii. No. of orders/year = $\frac{D}{Q^*} = \frac{12000}{490} = 24.49$

iii. Time between successive order = $\frac{Q^*}{D} = \frac{490}{12000} = 0.04$ year = 0.48 month

Example 2: ABC corporation has got a demand for particular part at 10000 units per year. The cost/unit is Rs 2 and it costs Rs. 36 to place an order and to process the delivery. The inventory carrying cost is estimated at 9% of average inventory investment. Find

i. Economic Order Quantity
ii. Optimum no. of orders to be placed per annum
iii. Minimum total cost of inventory per annum

Solution:

Given Annual demand (D) = 10000 units/yr., Ordering cost (Co) = Rs 36/order

Cost per unit (C_p) = Rs 2 /unit, Inventory carrying cost (I) =0.09

i. Economic Order Quantity $EOQ = Q^* = \sqrt{\frac{2DC_o}{C_p I}} = \sqrt{\frac{2\times10000\times36}{2\times0.09}} = 2000$ units

ii. Optimum no. of orders $= \frac{D}{Q^*} = \frac{10000}{2000} = 5$

iii. Total inventory cost $= T_{cm} = \sqrt{2DC_oC_c} = \sqrt{2\times10000\times36\times(2\times0.09)} =$ Rs. 360 / annum

Example 3: A manufacturer has to supply his customers 3600 units of his product per annum. Shortage are not permitted. Inventory carrying cost amounts Rs. 1.2/unit/annum and set up cost per run is Rs. 80. Find

i. Economic Order Quantity
ii. Optimum no. of orders to be placed per annum
iii. Minimum total cost of inventory per annum
iv. Optimum period of supply per optimum order.

Solution:

Given Annual demand (D) = 3600 units/yr., Ordering cost (Co) = Rs 80/order

Inventory carrying cost (Cc) = Rs 1.2 / order /year

i. Economic Order Quantity $EOQ = Q^* = \sqrt{\frac{2DC_o}{C_c}} = \sqrt{\frac{2\times3600\times80}{1.2}} = 692.82 \approx 693$ units

ii. Optimum no. of orders $= N = \frac{D}{Q^*} = \frac{3600}{693} = 5.19 \simeq 5$ orders

iii. Total inventory cost $= T_{cm} = \sqrt{2DC_oC_c} = \sqrt{2\times3600\times80\times1.2} =$ Rs. 831.38 / annum

iv. Optimum period of supply per optimum order $= \frac{1}{N} = \frac{1}{5} = 0.2$ years

3.8 ABC Analysis:

It is a fundamental tool for exercising selective control over numerous inventory items.

- ABC means → Always Better Control
- ABC analysis divides inventories into three groupings in terms of percentage of number of items and percentage of total value. In ABC analysis important items (high usage valued items) are grouped in C and the remaining middle level items are considered 'B' items.

The inventory control is exercised on the principle of "management by exception" i.e., rigorous controls are exercised on A items and routine loose controls for C items and moderate control in 'B' items. The items classified by virtue of their uses as:

Category	% of items (approx.)	% value (approx.)
A – High value items	10	70
B – Medium value items	20	20
C – Low value items	70	10

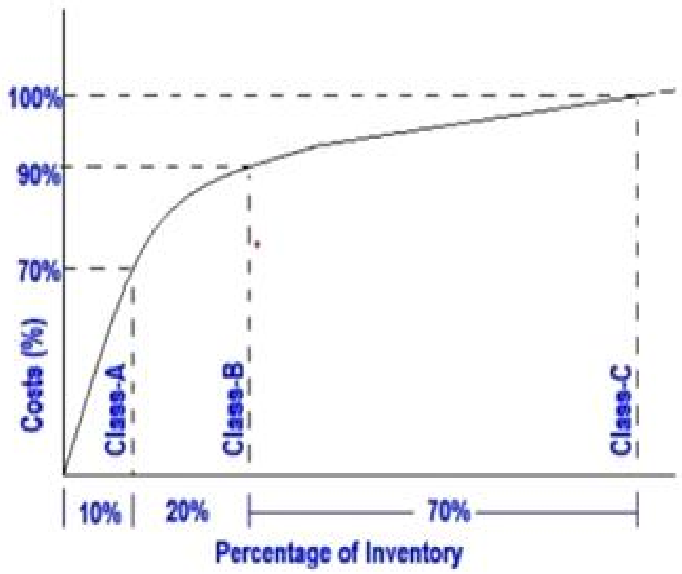


Fig. 3.3 Graphical representation of ABC analysis

<u>Control policies for A items</u>

i. 'A' items are high valued items hence should be ordered in small quantities in order to reduce capital blockage.
ii. The future requirement must be planned in advanced so that required quantities arrive a little before they are required for consumptions.
iii. Purchase and stock control of A items should be taken care by top executives in purchasing department.
iv. Maximum effort should be made to expedite the delivery.
v. The safety stock should be as less as possible (15 days or less).
vi. 'A' items are subjected to tight control w.r.t.
   - Issue
   - Balance
   - Storing method
vii. Ordering quantities, reorder point and maximum stock level should be revised more frequently.

Control policies for 'B' items

i. The policies for 'B' items are in general between A & C.
ii. Order for these items must be placed less frequently.
iii. Safety stock should be medium (3 months or less).
iv. 'B' items are subjected to moderate control.

Control policies for 'C' items

i. 'C' items are low valued items.
ii. Safety stock should be liberal (3 months or more).
iii. Annual or 6 monthly order should be placed to reduce paper work & ordering cost and to get the advantage of discount.
iv. In case of these items only routine check is required.

CHAPTER - 4

CHAPTER 4

INSPECTION AND QUALITY CONTROL

4.1 Define Inspection and Quality control

Definition of Quality:

The meaning of "Quality" is closely allied to cost and customer needs. "Quality" may simply be defined as **fitness for purpose at lowest cost**.

The component is said to possess good quality, if it works well in the equipment for which it is meant. Quality is thus defined as fitness for purpose.

Quality is the 'totality of features and characteristics' both for the products and services that can satisfy both the explicit and implicit needs of the customers.

"Quality" of any product is regarded as the degree to which it fulfills the requirements of the customer.

"Quality" means **degree of perfection**. Quality is not absolute but it can only be judged or realized by comparing with standards. It can be determined by some characteristics namely, design, size, material, chemical composition, mechanical functioning, workmanship, finish and other properties.

Meaning of Control:

Control is a system for measuring and checking (inspecting) a phenomenon. The process through which the standards are established and met with standards is called control. It suggests when to inspect, how often to inspect and how much to inspect. In addition, it incorporates a feedback mechanism which explores the causes of poor quality and takes corrective action.

Control differs from 'inspection', as it ascertains quality characteristics of an item, compares the same with prescribed quality standards and separates defective items from non-defective ones. Inspection, however, does not involve any mechanism to take corrective action.

Meaning of Quality Control:

Quality Control is a systematic control of various factors that affect the quality of the product. The various factors include material, tools, machines, type of labour, working conditions, measuring instruments, etc.

Quality Control can be defined as the entire collection of activities which ensures that the operation will produce the optimum Quality products at minimum cost.

As per A.Y. Feigorbaum Total Quality Control is: "An effective system for integrating the quality development, Quality maintenance and Quality improvement efforts of the various groups in an organization, so as to enable production and services at the most economical levels which allow full customer satisfaction"

In the words of Alford and Beatly, "Quality Control" may be broadly defined as that "Industrial management technique means of which products of uniform accepted quality are manufactured." Quality Control is concerned with making things right rather than discovering and rejecting those made wrong.

In short, we can say that quality control is a technique of management for achieving required standards of products.

Objectives of Quality Control:

Following are the objectives of quality control:

- To improve the company's income by making the production more acceptable to the customers, *i.e.*, by providing long life, greater usefulness, maintainability etc.
- To reduce companies cost through reduction of losses due to defects.
- To achieve interchangeability of manufacture in large scale production.
- To produce optimal quality at reduced price.
- To ensure satisfaction of customers with productions or services or high-quality level, to build customer goodwill, confidence and reputation of manufacturer.
- To make inspection prompt to ensure quality control.
- To check the variation during manufacturing.

The broad areas of application of quality control are incoming material control, process control and product control.

Benefits of Quality Control

- Improving the quality of products and services.
- Increasing the productivity of manufacturing processes, commercial business, corporations.
- Reducing manufacturing and corporate costs.
- Determining and improving the marketability of products and services.
- Reducing consumer prices of products and services.
- Improving and/or assuring on time deliveries and availability.
- Assisting in the management of an enterprise.

INSPECTION

Inspection is an important tool to achieve quality concept. It is necessary to assure confidence to manufacturer and aims satisfaction to customer. Inspection is an indispensable tool of modern manufacturing process. It helps to control quality, reduces manufacturing costs, eliminate scrap losses and assignable causes of defective work.

Inspection only measures the degree of conformance to a standard in the case of variables. In the case of attributes inspection merely separates the nonconforming from the conforming. Inspection does not show why the nonconforming units are being produced.

Inspection is the most common method of attaining standardization, uniformity and quality of workmanship. It is the cost art of controlling the production quality after comparison with the established standards and specifications. It is the function of quality control. If the said item does not fall within the zone of acceptability it will be rejected and corrective measure will be applied to see that the items in future conform to specified standards.

Objectives of Inspection:

- To detect and remove the faulty raw materials before it undergoes production.
- To detect the faulty products in production whenever it is detected.

- To bring facts to the notice of managers before they become serous to enable them to discover weaknesses and over the problem.
- To prevent the substandard reaching the customer and reducing complaints.
- To promote reputation for quality and reliability of product.

Purpose of Inspection

- To distinguish good lots from bad lots.
- To distinguish good pieces from bad pieces.
- To determine if the process is changing.
- To determine if the process is approaching the specification limits.
- To rate quality of product.
- To rate accuracy of inspectors.
- To measure the precision of the measuring instrument.
- To secure products-design information.
- To measure process capability.

4.2 PLANNING OF INSPECTION:

It includes

1.Locating the inspection station

2.Providing facilities for inspection station

1. Locating the inspection station:

For deciding the location of inspection station flow charts are consulted. Most usual location for inspection station is

a) at receipt of goods from supplier, generally known as incoming inspection
b) at the time of setup, a production process
c) during the critical or costly operation, also known as process inspection
d) prior to delivery of lot from processing department to another.
e) Prior to dispatch of completed product to storage or to customer also known as finished good inspection.
f) Sometimes depending upon the customer inspection is performed in the shipping area of supplier plant or at customer's place

2. Providing facilities for inspection station

Based upon the product specification and its application, quality characteristics are decided. Planner prepares a list of which quality characteristic are to be checked and at which inspection station.

The planner determines the detailed work to be done for each quality characteristics which include the following.

a) The type of test to be done. This requires the details description of testing environment, testing equipments, testing procedure, tolerance permissible for desired accuracy.
b) Sample size (number of units to be inspected in a lot)
c) Methods of selecting the sample to be tested

d) The type of measurement to be made (attributes, variables)
e) Conformance criteria or tolerance limit
f) There are certain characteristics which are difficult to measure by instrument, such characteristics uses senses of human being and are known as sensory characteristics examples-Taste, odour etc. Planner in such cases may try to describe the words define limiting factor for acceptability of the product.

4.3 Types of Inspection

Types of inspection are:

1. Floor inspection 2. Centralized inspection 3. Combined inspection 4. Functional inspection 5. First piece inspection 6. Pilot piece inspection 7. Final inspection

1. FLOOR INSPECTION

In this system, the inspection is performed at the place of production. It suggests the checking of materials in process at the machine or in the production time by patrolling inspectors. These inspectors move from machine to machine and from one to the other work centers. Inspectors have to be highly skilled. This method of inspection minimizes the material handling, does not disrupt the line layout of machinery and quickly locate the defect and readily offers field and correction.

Advantages

1. Detection of errors of the source reduces scrap and rework.
2. Correction is done before it affects further production, resulting in saving cost of unnecessary work on defective parts.
3. Material handling time is reduced.
4. Job satisfaction to worker as he can't be held responsible for bad work at a later date.
5. Greater number of pieces can be checked than a sample size.
6. Does not delay in production.

Disadvantages

1. Delicate instruments can be employed.
2. Measuring or inspection equipment have to be recalibrated often as they are subjected to wear or dust.
3. High cost of inspection because of numerous sets of inspections and skilled inspectors.
4. Supervision of inspectors is difficult due to vibration.
5. Pressure on inspector.
6. Possibility of biased inspection because of worker.

Suitability

1. Heavy products are produced.

2. Different work centers are integrated in continuous line layout.

2. CENTRALISED INSPECTION

Inspection is carried in a central place with all testing equipment, sensitive equipment is housed in air-conditioned area. Samples are brought to the inspection floor for checking. Centralised inspection may locate in one or more places in the manufacturing industry.

Advantages

1. Greater degree of inspection due to sensitive equipment.
2. Less number of inspectors and tools.
3. Equipment needs less frequency of recalibration.
4. Cost of inspection is reduced.
5. Unbiased inspection.
6. Supervision of inspectors made possible.
7. No distraction to the inspector.

Disadvantages

1. Defects of job are not revealed quickly for prevention.
2. Greater material handling.
3. High cost as products are subjected to production before they are prevented.
4. Greater delay in production.
5. Inspection of heavy work not possible.
6. Production control work is more complicated.
7. Greater scrap.

3. COMBINED INSPECTION

Combination of two methods whatever may be the method of inspection, whether floor or central. The main objective is to locate and prevent defect which may not repeat itself in subsequent operation to see whether any corrective measure is required and finally to maintain quality economically.

4. FUNCTIONAL INSPECTION

This system only checks for the main function, the product is expected to perform. Thus an electrical motor can be checked for the specified speed and load characteristics. It does not reveal the variation of individual parts but can assure combined satisfactory performance of all parts put together. Both manufacturers and purchasers can do this, if large number of articles are needed at regular intervals. This is also called assembly inspection.

5. FIRST PIECE OR FIRST-OFF INSPECTIONS

First piece of the shift or lot is inspected. This is particularly used where automatic machines are employed. Any discrepancy from the operator as machine tool can be checked to see that the product is within in control limits. Excepting for need for precautions for tool we are check and disturbance in machine set up, this yields good result if the operator is careful.

6. PILOT PIECE INSPECTION

This is done immediately after new design or product is developed. Manufacturer of product is done either on regular shop floor if production is not disturbed. If production is affected to a large extent, the product is manufactured in a pilot plant. This is suitable for mass production and products involving large number of components such as automobiles aero planes etc., and modification are design or manufacturing process is done until satisfactory performance is assured or established.

7. FINAL INSPECTION

This is also similar to functional or assembly inspection. This inspection is done only after completion of work. This is widely employed in process industries where there is not possible such as, electroplating or anodizing products. This is done in conjunction with incoming material inspection.

Steps in Quality Control

Following are the steps in quality control process:

1. Formulate quality policy.
2. Set the standards or specifications on the basis of customer's preference, cost and profit.
3. Select inspection plan and set up procedure for checking.
4. Detect deviations from set standards of specifications.
5. Take corrective actions or necessary changes to achieve standards.
6. Decide on salvage method *i.e.*, to decide how the defective parts are disposed of, entire scrap or rework.
7. Coordination of quality problems.
8. Developing quality consciousness both within and outside the organization.
9. Developing procedures for good vendor-vendee relations.

Objectives of Quality Control

Following are the objectives of quality control:

1. To improve the company's income by making the production more acceptable to the customers, *i.e.*, by providing long life, greater usefulness, maintainability etc.
2. To reduce companies cost through reduction of losses due to defects.
3. To achieve interchangeability of manufacture in large scale production.
4. To produce optimal quality at reduced price.

5. To ensure satisfaction of customers with productions or services or high-quality level, to build customer goodwill, confidence and reputation of manufacturer.

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- Reducing consumer prices of products and services.
- Improving and/or assuring on time deliveries and availability.
- Assisting in the management of an enterprise.

4.5 Factors influencing the quality of manufacture:

The nine fundamental factors **(9 M's)**, which are affecting the quality of products and services, are: markets, money, management, men, motivation, materials, machines and mechanization. Modern information methods and mounting product requirements.

1. Market: Because of technology advancement, we could see many new products to satisfy customer wants. At the same time, the customer wants are also changing dynamically. So, it is the role of companies to identify needs and then meet it with existing technologies or by developing new technologies.

2. Money: The increased global competition necessitates huge outlays for new equipments and process. This should be rewarded by improved productivity. This is possible by minimizing quality costs associated with the maintenance and improvements of quality level.

3. Management: Because of the increased complex structure of business organization, the quality related responsibilities lie with persons at different levels in the organization.

4. Men: The rapid growth in technical knowledge leads to development of human resource with different specialization. This necessitates some groups like, system engineering group to integrate the idea of full specialization.

5. Motivation: If we fix the responsibility of achieving quality with each individual in the organization with proper motivation techniques, there will not be any problem in producing the designed quality products.

6. Materials: Selection of proper materials to meet the desired tolerance limit is also an important consideration. Quality attributes like, surface finish, strength, diameter etc., can be obtained by proper selection of material.

7. Machines and mechanization: In order to have quality products which will lead to higher productivity of any organization, we need to use advanced machines and mechanize various operations.

8. Modern information methods: The modern information methods help in storing and retrieving needed data for manufacturing, marketing and servicing.

9. Mounting product requirements: Product diversification to meet customers taste leads to intricacy in design, manufacturing and quality standards. Hence, companies should plan adequate system to tackle all these requirements.

Statistical Quality Control (S.Q.C):

Statistics: Statistics means data, a good amount of data to obtain reliable results. The science of statistics handles this data in order to draw certain conclusions.

S.Q.C: This is a quality control system employing the statistical techniques to control quality by performing inspection, testing and analysis to conclude whether the quality of the product is as per the laid quality standards.

Using statistical techniques, S.Q.C. collects and analyses data in assessing and controlling product quality. The technique of S.Q.C. was though developed in 1924 by Dr. WalterA. Shewartan American scientist, it got recognition in industry only second world war. The technique permits a more fundamental control.

"Statistical quality control can be simply defined as an economic & effective system of maintaining & improving the quality of outputs throughout the whole operating process of specification, production & inspection based on continuous testing with random samples." -YA LUN CHOU

"Statistical quality control should be viewed as a kit of tools which may influence decisions to the functions of specification, production or inspection. - EUGENE L. GRANT

The fundamental basis of S.Q.C. is the theory of probability. According to the theories of probability, the dimensions of the components made on the same machine and in one batch (if measured accurately) vary from component to component. This may be due to inherent machine characteristics or the environmental conditions.

The chance or condition that a sample will represent the entire batch or population is developed from the theory of probability.

Relying itself on the probability theory, S.Q.C. evaluates batch quality and controls the quality of processes and products. S.Q.C. uses three scientific techniques, namely;

- Sampling inspection
- Analysis of the data, and
- Control charting

Advantages of S.Q.C:

S.Q.C is one of the tools for scientific management, and has following main advantages over 100 percent inspection:

1. Reduction in cost: Since only a fractional output is inspected, hence cost of inspection is greatly reduced.

2. Greater efficiency: It requires lesser time and boredom as compared to the 100 percent inspection and hence the efficiency increases.

3. Easy to apply: Once the S.Q.C plan is established; it is easy to apply even by man who does not have extensive specialized training.

4. Accurate prediction: Specifications can easily be predicted for the future, which is not possible even with 100 percent inspection.

5. Can be used where inspection is needs destruction of items: In cases where destruction of product is necessary for inspecting it, 100 percent inspection is not possible (which will spoil all the products), sampling inspection is resorted to.

6. Early detection of faults: The moment a sample point falls outside the control limits, it is taken as a danger signal and necessary corrective measures are taken. Whereas in 100 percent inspection, unwanted variations in quality may be detected after large number of defective items have already been produced. Thus, by using the control charts, we can know from graphic picture that how the production is proceeding and where corrective action is required and where it is not required.

CONTROL CHARTS:

Since variations in manufacturing process are unavoidable, the control chart tells when to leave a process alone and thus prevent unnecessary frequent adjustments. Control charts are graphical representation and are based on statistical sampling theory, according to which an adequate sized random sample is drawn from each lot.

Control charts detect variations in the processing and warn if there is any departure from the specified tolerance limits. These control charts immediately tell the undesired variations and help in detecting the cause and its removal.

In control charts, where both upper and lower values are specified for a quality characteristic, as soon as some products show variation outside the tolerances, a review of situation is taken and corrective step is immediately taken.

If analysis of the control chart indicates that the process is currently under control (i.e., is stable, with variation only coming from sources common to the process) then data from the process can be used to predict the future performance of the process. If the chart indicates that the process being monitored is not in control, analysis of the chart can help determine the sources of variation, which can then be eliminated to bring the process back into control. A control chart is a specific kind of run chart that allows significant change to be differentiated from the natural variability of the process.

The control chart can be seen as part of an objective and disciplined approach that enables correct decisions regarding control of the process, including whether or not to change process control parameters. Process parameters should never be adjusted for a process that is in control, as this will result in degraded process performance.

In other words, control chart is:

- A device which specifies the state of statistical control,
- A device for attaining statistical control,
- A device to judge whether statistical control has been attained or not.

Purpose and Advantages:

1. A control charts indicates whether the process is in control or out of control.

2. It determines process variability and detects unusual variations taking place in a process.

3. It ensures product quality level.

4. It warns in time, and if the process is rectified at that time, scrap or percentage rejection can be reduced.

5. It provides information about the selection of process and setting of tolerance limits.

6. Control charts build up the reputation of the organization through customer's satisfaction.

A control chart consists of:

- Points representing a statistic (e.g., a mean, range, proportion) of measurements of a quality characteristic in samples taken from the process at different times [the data]
- The mean of this statistic using all the samples is calculated (e.g., the mean of the means, mean of the ranges, mean of the proportions)
- A center line (CL) is drawn at the value of the mean of the statistic
- The standard error of the statistic is also calculated using all the samples
- Upper and lower control limits (sometimes called "natural process limits" or UCL and LCL) that indicate the threshold at which the process output is considered statistically 'unlikely' are drawn typically at 3 standard errors from the center line

The control chart has a horizontal scale that represents the consecutive sample number and a vertical scale representing the characteristic quality of each sample. This is shown in Figure 4.1

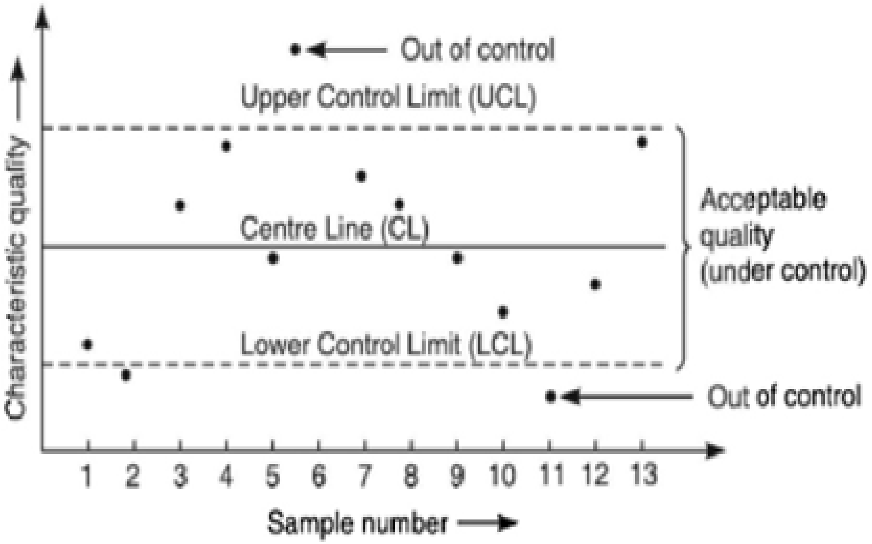


Figure 4.1

Types of Control Charts

Control charts can be used to measure any characteristic of a product, such as the weight of a cereal box, the number of chocolates in a box, or the volume of bottled water. The different characteristics that can be measured by control charts can be divided into two groups: **variables** and **attributes.**

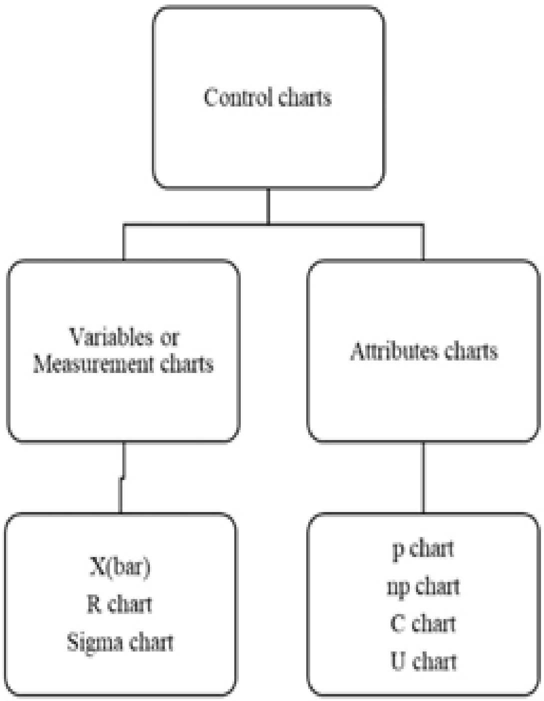


Figure 4.2

control chart for variables, is used to monitor characteristics that can be measured and have a continuum of values, such as height, weight, or volume. A soft drink bottling operation is an example of a variable measure, since the amount of liquid in the bottles is measured and can take on a number of different values. Other examples are the weight of a bag of sugar, the temperature of a baking oven, or the diameter of plastic tubing.

control chart for attributes, on the other hand, is used to monitor characteristics that have discrete values and can be counted. Often, they can be evaluated with a simple yes or no decision. Examples include color, taste, or smell. The monitoring of attributes usually takes less time than that of variables because a variable need to be measured (e.g., the bottle of soft drink contains 15.9 liters of liquid). An attribute requires only a single decision, such as yes or no, good or bad, acceptable or unacceptable (e.g., the apple is good or rotten, the meat is good or stale, the shoes have a defect or do not have a defect, the lightbulb works or it does not work) or counting the number of defects (e.g., the number of broken cookies in the box, the number of dents in the car, the number of barnacles on the bottom of a boat).

Commonly used charts, like

1. ($\bar{X}$) and R charts, for process control.

2. P chart, for analysis of fraction defectives

3. C chart, for control of number of defects per unit.

Mean ($\bar{X}$) or (X bar) Charts

A mean control chart is often referred to as an ***x-bar chart.*** It is used to monitor changes in the mean of a process. To construct a mean chart, we first need to construct the center line of the chart. To do this we take multiple samples and compute their means. Usually these samples are small, with about four or five observations. Each sample has its own mean. The center line of the chart is then computed as the mean of all sample means, where *n* is the number of samples:

1. It shows changes in process average and is affected by changes in process variability.

2. It is a chart for the measure of central tendency.

3. It shows erratic or cyclic shifts in the process.

4. It detects steady progress changes, like tool wear.

5. It is the most commonly used variables chart.

6. When used along with R chart:

   a) It tells when to leave the process alone and when to chase and go for the causes leading to variation;
   b) It secures information in establishing or modifying processes, specifications or inspection procedures;
   c) It controls the quality of incoming material.

7. X-Bar and R charts when used together form a powerful instrument for diagnosing quality problems.

Range (R) charts

These are another type of control chart for variables. Whereas x-bar charts measure shift in the central tendency of the process, range charts monitor the dispersion or variability of the process. The method for developing and using R-charts are the same as that for x-bar charts. The center line of the control chart is the average range, and the upper and lower control limits are computed. The R chart is used to monitor process variability when sample sizes are small ($n<10$), or to simplify the calculations made by process operators. This chart is called the R chart because the statistic being plotted is the sample range.

1. It controls general variability of the process and is affected by changes in process variability.

2. It is a chart for measure of spread.

3. It is generally used along with X-bar chart.

Plotting of $\bar{X}$ and R charts:

A number of samples of component coming out of the process are taken over a period of time. Each sample must be taken at random and the size of sample is generally kept as 5 but 10 to15 units can be taken for sensitive control charts. For each sample, the average value $\bar{X}$ of all the measurements and the range R are calculated. The grand average $\bar{\bar{X}}$ (equal to the average value of all the average $\bar{X}$)

and $\overline{R}$ ($\overline{R}$ is equal to the average of all the ranges R) are found and from these we can calculate the control limits for the $\overline{X}$ and R charts. Therefore,

Average of sample mean or grand average is given by

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \overline{X}_3 + \ldots\ldots + \overline{X}_n}{n} = \sum_{i=1}^{n} \frac{\overline{X}_i}{n}$$

$$\overline{R} = \frac{R_1 + R_2 + R_3 + \ldots\ldots + R_n}{n} = \sum_{i=1}^{n} \frac{R_i}{n}$$

$$\text{Range } R = X_{max} - X_{min}$$

Where n=no of samples

(a) Standard Deviation of the Process, σ, Unknown

X -Chart*:* The control limits are:

$$CL = \overline{\overline{X}}$$

$$UCL = \overline{\overline{X}} + A_2\overline{R}$$

$$LCL = \overline{\overline{X}} - A_2\overline{R}$$

where $\overline{\overline{X}}$ = central line of the chart and the average of past sample mean's, and A2 = constant to provide three-sigma limits for the process mean.

R-Chart*:* To calculate the range of the data, subtract the smallest from the largest measurement in the sample.

The control limits are:

$$CL = \overline{R}$$

$$UCL = \overline{R}\ D_4$$

$$LCL = \overline{R}\ D_3$$

where $\overline{R}$ = average of several past *R* values and is the central line of the control chart, and

D_3, D_4 = constants that provide three standard deviation (three-sigma) limits for a given sample size

(b) Standard Deviation of the Process, σ, Known

Control charts for variables (with the standard deviation of the process, σ, known) monitor the mean, $\overline{\overline{X}}$, of the process distribution.

The control limits are:

$$CL = \overline{\overline{X}}$$

$$UCL = \overline{\overline{X}} + 3\sigma_{\bar{X}}$$

$$LCL = \overline{\overline{X}} - 3\sigma_{\bar{X}}$$

where $\overline{\overline{X}}$ = Centre line of the chart and the average of several past sample means

$\sigma_{\bar{X}} = \sigma/\sqrt{n}$ is the standard deviation of the distribution of sample means, and n is the sample size

Factors for Constructing Variables Control Charts

Observations in Sample, n	Chart for Averages					Chart for Standard Deviations						Chart for Ranges				
	Factors for Control Limits			Factors for Center Line		Factors for Control Limits				Factors for Center Line		Factors for Control Limits				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

For $n > 25$.

$$A = \frac{3}{\sqrt{n}} \quad A_3 = \frac{3}{c_4\sqrt{n}} \quad c_4 \cong \frac{4(n-1)}{4n-3}$$

$$B_3 = 1 - \frac{3}{c_4\sqrt{2(n-1)}} \quad B_4 = 1 + \frac{3}{c_4\sqrt{2(n-1)}}$$

$$B_5 = c_4 - \frac{3}{\sqrt{2(n-1)}} \quad B_6 = c_4 + \frac{3}{\sqrt{2(n-1)}}$$

Control Charts for Attributes:

Two of the most common types of control charts for attributes are p-charts and c-charts.

P-charts are used to measure the proportion of items in a sample that are defective. Examples are the proportion of broken cookies in a batch and the proportion of cars produced with a misaligned fender. P-charts are appropriate when both the number of defectives measured and the size of the total sample can be counted. A proportion can then be computed and used as the statistic of measurement.

1. It can be a fraction defective chart.
2. Each item is classified as good (non-defective) or bad (defective).
3. This chart is used to control the general quality of the component parts and it checks if the fluctuations in product quality (level) are due to chance alone.

<u>Plotting of P-charts</u>: By calculating, first, the fraction defective and then the control limits. The process is said to be in control if fraction defective values fall within the control limits. In case the process is out of control an investigation to hunt for the cause becomes necessary.

The mean proportion defective ($\bar{p}$) is given by

$$\bar{p} = \frac{\text{Total number of Defectives}}{\text{Total number Inspected}}$$

The standard deviation of p is given by

$$\sigma_{\bar{p}} = \sqrt{\frac{p(1-P)}{n}} \quad \text{where n=sample size}$$

The control limits are:

$$UCL = \bar{p} + 3 * \sigma_{\bar{p}}$$

$$CL = \bar{p}$$

$$LCL = \bar{p} - 3 * \sigma_{\bar{p}}$$

C-charts count the actual number of defects. For example, we can count the number of complaints from customers in a month, the number of bacteria on a petri dish, or the number of barnacles on the bottom of a boat. However, we cannot compute the proportion of complaints from customers, the proportion of bacteria on a petri dish, or the proportion of barnacles on the bottom of a boat. In such cases we can base control limits on the assumption that the **Poisson distribution** is applicable.

Since the mean and variance of a Poisson distribution are equal, the standard deviation is given by

$$\sigma_C = \sqrt{\bar{C}}$$

where $\bar{C}$ denotes the average number of defects in a sample and is given by

$$\overline{C} = \frac{\text{Total no. of defects in all samples}}{\text{Total no. of samples inspected}}$$

Thus, the control limits are:

$$UCL = \overline{C} + 3\sigma_C = \overline{C} + 3\sqrt{\overline{C}}$$
$$CL = \overline{C}$$
$$LCL = \overline{C} - 3\sigma_C = \overline{C} - 3\sqrt{\overline{C}}$$

Note: A P-chart is used when both the total sample size and the number of defects can be computed whereas C-chart is used when we can compute *only* the number of defects but cannot compute the proportion that is defective.

EXAMPLE 1:

In a factory 20 samples of 5 units each were taken. The population mean was found to be 25cm and the sum of the ranges for 20 samples is 130 cm. Find the control limits. A_2 for n = 5 is 0.58.

Solution

Here, $\overline{\overline{X}} = 25$ cm, n = 5, k = 20, $\overline{R} = \frac{130}{20} = 6.5$ cm, $A_2 = 0.58$.

The control limits are

$$CL = \overline{\overline{X}} = 25,$$
$$UCL = \overline{\overline{X}} + A_2\overline{R} = 25 + .58x6.5 = 28.77,$$
$$LCL = \overline{\overline{X}} - A_2\overline{R} = 25 - .58x6.5 = 21.23.$$

EXAMPLE 2

A company manufactures screws to a nominal diameter 0.500 ± 0.030 cm. Five samples were taken randomly from the manufactured lot and 3 measurements were taken on each sample at different lengths. The readings are shown in the table below.

Sample no.	*Measurements per sample (cm) x*		
	1	*2*	*3*
1	*0.488*	*0.489*	*0.505*
2	*0.494*	*0.495*	*0.499*
3	*0.498*	*0.515*	*0.487*
4	*0.492*	*0.509*	*0.514*
5	*0.490*	*0.508*	*0.499*

Calculate the control limits on x and R-charts and draw the charts.

Calculation of mean

For sample 1, $\bar{x}_1 = \frac{0.488 + .489 + .505}{3} = 0.494$

For sample 2, $\bar{x}_2 = \frac{0.494 + .495 + .499}{3} = 0.496$

Similarly, $\bar{x}_3 = 0.500, \bar{x}_4 = 0.505, \bar{x}_5 = 0.499$

$\therefore \quad \bar{\bar{X}} = \frac{\bar{x}_1 + \bar{x}_2 + \bar{x}_3 + \bar{x}_4 + \bar{x}_5}{5} = 0.499$

Calculation of range

For sample 1, $R_1 = (X_{max} - X_{min}) = 0.505 - 0.488 = 0.017$

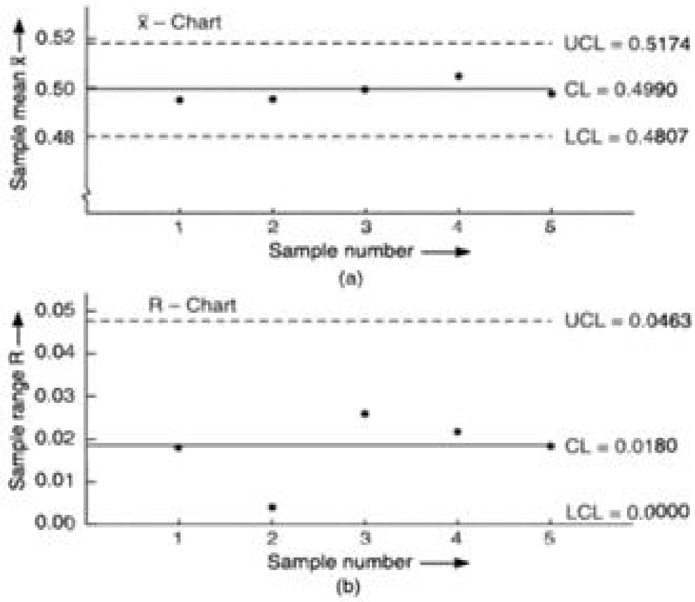
Similarly, $R_2 = 0.499 - 0.494 = 0.005,$

$R_3 = 0.515 - 0.487 = 0.028,$

$R_4 = 0.514 - 0.492 = 0.022,$

and $R_5 = 0.508 - 0.490 = 0.018.$

$\therefore \quad \bar{R} = \frac{R_1 + R_2 + R_3 + R_4 + R_5}{5} = 0.018$



Control limits for $\bar{\bar{X}}$ chart

$A_2 = 1.02$ for n = 3 from control chart constant table

$$CL = \bar{\bar{X}} = 0.499,$$

$$DCL = \bar{\bar{X}} + A_2 \times R = 0.499 + 1.02 \times 0.018 = 0.5174,$$

$$LCL = \bar{\bar{X}} - A_2 \times R = 0.499 - 1.02 \times 0.018 = 0.4807.$$

These control limits lie within the manufacturer's assigned limits of 0.50 + 0.03 = 0.53 and 0.50 - 0.03 = 0.47.

Control limits for R-chart

$$CL = \bar{R} = 0.018,$$

$$DCL = D_4 \times \bar{R} = 2.57 \times 0.018 = 0.0463, \text{ (}D_4\text{ and }D_3\text{ from table for } n = 3\text{)}$$

$$LCL = D_3 \times \bar{R} = 0 \times 0.018 = 0.00.$$

It can be seen from the figures that no value of *x* or R is out of the control limits. Therefore, the trial control limits are the actual control limits. The process is in statistical control *i.e.,* it is operating free from assignable causes of variations and is only under the influence of chance causes of variations.

EXAMPLE 3

The following are the mean lengths and ranges of lengths of a finished product from 10 samples each of size 5. The specification limits for length are 200 ±5 cm. Construct $\bar{X}$ and R charts and examine whether the process is under control and state your recommendations.

Sample no.	1	2	3	4	5	6	7	8	9	10
Mean $\bar{X}$	201	198	202	200	203	204	199	196	199	201
Range R	5	0	7	3	4	7	2	8	5	6

Assume for n = 5, $A_2 = 0.577$, $D_3 = 0$, $D_4 = 2.115$.

Solution

The specification limits for length are given to be 200 ± 5 cm. Hence, mean is known whereas standard deviation is unknown.

Control limits for $\bar{X}$ chart

$$\text{Central limit, } CL = \bar{\bar{X}} = 200,$$

$$\bar{R} = \frac{\sum_{i=1}^{10} X_i}{10} = \frac{47}{10} = 4.7$$

$$UCL = \overline{\overline{X}} + A_2\overline{R} = 200 + 0.577 \times 4.7 = 202.71$$

$$LCL = \overline{\overline{X}} - A_2\overline{R} = 200 - 0.577 \times 4.7 = 197.29$$

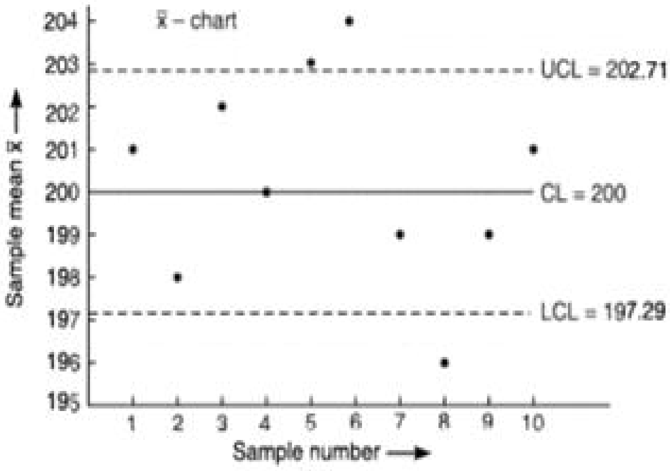
Control limits for R-chart

$$CL = \overline{R} = 4.7,$$

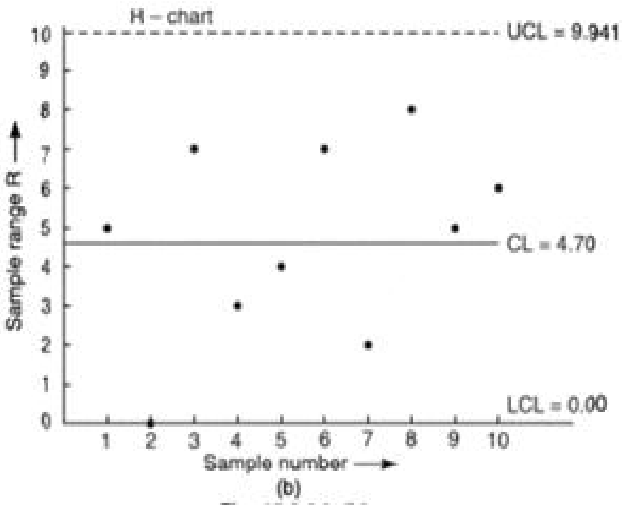
$$UCL = D_4\overline{R} = 2.115 \times 4.7 = 9.941,$$

$$LCL = D_3\overline{R} = 0 \times 4.7 = 0$$

The $\overline{X}$ and R-charts are drawn in Fig.(a) and (b) respectively.



(a)



(b)

It can be seen that all points lie within the control limits of R -chart. The process variability is, therefore, under control. However, three points corresponding to sample no. 5,6 and 8 lie outside the control limits of $\overline{X}$ -chart. The process is, therefore, not in statistical control. The process, therefore, should be halted to check whether there are any assignable causes. If they are found, the process should be readjusted to remove them, otherwise fluctuations are going to be there.

EXAMPLE 4

15 samples of size 4 each were drawn and the following measurements were made:

Sample no.	Observation	Sample no.	Observation
1	33,30,22, 6	8	19, 17, 11,21
2	52, 45, 36, 47	9	11,24, 26, 31
3	35,15,42,63	10	36,32,33,36
4	26, 34, 30, 22	11	31, 56, 37, 29
5	31,27,30,29	12	40,27,47,53
6	29,34,27,	16	13 34, 16,37,33
7	28,34,33,32	14	27,34,24,37
		15	12,10,15,28

Determine the control limits for $\overline{X}$ chart and R-chart and draw these charts. Take $A_2 = 0.729$, $D_3 = 0$ and $D_4 = 2.282$ for n = 4.

Solution

The sample mean *x* and variance *R* are calculated in following table

Sample no. (1)	*Sample observation, x (2)*				Σx	*Sample mean* $\overline{x} = \Sigma x/4$	*Sample range* $R = x_{max} - x_{min}$
1	33	30	22	6	91	22.75	27
2	52	45	36	47	180	45.00	16
3	35	15	42	63	155	38.75	48
4	26	34	30	22	112	28.00	12
5	31	27	30	29	117	29.25	4
6	29	34	27	16	106	26.50	18
7	28	34	33	32	127	31.75	6
8	19	17	11	21	68	17.00	10
9	11	24	26	31	92	23.00	20
10	36	32	33	26	127	31.75	10
11	31	16	37	29	113	28.25	21
12	40	27	47	53	167	41.75	26
13	34	16	37	33	120	30.00	21
14	27	34	24	37	122	30.50	13
15	12	10	15	28	65	16.25	18
					Total:	440.50	270

$$\overline{\overline{X}} = \frac{440.50}{15} = 29.37, \qquad \overline{R} = \frac{270}{15} = 18$$

Control limits for $\bar{X}$ chart

$$CL = \bar{\bar{X}} = 29.37,$$

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 29.37 + 0.729 \times 18 = 29.37 + 13.122 = 42.492,$$

$$LCL = \bar{\bar{X}} - A_2\bar{R} = 29.37 - 0.729 \times 18 = 29.37 - 13.122 = 16.248.$$

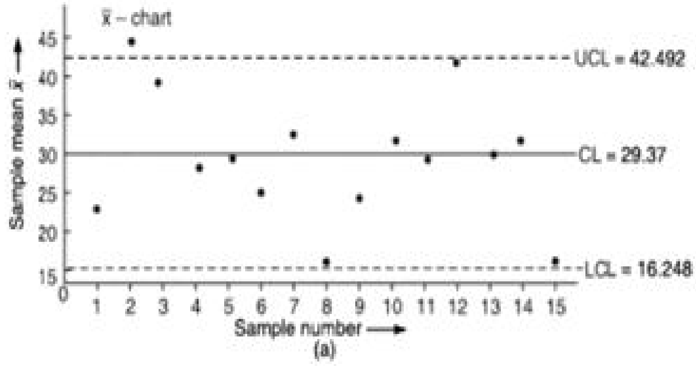
Control limits for R-chart

$$CL = \bar{R} = 18,$$

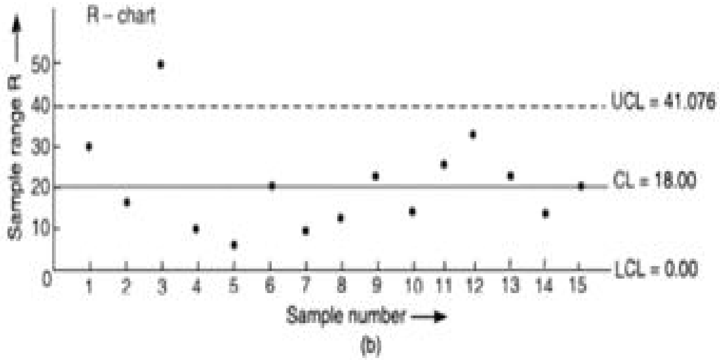
$$UCL = D_4\bar{R} = 2.282 \times 18 = 41.076,$$

$$LCL = D_3\bar{R} = 0 \times 18 = 0.$$

The $\bar{X}$ chart and R-chart are shown plotted in following Fig. (a) and *(b)* respectively.



(a)



(b)

Since sample range corresponding to sample no. 3 is outside the control limits, the process is out of control with respect to variability and there is no significance of drawing $\bar{X}$ -chart. However, $\bar{X}$ -chart is also drawn in Fig.*(a)* to just illustrate the procedure for plotting the points. Even in this chart, sample mean corresponding to sample no. 2 is out of the upper control limit. The process is clearly out of control.

EXAMPLE 5

Twenty samples each of size 100 were inspected and the results are given below:

Sample no.	1	2	3	4	5	6	7	8	9	10
No. of defectives:	2	1	3	0	2	3	1	2	0	4
Sample no.	11	12	13	14	15	16	17	18	19	20
No. of defectives:	3	2	0	4	1	7	0	1	3	1

Draw p-chart taking 3σ limits.

Solution

Here, n = 100, k = 20.

$$\therefore \quad \bar{p} = \frac{\sum p_i}{n \times k} = \frac{40}{20 \times 100} = 0.02$$

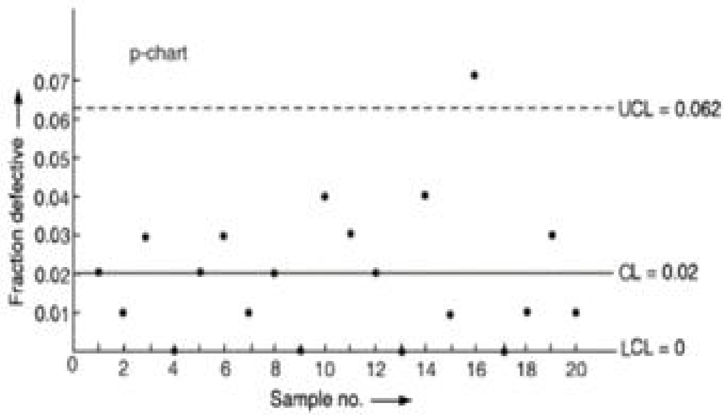
p-chart

Control limits for p-chart for 3σ limits are

$$CL = \bar{p} = 0.02,$$

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.02 + 3\sqrt{\frac{0.02 \times 0.98}{100}} = 0.02 + 0.042 = 0.062,$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.02 - 3\sqrt{\frac{0.02 \times 0.98}{100}} = 0.02 - 0.042 = 0.022 \simeq 0,$$



p-chart for 3σ limits is drawn in above Fig. It can be observed that the point corresponding to sample number 16 lies outside the upper control limit.

EXAMPLE 6

The cloth of a particular manufacturer was inspected. 100 sq. meters is considered as a unit. The effects in each unit were recorded and are given below. Is the production process under statistical control?

100 sq. m. cloth length no.:	1	2	3	4	5	6	7	8	9	10
No. of defects in each sample:	2	3	1	4	4	0	2	1	4	2

Solution

Here, no. of samples = 10, total number of defects = 23.

Average number of defects in a sample, $\overline{C} = 23/10 = 2.3$,

standard deviation, $\sigma_C = \sqrt{\overline{C}} = \sqrt{2.3} = 1.517$

Control limits of C chart

$$CL = \overline{C} = 2.3,$$
$$UCL = \overline{C} + 3\sqrt{\overline{C}} = 2.3 + 3 \times 1.517 = 6.85,$$
$$LCL = \overline{C} - 3\sqrt{\overline{C}} = 2.3 - 3 \times 1.517 = -2.251 \simeq 0.$$

Since the no. of defects for each sample lie within the control limits, the process is in control.

The seven tools of Quality Control:

1. Cause and effect analysis
2. Flowcharts
3. Checklists
4. Control techniques including Statistical quality control and control charts.
5. Scatter diagram
6. Pareto analysis which means identification of vital few from many at a glance. This is used for fixing the priorities in tackling a problem.
7. Histograms.

Cause-and-Effect Diagrams

Cause-and-effect diagrams are charts that identify potential causes for particular quality problems. They are often called fishbone diagrams because they look like the bones of a fish. A general cause-and-effect diagram is shown in Figure 4.3. The "head" of the fish is the quality problem, such as damaged zippers on a garment or broken valves on a tire. The diagram is drawn so that the "spine" of the fish connects the "head" to the possible cause of the problem. These causes could be related to the machines, workers, measurement, suppliers, materials, and many other aspects of the production process. Each of these possible causes can then have smaller "bones" that address specific issues that

Scatter Diagrams

relate to each cause. For example, a problem with machines could be due to a need for adjustment, old equipment, or tooling problems. Similarly, a problem with workers could be related to lack of training, poor supervision, or fatigue. Cause-and-effect diagrams are problem-solving tools commonly used by quality control teams. Specific causes of problems can be explored through brainstorming.

The development of a cause-and-effect diagram requires the team to think through all the possible causes of poor quality.

Flowcharts

A flowchart is a schematic diagram of the sequence of steps involved in an operation or process. It provides a visual tool that is easy to use and understand.

By seeing the steps involved in an operation or process, everyone develops a clear picture of how the operation works and where problems could arise.

Checklists

A checklist is a list of common defects and the number of observed occurrences of these defects. It is a simple yet effective fact-finding tool that allows the worker to collect specific information regarding the defects observed. The checklist in Figure 4.3 shows four defects and the number of times they have been observed.

It is clear that the biggest problem is ripped material. This means that the plant needs to focus on this specific problem—for example, by going to the source of supply or seeing whether the material rips during a particular production process.

A checklist can also be used to focus on other dimensions, such as location or time.

For example, if a defect is being observed frequently, a checklist can be developed that measures the number of occurrences per shift, per machine, or per operator. In this fashion we can isolate the location of the particular defect and then focus on correcting the problem.

Control Charts

Control charts are a very important quality control tool. We will study the use of control charts at great length in the previous chapter. These charts are used to evaluate whether a process is operating within expectations relative to some measured value such as weight, width, or volume.

For example, we could measure the weight of a sack of flour, the width of a tire, or the volume of a bottle of soft drink. When the production process is operating within expectations, we say that it is "in control."

To evaluate whether or not a process is in control, we regularly measure the variable of interest and plot it on a control chart. The chart has a line down the center representing the average value of the variable we are measuring. Above and below the center line are two lines, called the upper control limit (UCL) and the lower control limit (LCL). As long as the observed values fall within the upper and lower control limits, the process is in control and there is no problem with quality. When a measured observation falls outside of these limits, there is a problem.

Scatter diagrams are graphs that show how two variables are related to one another. They are particularly useful in detecting the amount of correlation, or the degree of linear relationship, between two variables.

For example, increased production speed and number of defects could be correlated positively; as production speed increases, so does the number of defects. Two variables could also be correlated negatively, so that an increase in one of the variables is associated with a decrease in the other. For example, increased worker training might be associated with a decrease in the number of defects observed.

The greater the degree of correlation, the more linear are the observations in the scatter diagram. On the other hand, the more scattered the observations in the diagram, the less correlation exists between the variables. Of course, other types of relationships can also be observed on a scatter diagram, such as an inverted.

This may be the case when one is observing the relationship between two variables such as oven temperature and number of defects, since temperatures below and above the ideal could lead to defects.

Pareto Analysis

Pareto analysis is a technique used to identify quality problems based on their degree of importance. The logic behind Pareto analysis is that only a few quality problems are important, whereas many others are not critical. The technique was named after Vilfredo Pareto, a nineteenth-century Italian economist who determined that only a small percentage of people controlled most of the wealth. This concept has often been called the 80–20 rule and has been extended too many areas. In quality management the logic behind Pareto's principle is that most quality problems are a result of only a few causes. The trick is to identify these causes.

One way to use Pareto analysis is to develop a chart that ranks the causes of poor quality in decreasing order based on the percentage of defects each has caused. For example, a tally can be made of the number of defects that result from different causes, such as operator error, defective parts, or inaccurate machine calibrations.

Percentages of defects can be computed from the tally and placed in a chart like those shown in Figure. 4.3 We generally tend to find that a few causes account for most of the defects.

Histograms

A **histogram** is a chart that shows the frequency distribution of observed values of a variable. We can see from the plot what type of distribution a particular variable displays, such as whether it has a normal distribution and whether the distribution is symmetrical.

In the food service industry, the use of quality control tools is important in identifying quality problems. Grocery store chains, such as Kroger and Meijer, must record and monitor the quality of incoming produce, such as tomatoes and lettuce. Quality tools can be used to evaluate the acceptability of product quality and to monitor product quality from individual suppliers. They can also be used to evaluate causes of quality problems, such as long transit time or poor refrigeration.

Similarly, restaurants use quality control tools to evaluate and monitor the quality of delivered goods, such as meats, produce, or baked goods.

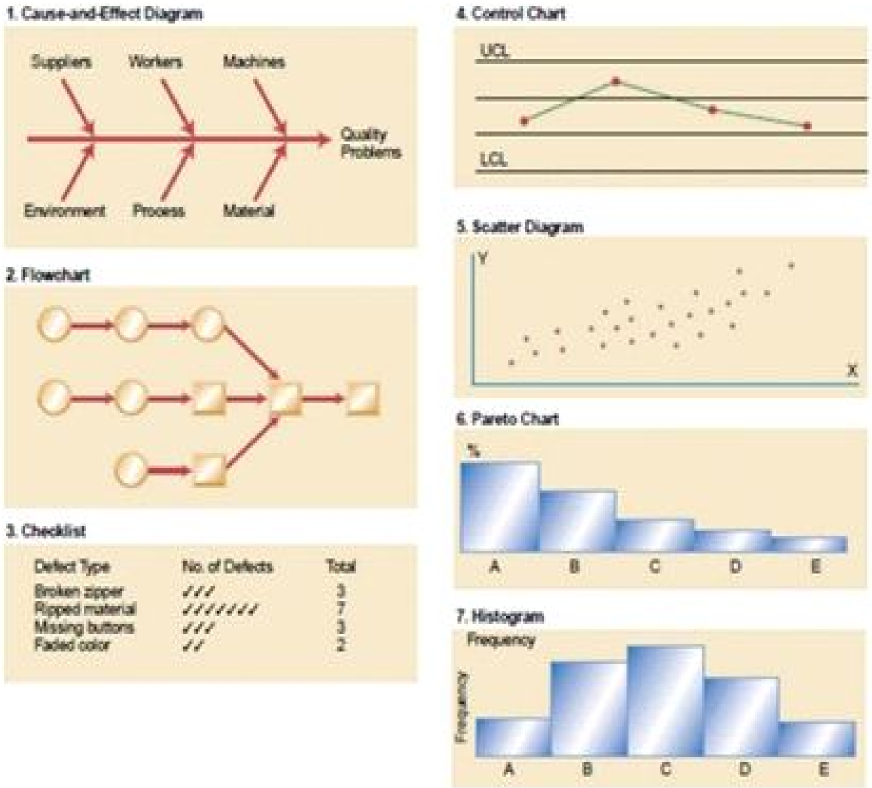


Figure 4.3 Seven tools of QC

4.8 ISO 9000 Standards

Increases in international trade during the 1980s created a need for the development of universal standards of quality. Universal standards were seen as necessary in order for companies to be able to objectively document their quality practices around the world. Then in 1987 the International Organization for Standardization (ISO) published its first set of standards for quality management called ISO 9000.

The International Organization for Standardization (ISO) is an international organization whose purpose is to establish agreement on international quality standards. Bureau of Indian Standards (BIS) are the Indian representative to ISO, ISO and International Electro Technical Commission (IEC)) operate jointly as a single system. These are non-governmental organizations, which exist to provide common standards on international trade of goods and services.

ISO 9000 standards expect firms to have a quality manual that meets ISO guidelines, documents, quality procedures and job instructions, and verification of compliance by third-party auditors. ISO 9000 series has five international standards on quality managements. They are:

1. ISO 9000 — Quality management and Quality assurance standards
2. ISO 9001 — Quality systems: Quality in design

3. ISO 9002 — Quality systems: Production and Installation
4. ISO 9003 — Quality systems: Final inspection and test
5. ISO 9004 — Quality management and systems

Objectives of ISO 9000 Series

The objectives of ISO 9000 series are listed in following Table 4.1

Standard	Objectives/Tasks
ISO 9000	This provides guidelines on selection and use of quality management and quality assurance standards.
ISO 9001	It has 20 elements covering design, development, production, installation and servicing.
ISO 9002	It has 18 elements covering production and installation. It is same as ISO 9001 without the first two tasks, *viz.*, design and development. This is applicable for the units excluding R & D functions.
ISO 9003	It has 12 elements covering final inspection and testing for laboratories and warehouses etc.
ISO 9004	This provides guidelines to interpret the quality management and quality assurance. This also has suggestions which are not mandatory.

Table 4.1 Objective of ISO 9000 standard series

4.9.1 Steps in ISO 9000 Registration

1. Selection of appropriate standard from ISO 9001, ISO 9002 and ISO 9003 using the guidelines given in ISO 9000.
2. Preparation of quality manual to cover all the elements in the selected model.
3. Preparation of procedures and shop floor instructions which are used at the time of implementing the system. Also document these items.
4. Self-auditing to check compliance of the selected model.
5. Selection of a registrar and making application to obtain certificate for the selected model.

A registrar is an independent body with knowledge and experience to evaluate any one of the three models of the company's quality system (ISO 9002). Registrars are approved and certified by acridities.

The registrar, on successful verification and assessment will register the company. Before selecting a registrar, one should know the following:

1. Accreditors of the registrar.
2. Background and credibility of the registrar.
3. Cost of registration through the proposed registrar.
4. Expected harmony between the company and the potential registrar while working towards implementing ISO model in the company.

4.9.2 Benefits of ISO 9000 Series

ISO 9000 series provides several tangible and intangible benefits which are listed below:

1. This gives competitive advantage in the global market.
2. Consistency in quality, since ISO helps in detecting non-conformity early which makes it possible to take corrective action.
3. Documentation of quality procedures adds clarity to quality system.

4. ISO 9000 ensures adequate and regular quality training for all members of the organization.
5. ISO helps the customers to have cost effective purchase procedure.
6. The customers while making purchases from companies with ISO certificate need not spend much on inspection and testing. This will reduce the quality cost and lead-time.
7. This will help in increasing productivity.
8. This will aid to improved morale and involvement of workers.
9. The level of job satisfaction would be more.

4.9.3 Just in Time (JIT)

The Just-in-time production concept was first implemented in Japan around 1970's to eliminate waste of

- Materials
- M/C
- Capital
- Manpower
- Inventory

throughout the manufacturing system.

The JIT concept has the following objectives:

- Receive supplies (raw material) just in time to be used.
- Produce parts just in time to be made into subassembly.
- Produce subassemblies just in time to be assembled into finished products.
- Produce and deliver finished products just in time to be sold.

In order to achieve these objectives, every point in the organization where buffer stocks normally occur is identified. Then, critical examinations of reasons for such stocks are made.

A set of possible reasons for maintaining high stock is listed below:

- Unreliable/unpredictable deliveries
- Poor qualities from supplier
- Increased varieties of materials
- Machine break down
- Labour absenteeism
- Frequent machine setting
- Variations in operators' capabilities
- Schedule charges
- Changing product priorities
- Product modification

In traditional manufacturing, the parts are made in batches, placed in the stock of finished product and used whenever necessary. This approach is known as "push system". Which means that parts are made according to schedule and are kept in inventory to be used as and when they are needed.

In contrast, Just In Time is a "pull system" which means that parts are produced in accordance with the order. It means the rate at which the products come out at the end of final assembly matches with the order quantity for that product. There no stock piles within the production process. This is also called zero inventory, stockless production, demand scheduling.

Moreover, parts are inspected by the workers as they are manufactured. And this process of inspection takes a very short period. As a result of which workers can maintain continuous production control immediately identifying defective parts and reducing process variation. Therefore, the JIT system ensures quality products. Extra work involved in stockpiling parts are eliminated.

Advantages of JIT

1. Exact delivery schedule is possible with JIT practices.
2. Quality of product is improved.
3. Lower defect rates i.e., lower inspection cost.
4. Lower raw material inventory, in process inventory and finished product inventory resulting lower product cost.
5. Satisfying market demand without delay in delivery.
6. Flexibility in utilizing manpower as workers is trained to do many jobs.
7. JIT helps in effective communication and reduce waste.
8. Less shop floor space is required.
9. Employee morale is high in an efficient working environment.
10. JIT reduces scrap and need for rework.

Six Sigma

HISTORICALVIEW

- The term "Six Sigma" was coined by Bill Smith (Father of Six sigma), an engineer with Motor
- Late1970s-Motorola started experimenting with problem solving through statistical analysis
- In1987-Motorola officially launched its Six Sigma program, and due to the use of Six Sigma Motorola is known worldwide as a quality leader and a profit leader. The secret of their success became Public knowledge after Motorola-won the 'Malcolm Baldrige National Quality Award in 1988.
- In1991-Motorola certified it's first "blackbelt" experts, which indicates the beginning of formation of the accredited training of six sigma methods
- In1995-Six sigma become well known after Mr. Jack Welch made it a central focus of his business strategy at General Electric (An American multinational conglomerate corporation incorporate in New York), today it is used in different sectors of industry.

What is Sigma?

The term "sigma" is used to designate the distribution or spread about the mean (average) of any process or procedure. For a process, the sigma capability(z-value) is a metric that indicates how well that process is performing. The higher the sigma, capability will be better. Sigma capability measures the capability of the process to produce defect-free outputs.

What is Six Sigma?

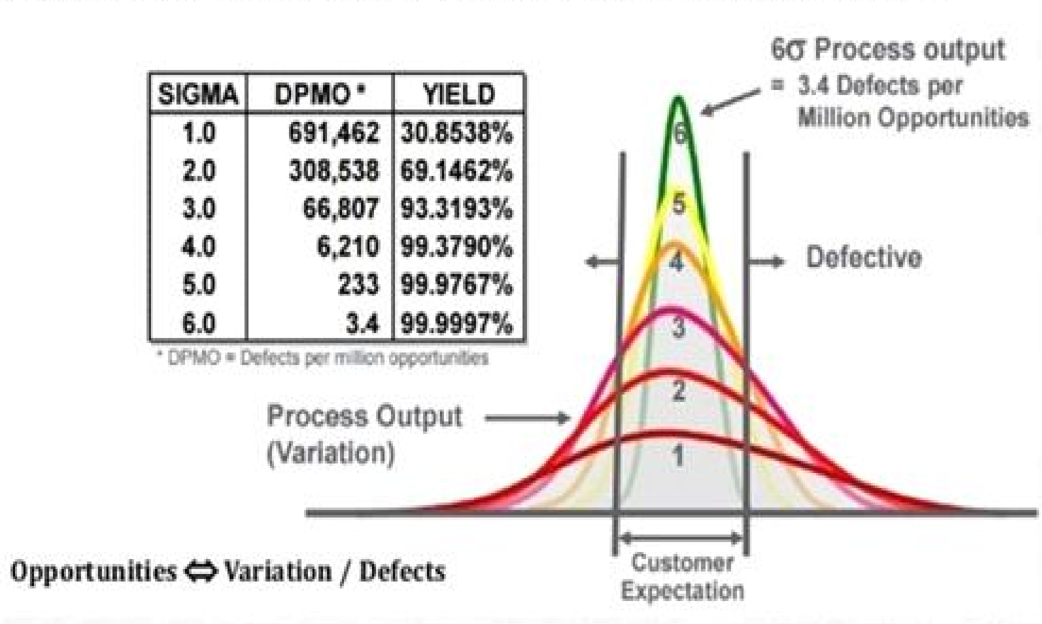
- Six Sigma has been around for more than 20 years and heavily influenced by TQM (total quality management) and Zero-Defect principles. In its methodology, it asserts that in order to achieve high quality manufacturing and business processes, continued efforts must be made to reduce variations.
- The idea behind Six Sigma is that if you can measure how many "defects" you have in a process, you can systematically figure out how to eliminate them and get as close to "zero

defects" as possible. It starts with the application of statistical methods for translating information from customers into specifications for products or service being developed or produced.

- ❖ It is a highly disciplined process that enables organizations to deliver nearly perfect products and services. Six Sigma is a methodology that provides businesses with the tools to improve the capability of their business processes. This increase in performance and decrease in process variation leads to defect reduction and vast improvement in profits, employee morale and quality of product.
- ❖ It is a rigorous and a systematic methodology that utilizes information (management by facts) and statistical analysis to measure and improve a company's operational performance, practices and systems by identifying and preventing 'defects' in manufacturing and service-related processes in order to anticipate and exceed expectations of all stakeholders to accomplish effectiveness.

Benefits of Six Sigma

Six Sigma emerged as a natural evolution in business to increase profit by eliminating defects (A defect is any incident or event which fails to meet the customers' expectations). By aiming processes at Six Sigma, there would not be more than 3.4 defects per one million opportunities. Then processes can be evaluated to reach a target level with upper and lower limits. In order to reach these limits, the process variation will have to be reduced. Then as a result of which the curve will become more peaked



SIGMA	DPMO *	YIELD
1.0	691,462	30.8538%
2.0	308,538	69.1462%
3.0	66,807	93.3193%
4.0	6,210	99.3790%
5.0	233	99.9767%
6.0	3.4	99.9997%

Fig 4.4 DPMO for different sigma

Use of Six Sigma:

- ➢ Its usage depends on the type of business. In general, "If there are processes that generate a lot of negative customer feedback, whether that customer is internal or external, the components of Six Sigma should be considered as a means to study and rectify the problem."

- Within any organization, Six Sigma:
  - Generates sustained success
  - Sets performance goal for everyone
  - Enhances value for customers
  - Accelerates rate of improvement
  - Promotes learning across boundaries
  - Executes strategic change

Defects Per Million Opportunities (DPMO)

- To maintain Six Sigma quality, a process must not produce more than 3.4 defects per million opportunities. Opportunities can be defined as the total number of chances per unit to exhibit a defect. Each opportunity must be independent of other opportunities and must be measurable and observable.
- The DPMO can also be thought of as the capability of the process. The more capable the process the less the DPMO. Finally, this can be converted into a Sigma or standard deviation. The higher the standard deviation the lower the DPMO, which indicates a more capable process.

- Defects Per Million Opportunities (DPMO) can be defined as

$$\text{DPMO} = \frac{\text{Number of Defects}}{[\text{Number of opportunities for error per unit}] \times \text{Number of units}} \times 1000000$$

SIX SIGMA METHODOLOGY

The Six Sigma methodology is widely used in many top corporations in the United States and around the world. It is normally defined as a set of practices that improve efficiency and" eliminate defects.

Six Sigma project follow two project methodologies:

1. DMAIC

2. DMADV

1.DMAIC

DMAIC is a basic component of the Six Sigma methodology- a way to improve work processes by eliminating defects

Figure 4.5 Six Sigma DMAIC

Define: Define is the first step in the process. In this step, it is important to define specific goals in achieving outcomes that are consistent with both your customer's demands and your own business's strategy. In essence, you are laying down a road map for accomplishment.

Measure: In order to determine whether or not defects have been reduced, you need a base measurement. In this step, accurate measurements must be made and relevant data must be collected so that future comparisons can be measured to determine whether or not defects have been reduced.

Analyze: Analysis is extremely important to determine relationships and the factors of causality. If you are trying to understand how to fix a problem, cause and effect is extremely necessary and must be considered.

Improve: Making improvements or optimizing your processes based on measurements and analysis can ensure that defects are lowered and processes are streamlined.

Control: This is the last step in the DMAIC methodology. Control ensures that any variances stand out and are corrected before they can influence a process negatively causing defects. Controls can be in the form of pilot runs to determine if the processes are capable and then once data is collected, a process can transition into standard production. However, continued measurement and analysis must ensue to keep processes on track and free of defects below the Six Sigma limit.

2.DMADV

There are certain situations where the management team members may feel that a process needs to be replaced by a new process rather than simplifying and improving the existing process. The demands of the customers with respect to quality cannot be satisfied by the existing process. At times, an organization must decide to launch a new product or service to grab a new business opportunity offered by the environment. In all such situations, the last two steps used in the DMAIC, namely, "improve" and "control" can be replaced by "design" and "verify" so that it becomes DMADV.

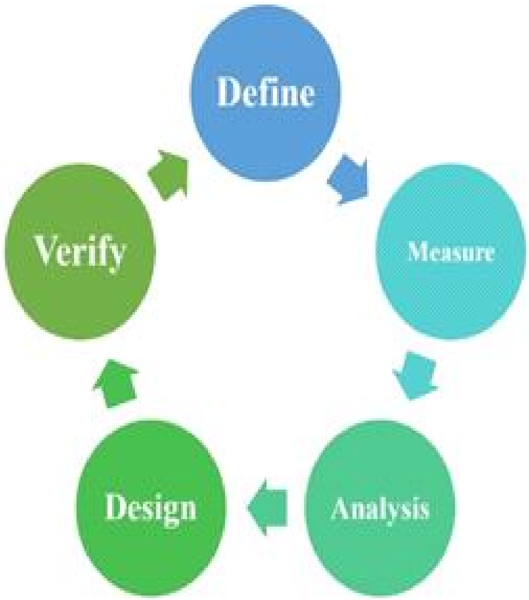


Figure 4.6 Six Sigma DMADV

Define: It refers to define the design goals that are consistent with customer demand and business strategy.

Measure: It refers to identify and identify characteristics that are critical to quality, product capabilities, production process capabilities, and risks.

Analyze: It refers to develop and design alternatives.

Design: It refers to design an improved alternative that is best suited as design perspective.

Verify: It refers to verify the design, set up pilot runs, implement the production process and it over to the process owner.

DIFFERENT LEVELS IN SIX SIGMA

Six Sigma uses a colored belt tier system for its certification. To receive Six Sigma Certification, and the associated belt, there is a hierarchical process.

Here are the Six Sigma Belt Levels:

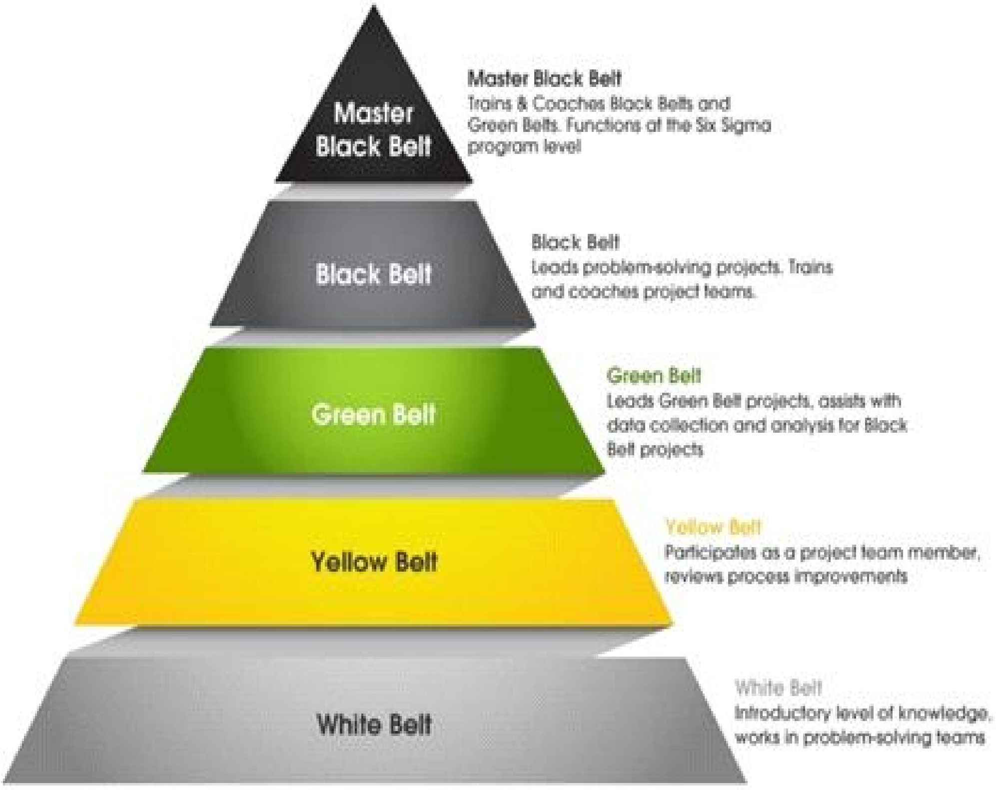


Fig. 4.7 Six Sigma level

Six Sigma White Belts: White Belts focus on solving problems at a local level. White Belts will connect with higher-tier individuals such as a Green or Black belt to solve each problem. The goal of a White Belt is to understand the fundamental concepts of Six Sigma.

Six Sigma Yellow Belts: Yellow Belt is where you get into the specifics of how Six Sigma works, what it is, how the disciplines can be applied to the workplace. A Yellow Belt is versed in the basics of Six Sigma, which includes all aspects of the phases of D-M-C. Yellow Belt is just getting started to eliminate defects from within enterprise systems.

Six Sigma Green Belts: A Green Belt supports a Six Sigma Black Belt by analyzing and solving quality problems and is involved in quality-improvement projects. Green Belts assist in reviewing data and suggestions sent by lower-tiered belts. Green Belts will have enough experience to lead and manage a project of their own.

Green Belts will be able to apply learned tools such as define, measure, analyze, improve and control to everyday work problems. They will also be able to assist Black Belts in Six Sigma teams and team projects to provide measurable improvement to the enterprise.

Candidates that have a thorough knowledge of the Six Sigma methods and procedures at the Green Belt level have a distinct advantage when searching for a career. Hiring managers seek candidates with the knowledge and expertise those with a Green Belt possess.

Typical jobs for those with a Six Sigma Green Belt include: Compliance structural engineer, lead manufacturing engineer, operating systems specialist, business process analyst, project engineer, and senior IT project manager.

Six Sigma Black Belts: A **Six Sigma Black Belt** understands Six Sigma philosophies and principles, including the supporting systems and tools. This person demonstrates team leadership and understands all aspects of the **DMAIC** model [in accordance with] Six Sigma principles.

Black Belts are known as agents of change. They have a deep understanding of team dynamics and handle assigning roles and responsibilities to team members. It is the goal of a Black Belt to improve overall quality and profitability. Typical jobs for those with a Six Sigma Black Belt include: Project Manager, Vice President of Operations, and Manager of Manufacturing.

Six Sigma Master Black Belts: Master Black Belts are the top of the hierarchy for Six Sigma. The Master Black Belt (MBB) requirements for individuals are at least five years as a Black Belt Six Sigma (BBSS) or experience on a minimum of 10 BBSS projects throughout their experience as a professional. The aforementioned is what you are required to submit for portfolio review and acceptance as a MBB student. Experience as a Six Sigma professional, which includes coaching and teaching, mentoring, your responsibilities as a BBSS professional, and your depth and breadth of technical experience and innovation is expected.

Implementation of Six Sigma:

The main aim of Six Sigma is to achieve less than 3.4 defects per million opportunities by training internal leaders to apply established techniques. The following is a step-by-step approach for implementing Six Sigma.

- **Step -1:** Every Successful performance improvement must begin with senior leadership, make sure all top-level management is on board and that financial and managerial resources are available. Training needs are rigorously assessed and training programmers are conductor for employees. Commitment is made to the project.
- **Step - 2:** Define the project scope and aim based on customer feedback and needs. Inspiration for Six Sigma projects can come from surveys, studies or existing projects. Always set goals for the whole organization or for a specific level of the organization that needs improvement.
- **Step - 3:** Analyze the system to identify defects. Measure the defects in the current system and performance. Identify the possible causes of problems. Explore possible solutions of the problems and asses their possible effect on the organization.
- **Step - 4:** Improve the system by finding different ways to do things faster, cheaper or better. Use management and planning tools to put improvement projects into place.
- **Step - 5:** Control the new process by modifying systems and measuring processes to continue and get good results. Use customer feedback to recognize and solve future problems.

7S

Seven S (7S) methodology adopted for the workplace organization by eliminating or reducing Waste, Inconsistency and Physical strain. The 7S implementation consists of seven phases shown in Figure 4.8 viz. Sort, set in order, Shine, Standardize, Sustain or Self Discipline, Safety and Spirit.

Each phase continuously improves the performance of an organization by eliminating wastages of searching, waiting, transportation, motion, work in progress inventory etc. 7S also makes the working environment clean and safe that improves the morale of the employees. The improvement in the form of the morale is a qualitative form that is responsible for the reduction in the Manufacturing Lead Time (MLT). So, the 7S helps to reduce MLT in quantitative form as well as in qualitative form. The quantifiable variables are searching, move, waiting time, cycle time, lead time, production rate, productivity, quality, profit and client network and the qualitative variables are working environment, communication and morale.

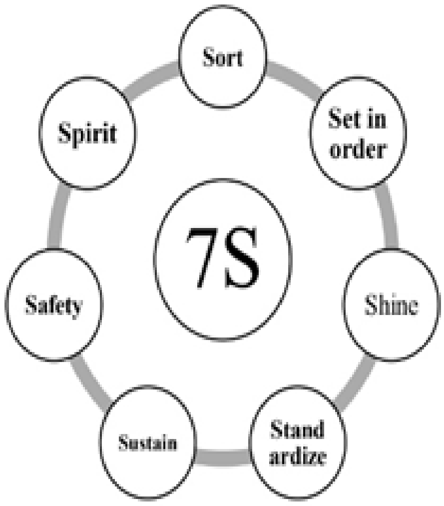


Fig. 4.8 Phases of 7S

The description of each phase of 7S implementation is as follows-

(1S) Sort: This means distinguishing or sort out between wanted (Value Added) and unwanted (Non-Value Added) items at place of work and removal of unwanted (NVA) items.

Action Steps:

- Identify a 5S-project area and take "before" pictures
- Review sorting criteria
- Create a local red tag area
- Tag, record, and move red tagged items
- Take "after" pictures

Resources required:

- Red Tags
- Red Tag Record Forms
- Camera for “before” and “after” pictures

Target Outcomes:

- Increase in floor space utilization.
- Searching time of tools, materials, and papers is reduced.
- Better flow of work.
- Inventory cost of unnecessary items is reduced.

(2S) Set in order:

Arranging and labeling items in such a manner that they are easy to find and use.

Action Steps:

- Take "before" pictures
- Implement workplace changes
- Mark locations by creating addresses and applying labeling, marking, and color-coding
- Take "after" pictures

Resources required:

- Existing plant standards for labeling, marking, and color-coding
- Labeling supplies
- Tape for creating borders on work surfaces and floors
- Paint and painting supplies

Target Outcomes:

- Take things out and keep things back easily.
- Make lesser mistakes.
- Reduce searching time.
- Work environment becomes safe

(3S) Shine:

This means removing dirt, strain, filth, soot and dust from the work area. This includes cleaning and care for equipment and facilities and also inspecting them for abnormalities. In a way it also includes primary maintenance of equipment.

Action Steps:

- Define "clean"
- Get cleaning supplies
- Take "before" pictures
- Clean the work area
- Identify contamination sources
- Fix small imperfections
- Take "after" pictures

Resources required:

- Cleaning supplies such as brooms, dust pans, rags, degreasers, and floor cleaner.
- Personal protective equipment such as gloves and eye protection.

Target Outcomes:

- Work place becomes free of dirt and stains which is the starting point for quality.
- Equipment lifespan will be prolonged and breakdowns will be less.
- Creates a pleasant environment.
- Prevents accidents.

(4S) Standardize:

This call for systematizing the above 4S practices. This means ensuring that whatever cleanliness and orderliness is achieved should be maintained. This should develop a work structure that will support the new practices and turn them into habits.

The purpose of standardization is to make sure that everyone in the company follows the same procedure, the same names of items, the same size of signalization/floor marking, shapes, colors, etc. Standardize also helps to do the right thing the right way every time.

Action Steps:

- Brainstorm ideas for making the 5S changes standard operating procedure
- Update documentation to reflect changes
- Make sure all stakeholders are aware of the new standards - inform and educate

Resources required:

- Support from those who can create documentation, job aids, and visual aids
- Information and approval from those responsible for maintaining company procedures
- Poster-making supplies for posting new standards in work areas

Target Outcomes:

- Activities will be simplified.
- Consistency in the work practices.
- Avoid mistakes.
- Better visual and transparency management work efficiency will improve.

(5S) Sustain or Self Discipline:

Sustain also means 'Discipline'. It denotes commitment to maintain orderliness and to practice first 3S as a way of life.

Action Steps:

- Monitor processes established during S4 -Standardize
- Expand 5S efforts to other work areas
- Evaluate 5S effectiveness and continuously improve
- Recognize and reward strong efforts

Resources required:

- Management audit forms
- Resources for communication and recognizing successes (newsletters, displays, awards)

- Presentation tools for sharing best practices with other work areas
- Management commitment and focus on maintaining the new standards

Target Outcomes:

- Promotes habit for complying with workplace rules and procedures.
- Creates healthy atmosphere and a good work place.
- Helps you to develop team work.
- Provides you with data for improving 5S.

(6S) Safety:

Safety is the condition of being protected against physical, social, spiritual, financial, political, emotional, occupational, psychological, educational, or other types or consequences of failure, damage, error, accident, harm, or any other event that could be considered non-desirable.

Action Steps:

- Error Proofing (Poka-yoke)
- Safety related instructions & symbols
- Alert, Warning, Hazard area identification and labeling with proper symbols
- Safety trainings to employees

Resources required:

- Safety related instruction and Symbols
- Personal Protective Equipment (PPE)
- Safety Trainer or Expert

Target Outcomes:

- Avoid errors or mistakes
- Reduces accidents
- Safer working environment

(7S) Spirit (Team Spirit):

Team spirit is a willingness to cooperate as part of a team.

Action Steps:

- Formation of 7S team with a team leader
- Regular meetings to set benchmark and strategies for achievement
- Motivational and co-operational speeches or trainings for each 7S team on regular basis

Resources required:

- 7S team manual for the conclusion or solutions obtained after brainstorming session or meetings
- Leader with knowledge, abilities, experience, good understanding and cooperating skills
- Questionnaire survey at regular basis for measuring and analyzing the team spirit
- 7S Audit form for checking overall performance

Target Outcomes:

- Better communication
- Higher confidence to do work
- Better Understanding & Analysis on problems
- Creates healthy working environment
- Reduces boredom approach toward the job

Benefits of implementing 7S are as follows-

- Workplace becomes cleaner, safer, well-organized and more pleasant;
- Floor space utilization is improved;
- Workflow becomes smoother and more systematic and non-value-added activities are reduced;
- Time for searching tools, materials and document is minimized;
- Machine breakdowns are reduced since clean and well-maintained equipment breaks down less frequently and it also becomes easier to diagnose and repair before breakdowns occur, therefore extending equipment life;
- Errors are minimized leading to making defect-free products;
- Consumables and material wastage are minimized;
- Morale and satisfaction of employees improve;
- Productivity of the organization improves together with the quality of products and services.

Lean Manufacturing

Lean manufacturing, or simply "lean," is a systematic method designed to minimize waste in a manufacturing system while productivity remains constant. Originating in Japan in the Toyota Production System (TPS), lean manufacturing strives to minimize waste within a manufacturing operation, with the idea being to clearly portray what adds value by removing what doesn't. As your company begins to think about lean manufacturing it's important to keep in mind the process of going lean takes time – like turning a cruise ship around.

There are several different lean techniques, allowing each organization to fit lean manufacturing techniques into its own distinct production process. We're going to discuss the eight types of waste lean manufacturing seeks to eliminate and five common lean principals, tools and techniques manufacturers around the world have implemented into their manufacturing processes.

Lean Manufacturing: 8 Types of Waste

As we mentioned earlier, going lean starts with eliminating waste to focus on what adds value to your process, which leads to adding value for your customers. It's important to know the types of waste and how they affect your business.

There are eight types of waste:

- Defects
- Overproduction
- Waiting
- Non-utilized talent
- Transportation
- Inventory
- Motion
- Extra Processing

Defects: Probably the most visible type of waste, defects are scrap products or products that don't meet commercial specifications. They can lead to many types of waste, most notably one we will discuss later – waiting. Defects cause delivery delays and logistics headaches which most likely leads to a decline in customer satisfaction. It's also going to cost money to rework defected products. Fixing defects causes your company to spend extra time fixing issues and filing paperwork.

Overproduction: Companies love to produce in bulk. While it seems like a good idea initially, customer needs change fairly constantly and the market fluctuates and forces change even more frequently. Overproduction causes excess inventory which leads to storage expenses like paying for space and paying for people and equipment to move the product around.

Waiting: Waiting is a byproduct of many types of waste and it wreaks havoc on customer satisfaction. A good way to look at waiting is, a product or your customer might be ready for the next step (packaging or shipping for example), but the next step in your process isn't ready to perform the task. In healthcare, this might look like a full waiting room. In manufacturing, this might look like machinery downtime causing packaging delays.

Non-utilized talent: Often overlooked as a form of waste, not using your employees to their full potential, talents or skills can have a big effect on your company's bottom line. Poor teamwork, minimal training, bad communication and unnecessary administrative tasks are common examples of non-utilized talent waste.

Transportation: Transportation is the movement of goods from one location to another. In manufacturing, this might mean performing different tasks in different locations. For example, producing product parts in China and shipping them to America to assemble. This process doesn't add value to the end product, it doesn't change the end result and it adds more cost. If you look at Toyota's manufacturing setup, many of their suppliers are near the production plants.

Inventory: Similar to overproduction, inventory waste happens when your product is sitting there waiting to be sold. The difference between overproduction and inventory waste is, inventory has a physical cost associated with it, whereas overproduction is assumed. Overproduction often causes inventory waste by making more than your customers want or assuming demand will be there down the road.

Motion: The unnecessary movement of people, machines or items that don't add value is the waste of motion. In other words, wasting time. This form of waste is usually caused by not following the 5s' lean manufacturing principal. Common examples include, employees looking for materials or equipment or poorly designed workspaces.

Extra Processing: Extra processing or over processing refers to adding work that isn't required. Extra processing costs hit you in the form of the time of your staff, materials used and equipment wear, and they add up over time. It also makes your process less efficient because employees performing the extra processing tasks could be doing value-adding tasks instead.

CHAPTER - 5

CHAPTER 5

PRODUCTION PLANNING AND CONTROL

5.1 INTRODUCTION

Production planning and control is a tool available to the management to achieve the stated objectives. Thus, a production system is encompassed by the four factors. *i.e.*, quantity, quality, cost and time. Production planning starts with the analysis of the given data, *i.e.*, demand for products, delivery schedule etc., and on the basis of the information available, a scheme of utilisation of firms resources like machines, materials and men are worked out to obtain the target in the most economical way.

Thus, production planning and control can be defined as the "*direction and coordination of firms' resources towards attaining the prefixed goals*." Production planning and control helps to achieve uninterrupted flow of materials through production line by making available the materials at right time and required quantity.

5.2 MAJOR FUNCTIONS OF PRODUCTION PLANNING AND CONTROL

Functions of production planning and controlling is classified into:

1. Pre-planning function
2. Planning function
3. Control function

The functions of production planning and controlling are depicted in the Fig. 5.1

1. PRE-PLANNING FUNCTION

Pre-planning is a macro level planning and deals with analysis of data and is an outline of the planning policy based upon the forecasted demand, market analysis and product design and development.

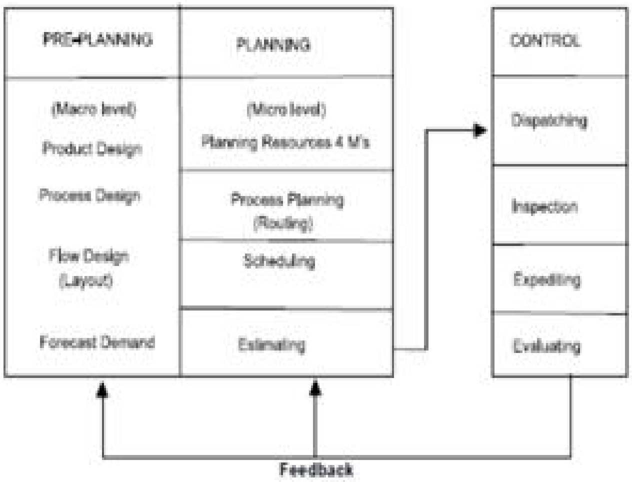


Fig. 5.1 *Functions of production planning and control*

This stage is concerned with process design (new processes and developments, equipment policy and replacement and work flow (Plant layout). The pre-planning function of PPC is concerned with decision-making with respect to methods, machines and work flow with respect to availability, scope and capacity.

2. PLANNING FUNCTION

The planning function starts once the task to be accomplished is specified, with the analysis of **four M's**, i.e., Machines, Methods, Materials and Manpower. This is followed by process planning (routing). Both short-term (near future) and long-term planning are considered. Standardisation, simplification of products and processes are given due consideration.

3. CONTROL FUNCTION

Control phase is affected by dispatching, inspection and expediting materials control, analysis of work-in-process. Finally, evaluation makes the PPC cycle complete and corrective actions are taken through a feedback from analysis. A good communication, and feedback system is essential to enhance and ensure effectiveness of PPC.

5.3 METHODS OF FORECASTING

Forecast: A prediction, projection, or estimate of some future activity, event, or occurrence.

Types of Forecasts

- Economic forecasts: -Predict a variety of economic indicators, like money supply, inflation rates, interest rates, etc.
- Technological forecasts: - Predict rates of technological progress and innovation.
- Demand forecasts: - Predict the future demand for a company's products or services.

Since virtually all the operations management decisions (in both the strategic category and the tactical category) require as input a good estimate of future demand, this is the type of forecasting that is emphasized in our textbook and in this course.

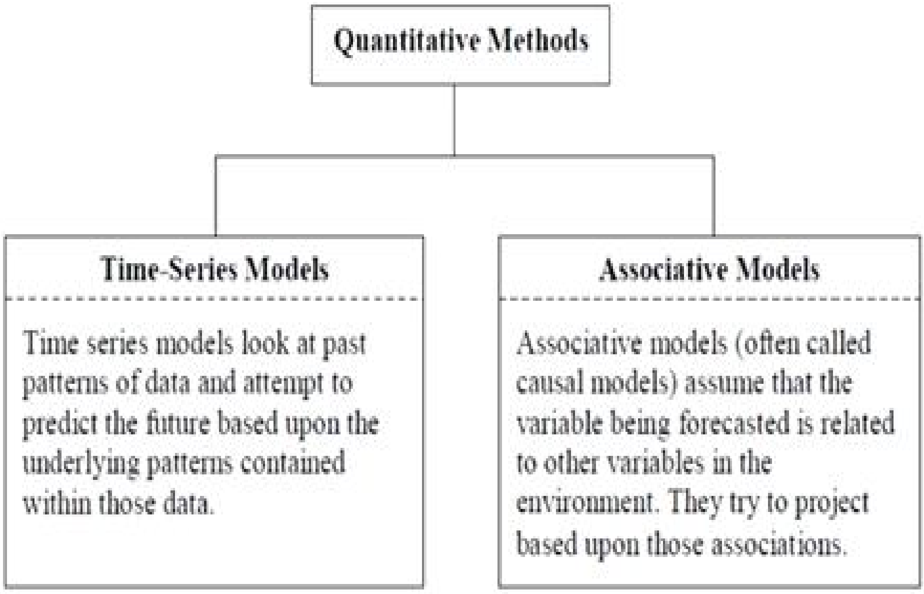
Types Of Forecasting Methods

Qualitative methods: These types of forecasting methods are based on judgments, opinions, intuition, emotions, or personal experiences and are subjective in nature. They do not rely on any rigorous mathematical computations.

Quantitative methods: These types of forecasting methods are based on mathematical (quantitative) models, and are objective in nature. They rely heavily on mathematical computations.

<u>Qualitative Forecasting Methods</u>

Quantitative Forecasting methods:



Average method:

Forecast sales for next period = Average sales for previous period

Example	Period No	Sales
	1	7
	2	5
	3	9
	4	8
	5	5
	6	8

Forecast sales for Period No 7 = $\frac{7+5+9+8+5+8}{6} = 7$

II. Forecast by Moving Average:

In this method the forecast is neither influenced by very old data nor does it solely reflect the figures of the previous period.

Example:

Year	Period	Sales	Four period average forecasting
1987	1	50	
	2	60	
	3	50	
	4	40	
1988	1	50	
	2	55	

$$\text{Forecast for 1988 period 1} = \frac{50+60+50+40}{4} = 50$$

$$\text{Forecast for 1988 period 2} = \frac{60+50+40+50}{4} = 50$$

III. Weighted Moving Average:

A weighted moving Average allows any weights to be placed on each element, providing of course, that the sum of all weights equals one.

Example:

Period	Sales
Month-1	100
Month-2	90
Month-3	105
Month-4	95
Month-5	110

Forecast (weights 40%, 30%, 20%, 10% of most recent month)

Forecast for month-5 would be:

$$F_5 = 0.4 \times 95 + 0.3 \times 105 + 0.2 \times 90 + 0.1 \times 100 = 97.5$$

Forecast for month-6 would be:

$$F_5 = 0.4 \times 110 + 0.3 \times 95 + 0.2 \times 105 + 0.1 \times 90 = 102.5$$

IV. Exponential Smoothing:

Simple exponential smoothing model estimates the average forecast for the next period by using the actual and the forecasted demand for the previous period.

Forecast for the period t (F_t)

=Forecasted demand for the last period + α[Actual demand for the last period-Forecasted demand for the last period]

$\therefore \quad F_t = F_{t-1} + \alpha\left[D_{t-1} - F_{t-1}\right]$

where α is called smoothing constant.

Generalized equation:

$$F_t = \alpha.(1-\alpha)^0 D_{t-1} + \alpha.(1-\alpha)^1 D_{t-2} + \alpha.(1-\alpha)^2 D_{t-2} + ... + \alpha.(1-\alpha)^{k-1} D_{t-k} + (1-\alpha)^k F_{t-k}$$

[Where k is the number of past periods]

Example:

The demand for the disposable plastic tubing for a general hospital is 300 units and 350 units for September and October respectively. Using 200 units as demand for September, compute the forecast for the month of November. Assume the value of α as 0.7.

Solution:

Here D_{t-1} = Demand for September =300 units

F_{t-1} = Forecast for September =200 units

(i) Forecast (Ft) can be written as,

$$F_t = F_{t-1} + \alpha\left[D_{t-1} - F_{t-1}\right]$$

Forecast for October can be computed as,

$$F_t = F_{t-1} + \alpha\left[D_{t-1} - F_{t-1}\right]$$
$$= 200 + 0.7 \times [300 - 200]$$
$$= 270 \text{ units.}$$

(ii) Forecast for the month of November

$$F_t = F_{t-1} + \alpha\left[D_{t-1} - F_{t-1}\right]$$
$$= 270 + 0.7 \times [350 - 270]$$
$$= 326 \text{ units.}$$

5.3.1 ROUTING

Routing may be defined as the selection of path which each part of the product will follow while being transformed from raw materials to finished products. Path of the product will also give sequence of operation to be adopted while being manufactured.

In other way, routing means determination of most advantageous path to be followed from department to department and machine to machine till raw material gets its final shape, which involves the following steps:

(*a*) Type of work to be done on product or its parts.

(*b*) Operation required to do the work.

(*c*) Sequence of operation required.

(*d*) Where the work will be done.

(*e*) A proper classification about the personnel required and the machine for doing the work.

For effective production control of a well-managed industry with standard conditions, the routing plays an important role, *i.e.*, to have the best results obtained from available plant capacity. Thus, routing provides the basis for scheduling, dispatching and follow-up.

5.3.2 SCHEDULING

Scheduling can be defined as "prescribing of when and where each operation necessary to manufacture the product is to be performed."

It is also defined as "establishing of times at which to begin and complete each event or operation comprising a procedure". The principle aim of scheduling is to plan the sequence of work so that production can be systematically arranged towards the end of completion of all products by due date.

5.3.2.1 Principles of Scheduling

1. **The principle of optimum task size:** Scheduling tends to achieve maximum efficiency when the task sizes are small, and all tasks of same order of magnitude.

2. **Principle of optimum production plan:** The planning should be such that it imposes an equal load on all plants.

3. **Principle of optimum sequence:** Scheduling tends to achieve the maximum efficiency when the work is planned so that work hours are normally used in the same sequence.

5.3.2.2. Inputs to Scheduling

1. *Performance standards:* The information regarding the performance standards (standard times for operations) helps to know the capacity in order to assign required machine hours to the facility.

2. Units in which loading and scheduling is to be expressed.

3. Effective capacity of the work centre.

4. Demand pattern and extent of flexibility to be provided for rush orders.

5. Overlapping of operations.

6. Individual job schedules.

5.3.3 DISPATCHING

This is the execution phase of planning. It is the process of setting production activities in motion through release of orders and instructions. It authorizes the start of production activities by releasing materials, components, tools, fixtures and instruction sheets to the operator.

The activities involved are:

(a) To assign definite work to definite machines, work centres and men.

(b) To issue required materials from stores.

(c) To issue jigs, fixtures and make them available at correct point of use.

(d) Release necessary work orders, time tickets, etc., to authorize timely start of operations.

(e) To record start and finish time of each job on each machine or by each man.

5.3.4 CONTROLLING

Inspite of planning to the minute details, yet always (most of the time) it is not possible to achieve production 100% as per the plan. There may be innumerable factors which affect the production system and because of which there is a deviation from the actual plan.

Some of the factors that affect are -

1. Non availability of materials (due to shortage etc.)

2. Plant, equipment and machine breakdown.

3. Changes in demand and rush orders.

4. Absenteeism of workers.

5. Lack of co-ordination and communication between various functional. areas of business.

Production control looks to utilize different type of control techniques to achieve optimum performance out of the production system as to achieve overall production planning targets. Therefore, objectives of production control are as follows:

- Regulate inventory management
- Organize the production schedules
- Optimum utilization of resources and production process

The advantages of robust production control are as follows:

- Ensure a smooth flow of all production processes
- Ensure production cost savings thereby improving the bottom line
- Control wastage of resources
- It maintains standard of quality through the production life cycle.

Production control cannot be same across all the organization. Production control is dependent upon the following factors:

- Nature of production (job oriented, service oriented, etc.)
- Nature of operation
- Size of operation

Production planning and control are essential for customer delight and overall-success of an organization.

Thus, if there is a deviation between actual production arid planned production, the control function comes into action.

Production control through control mechanism tries to take corrective· action to match the planned and actual production.

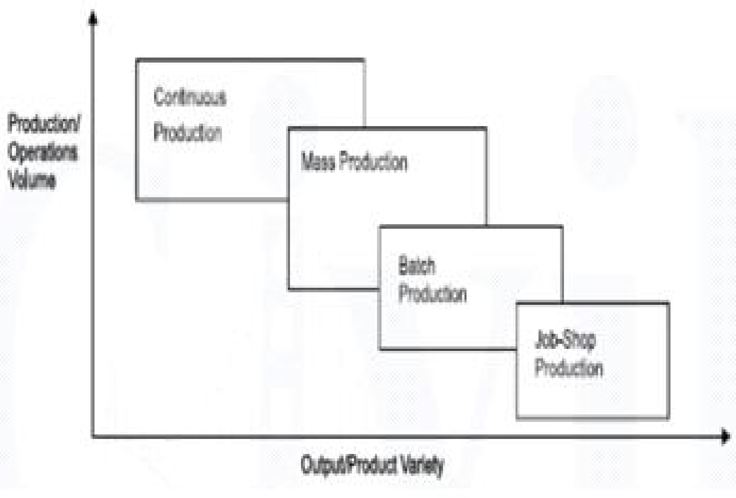
Thus, production control reviews the progress of the work, and takes corrective steps in order to ensure that programmed production takes place.

The essential steps in control activity are:

- Initiating the production.
- Progressing.
- Corrective action based upon the feedback and reporting back to the Production Planning.

5.4 TYPES OF PRODUCTION

Production systems can be classified as Job Shop, Batch, Mass and Continuous Production systems.



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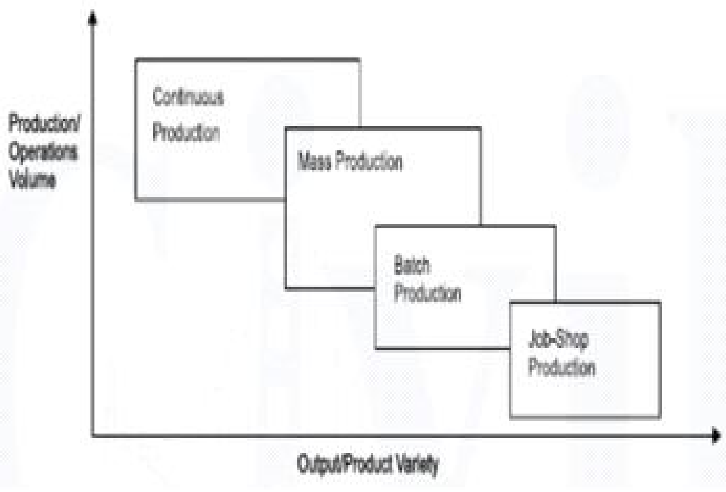

lot may have a different routing." It is characterised by the manufacture of limited number of products produced at regular intervals and stocked awaiting sales.

Characteristics

Batch production system is used under the following circumstances:

1. When there is shorter production runs.
2. When plant and machinery are flexible.
3. When plant and machinery set up is used for the production of item in a batch and change of set up is required for processing the next batch.
4. When manufacturing lead time and cost are lower as compared to job order production.

Advantages

Following are the advantages of batch production:

1. Better utilization of plant and machinery.
2. Promotes functional specialization.
3. Cost per unit is lower as compared to job order production.
4. Lower investment in plant and machinery.
5. Flexibility to accommodate and process number of products.
6. Job satisfaction exists for operators.

Limitations

Following are the limitations of batch production:

1. Material handling is complex because of irregular and longer flows.
2. Production planning and control is complex.

5.4.3 Job order production

The job order production system is characterized by the low production volume. It is related with manufacture of products to meet the specific consumer requirements.

The quantity to be produced is small usually one half or several halves and is usually concerned with special projects, special machinery or equipment to perform specialized and specific tasks. Large turbo generators, boilers, processing equipment, material handling equipment and ship building etc. are examples of this production group.

Three types of job order production can be defined according to the regularity of manufacture as follows:

(a) Small number of products produced only once.

(b) A small number of pieces produced intermittently when need arises.

(c) A small number of pieces produced periodically at known time intervals.

When the order is to be executed only once, there is little scope for improvement of manufacturing technique by introducing intricate method studies, special tools, jigs and fixtures etc. But if the order is to be repeated tooling and jigging as well as specially designed inspection gauges should be carefully considered to reduce the unproductive time and to accelerate the work-oriented activities.

Characteristics:

1. Commonly used to meet a particular consumer need

2. A wide variety of skilled workers conversant with manufacturing of various jobs will be needed

3. Production equipments are mostly general purpose and flexible to meet specific consumer orders which varies from time to time

4. Flexible financing may be required in view of variations in work load

5. A large inventory of raw materials, tools, finished components and parts will be required

6. Production lot size is generally small

7. Product variety is generally very high.

Limitations:

1. Insufficient utilization of machines and manpower possible due to less work load so there is no scope of commercial economy of this production system

2. Since the purchase of raw materials is less so raw materials shall cost slightly more

3. In view of handling of different types of jobs only skilled and intelligent workers are required so labour cost increases.

4. Scientific cost analysis is difficult due to heterogeneous production loads.

5.5 PRINCIPLES OF PRODUCT AND PROCESS PLANNING

Customer Demand

Before production planner plan to assign resources, it is essential e to know how much to produce. Production planning focuses on the principle of meeting the targeted customer demand rate in the most efficient way possible while keeping open the capability to respond to variations in demand which we refer it to as flexibility to meet the fluctuating demand to certain extent.

Materials

To fulfill production target, the materials availability needed to produce should be ensured. The most efficient production planning keeps the minimum materials as standard inventory. Planners should evaluate how much material the company needs, the lead times for orders, the delivery times for suppliers and the reliability of the supply.

Equipments

The production planner takes into account the capabilities of the equipment used to produce the output. Basic stability of equipment comprising of availability (A), performance (P) and quality (Q) parameters can be determined by Overall Equipment Effectiveness (OEE).

Manpower

Manpower planning requires accurately estimating the number of employees required to do the work. The capacity of the workforce has to match the capabilities of the equipment to plan for the highest efficiency.

Processes

Effective production planning makes sure that the processes used for the output continue to operate efficiently and safely. Often the normal operation of a process requires occasional testing and adjustments.

Controls

A final production planning principle puts in place controls that detect problems as soon as they occur. Verification of inventory, use of qualified suppliers and personnel, standardization where possible. When controls are in place, it enables to take possible corrective actions to minimize the effects and return production to the required levels.