Branch: MECHANICAL ENGINEERING
Semester: 6th Sem
Subject: INDUSTRIAL ENGINEERING & MANAGEMENT
Faculty: ER. SOMANATH BHUTIA & ER. SIBASISH SAHU

Industrial Engineering:

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.

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

PLANT LOCATION & LAYOUT

A plant is a place, where men, materials, money, equipment, machinery etc are brought together for manufacturing products.

The problem of plant location arises when starting a new concern or during the expansion of the existing plant.

Plant location means deciding a suitable location, area, place etc. where the plant or factory will start functioning.

Plant location involves two major activities

I. To select a proper geographic region
II. Selecting a specific site within the region

Plant location problem

1. Selection of region
2. selection as a community
3. selection of a particular site
   Conditions that demand city location
   Conditions that demand sub-urban location
   Conditions demanding rural location

Factors affecting plant location

1. Nearness to raw material – It will reduce the cost of transporting raw material from the vendor's end to the plant sugar, cement, jute and cotton textiles.
2. Transport facilities – A lot of money is spent both in transporting the raw material and the finished goods speedy transport facilities ensure timely supply of raw materials to the company and finished goods to the customers, There are time basic modes of physical transportation, air, road, rail, water and pipe line.
3. Nearness to market – It reduces the cost of transportation as well as the chances of the finished products getting damaged and spoiled in the way.
4. Availability of labour – Suitable labour force, of right kind, of adequate size (number), and at reasonable rates with its proper attitude towards work are a few factors which govern plant location to major extent. The purpose of the management is to face less boycotts, strikes or lockout and achieve lower labour cost per unit of production.
5. Availability of fuel and power – Steel industries are located near source of fuel (coal) to cut down fuel transportation costs. Electric power should remain available continuously in proper quantity and at reasonable rates.

6. Availability of water - Depending on the nature of the plant, water should be available in adequate quantity and should be of proper quality water is essential for paper and chemical industries.
7. Climatic condition – Climate greatly influence human efficiency and behavior. Textile mills require humidity with the developments in the field of heating, ventilating and air conditioning, climate of the region doesn't present much problem of course control of climate needs money.
8. Financial and other aids – Certain states give aids as loans, feed money, machinery, built up sheds etc. to attract industrialist.
9. Land – Topography, area, the shape of the site, cost, drainage and other facilities, the probability of floods, earthquakes etc. influence the selection of plant location.
10. Community attitude – Community attitude towards their work and towards the prospective industries cab make or mar the industry. Success of an industry depends on the attitude of the local people whether they want work or not.
11. Supporting industries – All industries will not make all the components and parts by itself and it subcontracts the work to vendors
12. Social Infrastructures – Availability of community facilities like
    A. Housing facilities
    B. Recreational facilities
    C. Educational facilities
    D. Medical facilities

    are to be considered.
13. Law and taxation – the policies of the state gent and local bodies concerning labour laws, building codes, safely its are the factors that demand attention.

Plant layout:

Plant layout means the disposition of the various facilities (equipments, material, manpower etc) and services of the plant within the area of the site selected previously.

It begins with the design of the factory building and goes up to the location and movement of a work table. All the facilities like equipments, raw materials, machinery, tools, fixtures, workers etc are given a proper place.

Plant layout is a plan of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling equipment and all other supporting services along with the design of best structure to contain all these facilities.

Plant layout problem (Need for the plant layout):

1. Changes in the product design.
2. Changes in the volume of demand for the company's product
3. Increasing frequency of accidents because of existing layout.
4. Plant and machinery becomes outdated and is to be replaced by new one

5. Poor working environment affecting worker efficiency and productivity.
6. Change in the location or markets.
7. Minimizing the cost through effective facilities location.

Objectives of plant layout:

1. Material handling and transportation is minimized and efficiently controlled.
2. Bottle necks and points of congestions are eliminated so that the raw material and semi finished goods move fast from one work station to another.
3. Workstations are designed suitably and properly.
4. Suitable places are allocated to production centers and service centers.
5. Movements made by the workers are minimized.
6. Waiting time of semifinished products is minimized.
7. Working conditions are safer, better and improved.
8. Increased flexibility of changes in product design and for future expansion.
9. Utilization of cubic space (length, width and height).
10. These are improved work methods and reduced production cycle times.
11. Plant maintenance is simpler.
12. Increased productivity and better product quality with reduced capital cost.
13. A good layout permits materials to move through the plant at the desired speed with the lowest cost.

Principle of plant layout:

1. Principle of integration:

   A good layout is one that integrates men, materials, machines and supporting services and other in order to get the optimum utilization of resources and maximum effectiveness.

2. Principle of minimum movements and material handling:

   The facilities should be arranged such that the total distances travelled by the men and materials should be minimum and as far as possible straight line movement is preferred. It is better to transport materials in bulk rather than in small amounts.

3. Principle of smooth and continuous flow :

   A good layout makes the materials to move in forward direction towards the completion stage. Bottle necks, congestion points and back tracking should be removed by proper line balancing techniques.

4. Principle of cubic space utilization :

   The good layout utilizes both horizontal and vertical space. Besides using the floor space of a room the ceiling height is also utilized. Boxes and bags containing raw material or goods cab be stacked are above the other to store more items in the same room.

5. Principle of safety and security and satisfaction :

   Working places safe-well ventilated and force from dust, noise, fumes, odours, and other hazardous conditions increase the operating efficiency of the workers and improve their morale.

6. Principle of maximum flexibility :

   The good layout is one that can be altered without much cost and time. The machinery is arranged in such a way that the changes of the production process can be achieved at the least cost or disturbance.

Advantage of plant layout:

1. Advantages to the worker
2. Advantages to the management
3. Advantages to manufacturing
4. Advantages to production control

Factors influencing plant layout

1. Type of production- Engg. Industry, process industry
2. Production system- Job shop, batch, mass production
3. Scale of production
4. Availability of total area
5. Arrangement of material handling system
6. Type of building- single storey, multi storey
7. Future expansion plan
8. Type of production facilities- Dedicated or general papers

Types of manufacturing system

1. Job type production:

   Manufacturing of one or few quantities of products designed and produced as per specifications high variety and low volume.

2. Batch production:

   Manufacture of limited no. of products produced at regular intervals and stocked at warehouse.

   Ex: Chemical, pharmaceutical, assembly stops.

3. Repetitive or mass production:

   Manufactures several standard products produced and stacked in the warehouses.

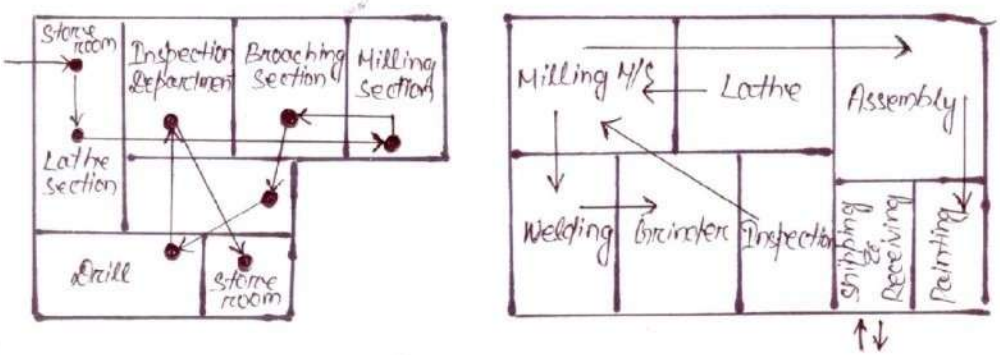
   High volume and low variety

   Ex: plastic goods, manufacture & assembly stages of automobiles

Types of layout:

1. Process layout (Functional layout):

The layout is recommended for batch production. All machines performing similar type of operations are grouped at one location in the process layout.
Ex – all lathes, milling machine kept at one place
The arrangements of facilities are grouped together according to their functions.



Advantages:

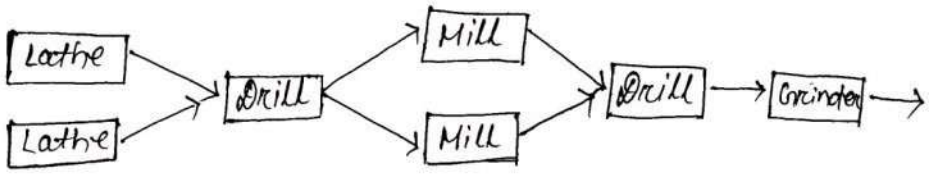
I. Wide flexibility exists during allotment of work to equipment and workers.
II. Better utilization of equipments
III. Lower investments on account of comparatively less no. of machine are used.
IV. Better product quality because to attend one type of machine.
V. Varieties of jobs coming as different job orders make the work more challenging and interesting.
VI. Workers in one section are one affected by the nature of another section.

Disadvantages:

I. For the same amount of production, more space is required.
II. Automatic material handling is difficult.
III. More materials in process remain in queue for further operation.
IV. Completion of same product takes more time.
V. Work-in-process inventory is large.
VI. Production planning and control is difficult.
VII. Raw materials have to travel larger distances for being processed to finished goods. Thus increases cost.
VIII. It means more inspections and efficient co-ordination.

2. Product layout (line layout):

The various operations on raw material are performed in a sequence and the machines are arranged in the sequence in which the raw material will be operated upon.



Advantage:

I. Less space requirements for the same volume of production.
II. Automatic material handling, less movements, so cost is reduced.
III. Less in process inventory.
IV. Product completes in lesser time.
V. Simplified production, planning and control
VI. Smooth and continuous work flow
VII. Less skilled workers can learn and serve the purpose

Disadvantage:

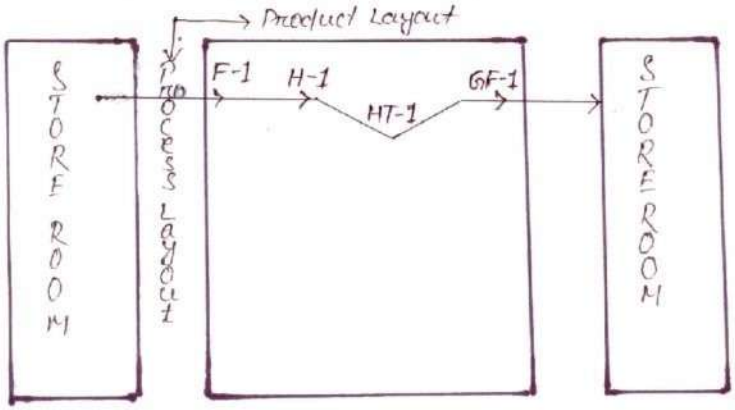
I. Lack of flexibility
II. Excessive idle time due to slowest machine
III. More machines to be purchased and kept which require high capital investment
IV. One inspector has to attend a no. of machine in a production line.
V. It is difficult to increase production beyond the capacities of the production lines.

3. Combination layout:

This is called the mixed type of layout usually a process layout is combined with the product layout.

Ex – refrigerator manufacturing uses a combination layout.

Manufacturing various components → process layout
For assembly of component → product layout



Ex – files, hacksaw, circular metal saws, wood saws.

4. Fixed position layout:

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

Ex – ship building, aircraft manufacturer

Advantage:

I. One or more skilled workers are engaged to one project
II. Least movement of materials
III. Maximum flexibility
IV. Different projects can be taken with the same layout.

Disadvantages:

I. Low content of work-in-progress
II. Low utilization of labour and equipment
III. High equipment handling cost

Plant layout procedure:

1. Accumulate basic data:

Such as

- Volume and rate of production
- Product specification and bill of material
- Process sheets indicating tools, equipments, the method and the product which will be manufactured
- Flow process charts
- Standard time to complete each operation

2. Analyze and co-ordinate basic data:

In order to

- The workforce size and type
- No. of workstation required
- Type of equipment required
- Storage and other space requirements
- Assembly chart and operation process chart help coordinating basic data

3. Decide equipment and machinery required:

Can be calculated by

- No. of articles to be produced
- Capacity of each equipment
- Time in which the order is to be completed

4. Select the material handling system:

Which depends upon

- Material or product to be moved
- Container in which it will be moved
- Length of movement
- Frequency of movement
- Speed of movement

5. Sketch plan of the plot:

To mark building outline, roads, storage and service etc

- The plan orientation should utilize maximum, the natural heat, light and other weather conditions.

6. Determine a general flow pattern:

- The flow pattern of materials should be such that the distance involved is least between the store and the shipping department through the production centers.
- There should be minimum back tracking
- Based upon the process or product requirement process, product or combination layout.
- Plant layout should be flexible to accommodate changes

7. Design individual workstations:

To get optimum

- Performance of operation
- Material and space utilization
- Safely and comfort of employees

8. Assemble the individual workstation layout: into total layout
9. Calculate the storage spaced required:

By knowing

- Volume of each store item

- No. of items to be kept at stores
- Time of keeping the item

10. Make flow diagrams for workstations:

    And allocate them to areas on plot plan.

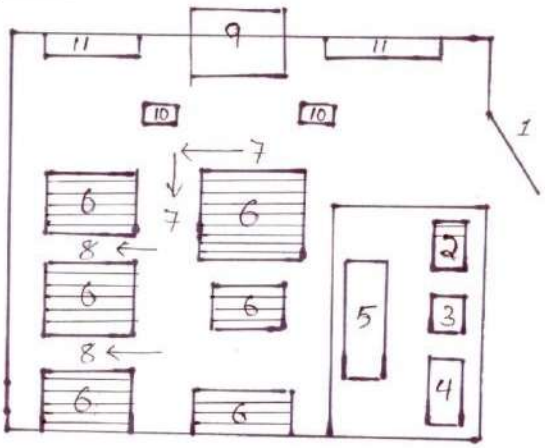
11. Plan and locate services areas such as offices, toilets, wash rooms, dispensary, cafeteria.
12. Make master layout by templates and models.
13. Check final layout:
    - Safe and economical material handling
    - Product design
    - Service area
    - Employee safety and comfort
14. Get official approval of the final layout about product drawings, BOM, man power requirements, estimated expenditure.
15. Install the approved layout.

Storage space requirements:

- Incoming new materials
- Checking and sorting the raw material
- Inspection of raw material
- Temporary storing the new material before it is placed at the proper location
- In process inventory
- Tools and other supplies
- Finished products

Space provided for above factors depends upon

1. Size and weight of raw material, in process goods and finished goods
2. Their quantity
3. Frequency of use



1. Incoming material receiving gate
2. Place for dumping raw material
3. Place for sorting and checking of raw material
4. Place for raw material inspection
5. Place for temporarily shorting the materials before putting them of racks.
6. Proper place for shorting each type of material
7. Main aisles
8. Side aisles
9. Service window
10. Boxes containing materials to be issued
11. Counters for keeping materials to be issued which have been brought from 6 and will be placed in 10

OPERATION RESEARCH

Optimization techniques:

The word optimization is form optimum which implies a point at which the conditions are best and most favorable.

An optimum point may represent a maximum position or minimum position.

Method for optimizing:

a) Search
b) Differential calculus
c) Statistical methods
d) Linear programming
    i. Graphical method
    ii. Transportation method
    iii. Simplex method
e) Queuing theory
f) Dynamic programming

Application:

Load allocation problems, component selection, load sharing.

Operation research:

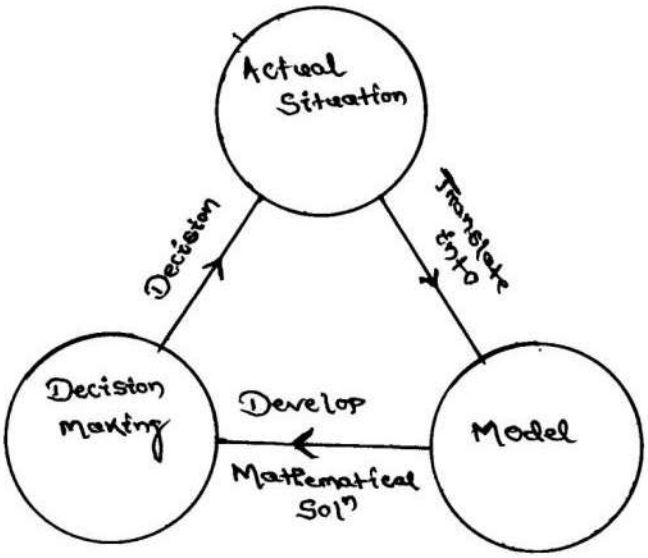
Operation research signifies research on operations. It is the organized application of modern science, mathematics and computer techniques to complex military, government, business or industrial problems arising in the direction and management of large systems of men, materials, money and machines

Methodology

1. Understand the actual real situation, capture the same and define the problem
2. Formulate a mathematical model
3. Develop a mathematical solution
4. Interpret the solution and prepare the information in such a form that it is meaningful, intelligible and quantitative. Translate it in to a decision.
5. Implement the decision to the real situation
6. Verify the results

Methods of operation research

1. Linear programming
    a) Graphical linear programming
    b) Transportation method
    c) Simplex method
2. Wait line queuing theory
3. Game theory
4. Dynamic programming



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

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.

Graphical method:

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

Example 1: A furniture manufacturer makes two products X_1 & X_2 namely chair and tables. Each chair contributes a profit of Rs 20 and each table that of Rs 40. Chairs and tables from raw material to finished product, are processed in 3 sections S_1, S_2, S_3. In section S_1 each chair (X_1) requires 1 Hr and each table (X_2) requires 4 Hrs of processing. In section S_2, each chair requires 3 Hrs and each table 1 Hr and in section S_3 the times are 1 and 1 Hr respectively. The manufacturer wants to optimize his profits if sections S_1, S_2, S_3 can be availed for not more than 24, 21 and 8 Hrs respectively.

ANS:

Let Chair = X_1

Table = X_2

Maximum $Z = 20X_1 + 40X_2$

	Chair	Table	Total
S_1	1	4	24
S_2	3	1	21
S_3	1	1	8

Subject to :

$X_1 + 4X_2 \leq 24$ (C_1)

$3X_1 + X_2 \leq 21$ (C_2)

$X_1 + X_2 \leq 8$ (C_3)

$X_1, X_2 \geq 0$ (C_4)

Where, C_1 is constraint No. 1.

C_2 is constraint No. 2.

C_3 is constraint No. 3.

C_4 is constraint No. 4.

Example 2: A firm can produce 3 types of cloth says A, B and C. Three kinds of wool are required for it say red wool, green wool and blue wool. One unit length of type A cloth needs 2 yards of red wool and 3 yards of blue wool. One unit length of type B cloth needs 3 yards of red wool, 2 yards green wool and 2 yards blue wool and one unit of type C cloth needs 5 yards of green and 4 yards of blue wool. The company has a stock of only 8 yards of red, 10 yards green wool and 15 yards of blue wool. The profit from sale of 1 unit length of type A is Rs 10, type B is Rs 8 and type C is Rs 5. Determine how the firm should use the available material so as to maximize the profit. Formulate this as LP problem.

ANS:

Let x_1, x_2 and x_3 be the no. of units of cloth of type A, type B and type C.

Objective is to maximize profit.

$$Z = 10x_1 + 8x_2 + 5x_3$$

Requirement wool	Clothes			Availability of
	A	B	C	
Red	2	3	___	8
Green	___	2	5	10
Blue	3	2	4	15

$$2x_1 + 3x_2 \leq 8$$

$$2x_2 + 5x_3 \leq 10$$

$$3x_1 + 2x_2 + 4x_3 \leq 15$$

Example 3 : A company produces two types of dolls A and B. Doll A is of superior quality and B is of lower quality. Profit on doll A and B is Rs 5 and Rs 3 respectively. Raw material required for each doll A is twice that is required for doll B. The supply of raw material is only 1000 per day of doll B. Doll A requires a special crown and only 400 such clips are available per day. For doll B 700 crowns are available per day. Find graphically the product mix so that the company makes maximum profit.

ANS:

$\text{Max. } Z = 2x_1 + x_2$

$2x_1 + x_2 \leq 1000$

$x_1 \leq 400$

$x_2 \leq 700$

$x_1, x_2 \geq 0$

Graphical method:

1st step:

Formulate the LPM.

$\text{Max } Z = 20x_1 + 40x_2$

Subjected to $x_1 + 4x_2 \leq 24$ (c_1)

$3x_1 + x_2 \leq 21$ (c_2)

$x_1 + x_2 \leq 8$ (c_3)

$x_1, x_2 \geq 0$ (c_4)

c_1 is constrain no. 1 and so on.

2nd step:

2nd steps convert the constraint inequalities temporarily into equations.

$x_1 + 4x_2 = 24$ (c_1)

$3x_1 + x_2 = 21$ (c_2)

$x_1 + x_2 = 8$ (c_3)

3rd steps: Axis are marked on the graph paper and labeled with variables x_1 & x_2.

4th steps:

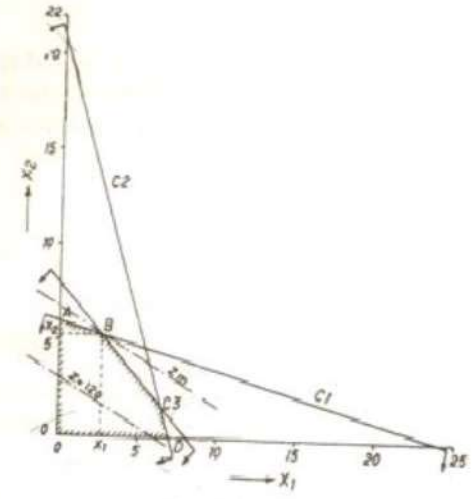
4th step is draw straight lines on the graph paper using constraint equations and to mark feasible solution on the graph paper.

Taking 1st constraint equation,

$x_1 + 4x_2 = 24$

$x_1 = 0, x_2 = 6$

$x_2 = 0, x_1 = 24$



Graphical method.

Mark the point of 24 at X_1 axis and point 6 on x_2 axis. The straight line represents c_1 equation.

Similarly, c_2 and c_3 can be plotted.

$3x_1 + x_2 = 21$ $x_1 + x_2 = 8$

$x_1 = 0, x_2 = 21$ $x_1 = 0, x_2 = 8$

$x_2 = 0, x_1 = 7$ $x_2 = 0, x_1 = 8$

According to constrain c_4, x_1 & x_2 are greater than or equal to zero, hence the marked area between $x_1 = x_2 = 0$ and c_1, c_2, c_3 represents the feasible solution.

5th step:

A dotted straight line representing the equation Z is drawn, assuming any suitable value of Z say 120.

$X_1 = 0, x_2 = 3$

$X_2 = 0, x_1 = 6$

6th steps:

A straight line Z_m is drawn parallel to the line Z, at the furthest point of the region of feasible solution i.e. point B, at the intersection of c_1 & c_3.

The co-ordinates at point B can be found by solving equation c_1 & c_3.

$x_1 + x_2 = 8$ (c_3)

$x_1 + 4x_2 = 24$ (c_1)

$3x_2 = 16 \Rightarrow x_2 = 5.3$

$3x_1 = 8 \Rightarrow x_1 = 2.7$

These values of x_1 and x_2 can also be read from the graph itself.

∴ The maximum value of Z is

$$Z_m = 20x_1 + 40x_2 = 20 \times \frac{8}{3} + 40 \times \frac{16}{3} = 266.6$$

NETWORK ANALYSIS

It is a system which plans projects both large and small by analyzing the project activities. Projects are broken down to individual tasks or activities, which are arranged in logical sequence.

Projects:

Project is any task which has definable beginning and definable end expenditure of one or more resources.

It is essential to manage effectively the projects through proper planning, scheduling and control as project requires a heavy investment, and is associated with risk and uncertainties.

Network scheduling:

It is a technique used for planning and scheduling large projects in the field of constructions, maintenance, fabrication and any other areas.

This technique is the method of minimizing the bottlenecks, delays and interruptions by determining the critical factors and coordinating various activities.

A network diagram:

A network diagram is constructed which presents visually the relationship between all the activities involved. Time, costs and other resources are allocated to different activities.

It helps designing, planning, coordinating, controlling and decision making in order to accomplish the project economically in the minimum available time with the limited available resources.

There are two basic planning and control techniques. They are Critical Path Method (CPM) and Program Evaluation and Review Techniques (PERT).

Objective of Network Analysis:

1. A powerful coordinating tool for planning, scheduling and controlling of projects.
2. Minimization of total project cost and time.
3. Effective utilization of resources and minimization of effective resources.

4. Minimization of delays and interruption during implementation of the project.

Application of Network Analysis (PERT and CPM):

1. Research and development projects.
2. Equipment maintenance and overhauling.
3. Construction projects (building, bridges, dams)
4. Setting up new industries
5. Planning and launching of new products.
6. Design of plants, machines and systems
7. Organization of big programs

Basic concepts in network:

Network:

It is a graphical representation of the project and it consists of series of activities arranged in a logical sequence and show the interrelationship between the activities.

Activities:

An activity is a physically identifiable part of the project, which consumes time and resources. Each activity has a definite start and end. It is represented by an arrow (→).

Event:

An event represents the start or completion of an activity. The beginning and end points of an activity are events.

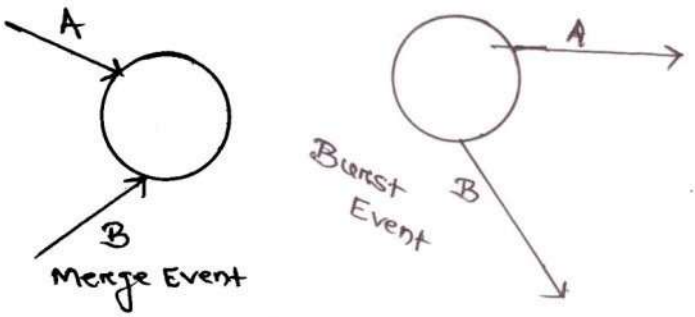
Ex – Machining a component is an activity.

Start machining is an event.

Machining completed is an event.

Tail event Head event

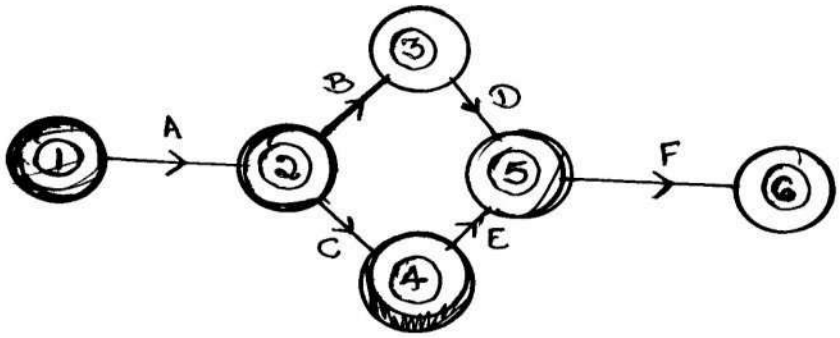
In a network a no. of activities may terminate into single node called merge node and a no. of activities may emanate from a single node called burst node.



Predecessor and successor activities:

All those activities, which must be completed before starting the activity under consideration are called its predecessor activities.

All the activities which nave to follow the activity under consideration are called its successor activities.



2-3, 2-4 are immediate successors

2-3 &2-4, 3-5, 4-5&5-1 are its successor's activities.

1-2, 2-3 are predecessors to 3-5.

2-3 is the immediate predecessors.

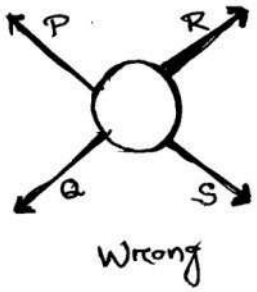
Path:

An unbroken chain of activities between two events is called a path.

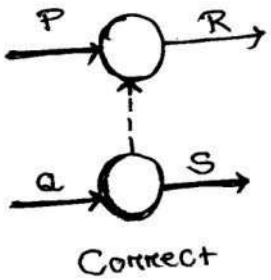
Ex – A-B-D-F is a path connecting 1 & 6.

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.



Wrong



Correct

Terms related to network planning methods:

Event (node):

An event is a specific instant of time which marks the start and the 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.

Ex – start the motor, loan approved.

Activity:

Every project consists of a no. of job operations or tasks which are called activities. An activity is an element of project and it any be a process, a material handling or material procurement cycle.

Ex – install machinery, arrange foreign exchange.

It is shown by an arrow and it begins and ends with an event. An activity is normally given a name like A, B, C etc i.e. marked below the arrow and the estimated time to accomplish the activity is marked above the arrow.

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 activities:

   When two activities start at the same instant of time, the head events are joined by a dotted arrow and this is known as dummy activity. It does not consume time. It may be non-critical or critical. It becomes a critical activity when its EST = LFT.

Critical path:

It is that sequence of activities which decide 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:

Duration is the estimated or actual time required to complete a task or an activity.

Total project time:

It is the time which will be taken to complete the project and is found from the sequence of critical activities. It is the duration or critical path.

Earliest start time (EST):

It is the earliest possible time at which activity can start and is calculated by moving from first to last event in a network diagram.

Earliest finish time (EFT):

It is the earliest possible time at which activity can finish. i.e. (EST + D)

Latest finish time (LFT):

It is calculated by moving backward i.e. from last event to first event of the network diagram. It is the last event time of the head event

Latest start time (LST):

It is the least possible time by which an activity can start.

LST = LFT – duration of that activity

Float or slack:

Slack is with reference to an event and float is with respect to an activity. It means spare time, a margin of extra time over and above its duration which a noncritical activity can consume without delaying the project.

Float is the difference between the time available for completing an activity and the time necessary to complete the same.

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 = EST of tail event – EST of head event – activity duration

3. Independent float:

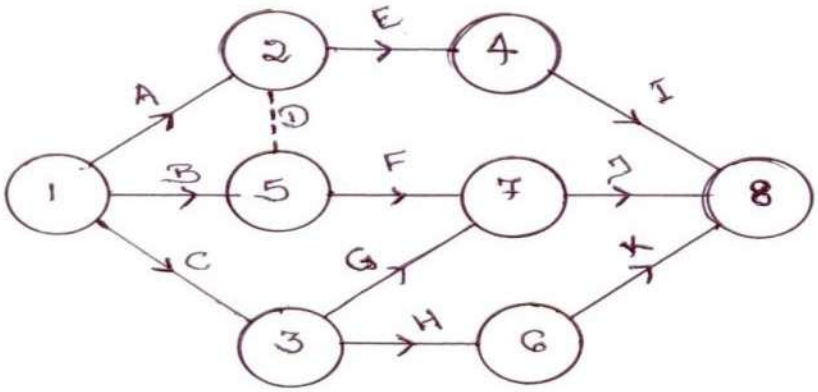
   It can be used to advantage. If one is interested to reduce the effort on a non-critical activity in order to apply the effort on a critical activity by reducing the project duration.

   IF = EST of tail event – LFT of head event – activity duration.

   If IF is negative, then taken as 0.

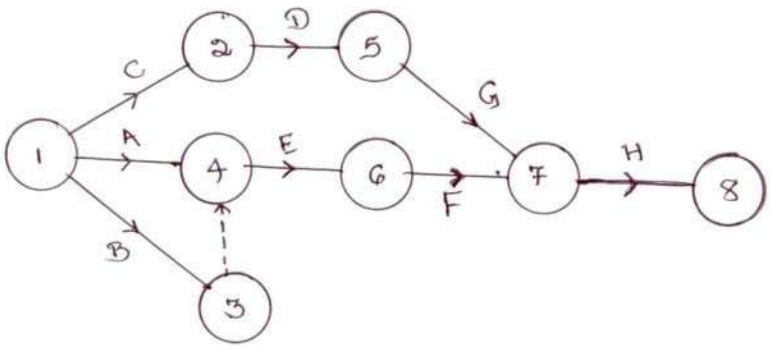
Numbering of events (Fulkerson's rule):

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.



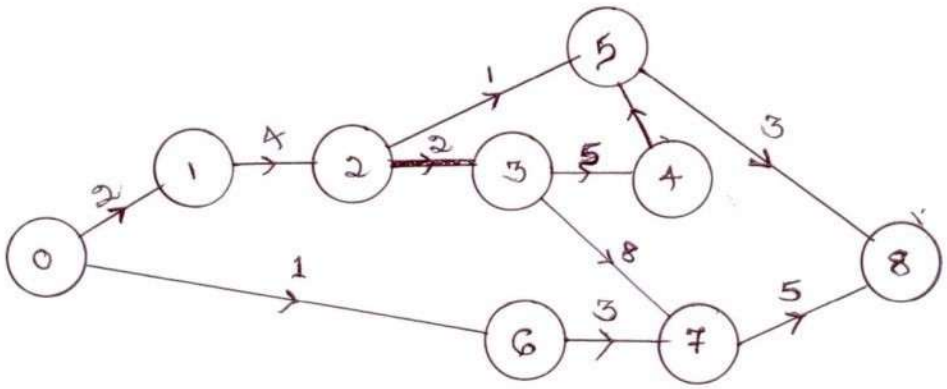
1. Construct the network from the information.

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



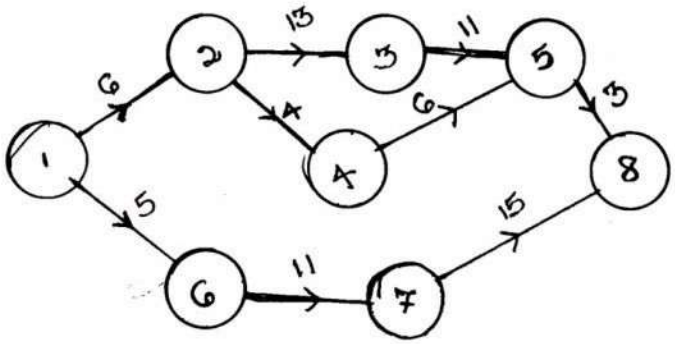
2. Construct the network from the information.

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		



3. Construct the network from the information.

Activity	Time	Activity	Time
1-2	6	3-5	11
1-6	5	4-5	6
2-3	13	6-7	11
2-4	4	5-8	3
------	------	7-8	15



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:

A small engineering project consists of 6 activities namely A, B, C, D, E & F with duration 4, 6, 5, 4, 3 & 3 days respectively. Draw the network diagram and calculate EST, LST, EFT, LFT and floats. Mark the critical path and find total project duration

Activity	Duration (days)	EST	LST (LFT - D)	EFT (EST + D)	LFT	TF
A	4	0	0	4	4	0
B	6	4	4	10	10	0
C	5	10	10	15	15	0
D	4	4	8	8	12	4
E	3	8	12	11	15	4
F	3	15	15	18	18	0

Critical path = 1-2-3-5-6

Total project duration = 4+6+5+3 = 18 days

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_0)
II. Most likely time (t_m)

III. Pessimistic time (t_p)

I. Optimistic time (t_0):

It is the shortest possible time in which an activity can be completed if everything goes perfectly without any complications.

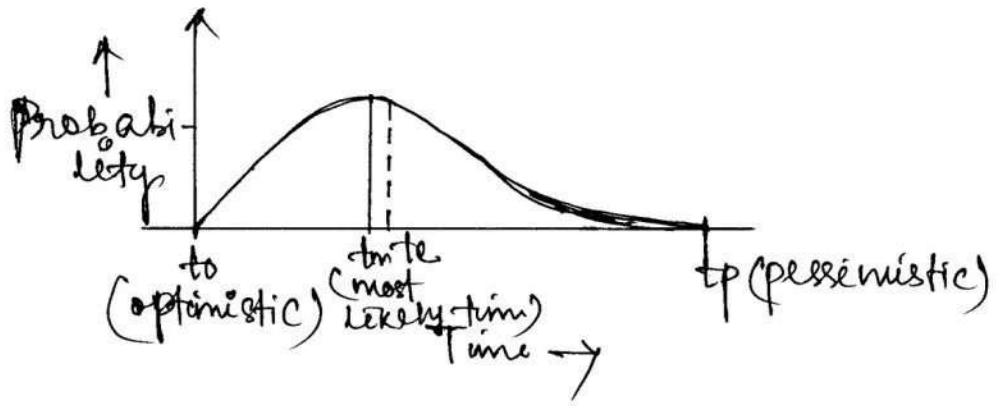
It is an estimate of minimum possible time to complete the activity under ideal condition.

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.



According to the β distribution curve

$$T_e = \frac{1}{6}t_0 + \frac{2}{3}t_m + \frac{1}{6}t_p$$

$$= \frac{t0 + 4tm + tp}{6}$$

The standard deviation of time required to complete each activity.

$$\text{Standard deviation}(\sigma) = \frac{tp - t0}{6}$$

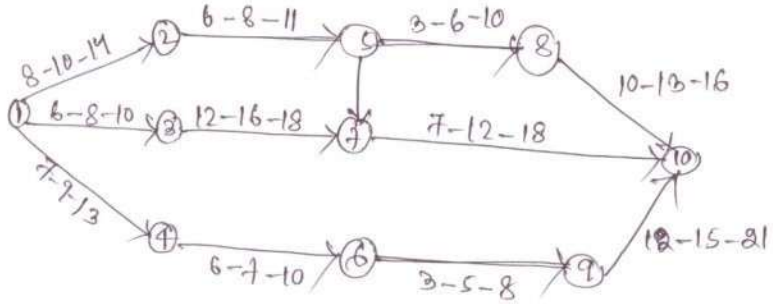
$$\text{Variance } \sigma^2 = \left(\frac{tp - t0}{6}\right)^2$$

Standard deviation of the time t_p to complete the project

The probability of completion of the project within scheduled is computed as

1. Calculate the mean of the event time (t_e) by adding the times of the activities along the critical path leading to the event.
2. Calculate the variance of the event time by adding up the variances of the activities on the critical path. Take the square root of this variances to get T (standard deviation)
3. Compute standard normal variate

$$Z = \frac{Ts - Te}{\sigma T} \qquad Z = \frac{D - Te}{St}$$



There are 4 paths to reach 1 to 10.

A → 1-2-5-8-10

B → 1-2-5-7-10

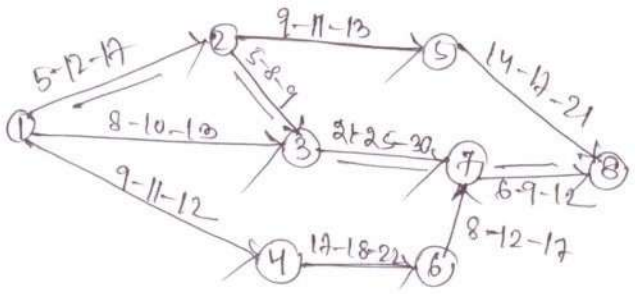
C → 1-3-7-10

D → 1-4-6-9-10

	Activity	t_0	t_m	T_p	T_e	Sum of t_e
Path A	1-2	8	10	14	10.33	37.67
	2-5	6	8	11	8.17	
	5-8	3	6	10	6.17	
	8-10	10	13	16	13	
Path D	1-4	7	9	13	9.33	37.34
	4-6	6	7	10	7.33	

	6-9	3	5	8		
	9-10	12	15	21		
Path C	1-3	6	8	10		35.84
	3-7	12	16	18		
	7-10	7	12	18		
Path B	1-2	8	10	14		37.84
	2-5	6	8	11		
	5-7	5	7	10		
	7-10	7	12	18		

Maximum time consumed is 37.84 is the critical path. So path B is the critical path.



Example – 2:

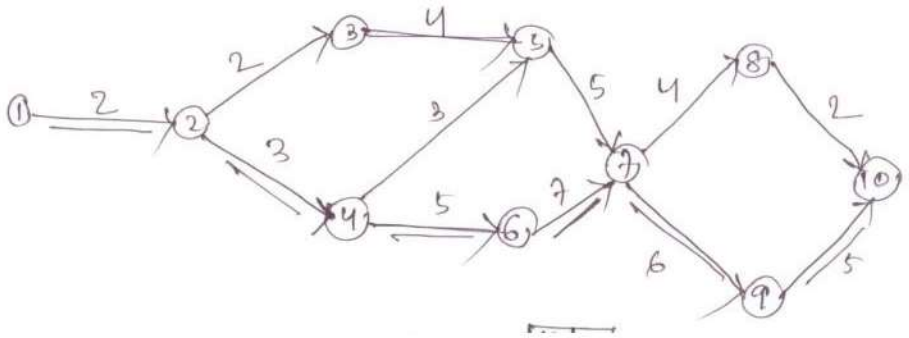
Construct the PERT network. Find the critical path and variance of each event. Find the project duration at 95 % probability.

Activity	Optimistic time	Pessimistic time	Most likely time
1-2	1	5	1.5
2-3	1	3	2
2-4	1	5	3

3-5	3	5	4
4-5	2	4	3
4-6	3	7	5
5-7	4	6	5
6-7	6	8	7
7-8	2	6	4
7-9	5	8	6
8-10	1	3	2
9-10	3	7	3

Solution:

Activity	t_o	t_p	t_m	t_e	Variance
1-2	1	5	1.5	2	4/9
2-3	1	3	2	2	1/9
2-4	1	5	3	3	4/9
3-5	3	5	4	4	4/9
4-5	2	4	3	3	1/9
4-6	3	7	5	5	4/9
5-7	4	6	5	5	1/9
6-7	6	8	7	7	4/9
7-8	2	6	4	4	4/9
7-9	5	8	6	6.16	1/4
8-10	1	3	2	2	1/9
9-10	3	7	3	5	4/9



The critical path is 1-2-4-6-7-9-10.

Expected duration of the project = 2+3+5+7+6.16+5 = 28.16 days

Project variance = 4/9+4/9+4/9+4/9+1/4+4/9 = 89/36

$Z = \frac{due\ date - expected\ date\ of\ of\ completion}{\sigma T}$

$= \frac{X-28.16}{89/36} = 0.8289$

⇨ X = 30.12 days

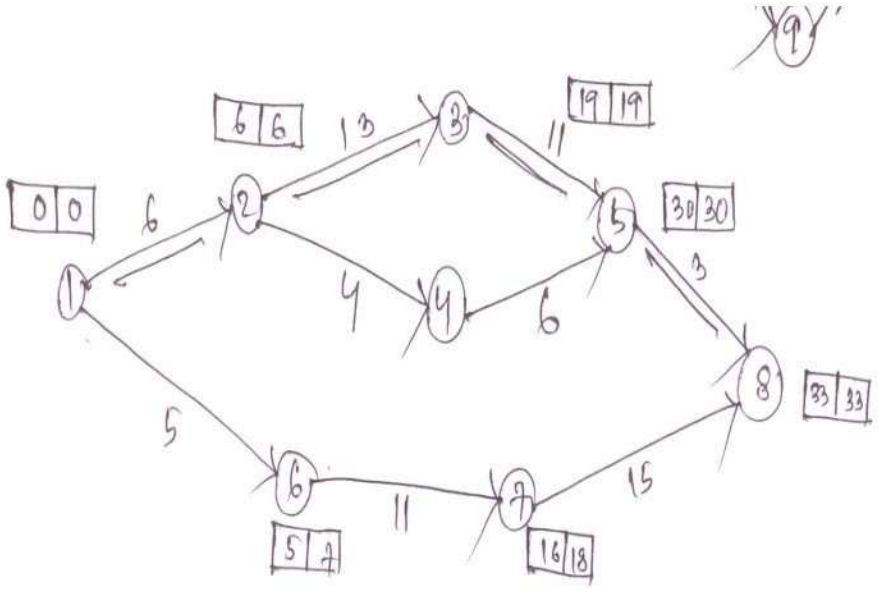
Example- 3:

A small engineering project consists of an activity. Three time estimates for each activity are given

a) Calculate values of expected time (t_e), standard deviation (s_t) and variance (v_t) for each activity.
b) Draw the network diagram and mark t_e on each activity.
c) Calculate EST and LFT and mark t_e on each activity.
d) Calculate total slack for each activity.
e) Indentify the critical paths and mark on the network diagram.
f) Find the length of critical paths or total project duration.
g) Calculate variance of critical path.
h) Calculate the probability that the jobs on the critical path will be finished by the due date of 38 days.
i) Calculate the approx probability that the jobs on the next most critical path will be completed by the due date of 38 days.
j) Estimate the probability that the entire project will be completed by the due date of 38 days.
k) If the project due date changes to 35 days what is the probability of not meeting the due date.
l) Find the due date which has a probability of 94.5 % of being met.

Solution:

Activity	T_o	T_m	T_p	T_e	V_t
1-2	2	5	14	6	4
1-6	2	5	8	5	1
2-3	5	11	29	13	16
2-4	1	4	7	4	1
3-5	5	11	17	11	4
4-5	2	5	14	6	4
6-7	3	9	27	11	16
5-8	2	2	8	3	1
7-8	7	13	31	15	16



Activity	EST	LST	LST - EST
1-2	0	0	0
1-6	0	2	2
2-3	6	6	0
2-4	6	20	14
3-5	19	19	0
4-5	10	24	14
6-7	5	7	2
5-8	30	30	0
7-8	16	18	2

e) Critical path is 1-2-3-5-8 and it is marked on the network diagram.

f) The length of the critical path or total project duration (T_e) is the sum of the duration of each critical activity = 6 + 13 + 11 + 3 = 33 days

g) Variance of the critical path is two of the each critical activity = 4 + 16 + 4 + 1 = 25

h) The probability that the project will meet the scheduled or due date is calculated from the $Z = \frac{D-Te}{St}$

Where T_e = total project duration

S_t = standard deviation = $\sqrt{varience}$

D = Due or scheduled deviations

$\therefore Z = \frac{38-33}{\sqrt{25}} = \frac{5}{5} = 1$ For Z = 1, probability = 0.841.

i) The next most critical path is 1-6-7-8 of 31 days.

Variance = 1+16+16 = 33 $s_t = \sqrt{33}$

$Z = \frac{38-31}{5.74} = 1.22$

For Z = 1.22, probability = 0.888

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.

Types of inventories:

1. Raw inventories (raw materials):
    - Raw materials and semifinished 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:
    - Semifinished 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.
      Eg – machine spares, oil, grease, spare parts, lubricants
    - For proper operation, repair and maintenance during manufacturing cycle.

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

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

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

Advantages or benefits 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

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.

Cost associated with inventory

1. Purchase (or production) cost:

   The value of an item is its unit purchasing or production cost.

2. Capital cost:

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

3. 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.

   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.

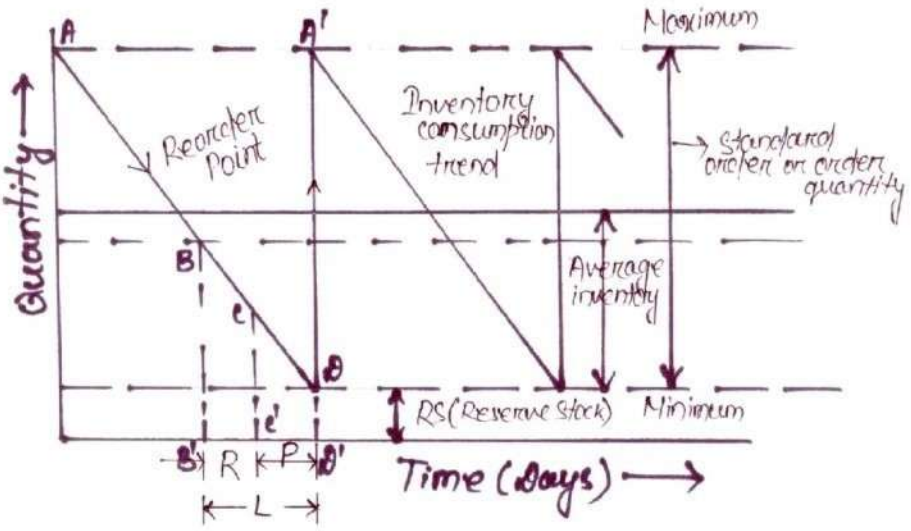
      This includes-

   I. Storage costs (rent, heating, lighting etc.)
   II. Handling costs (associated with moving the items. Such as labour cost, equipment for handling)
   III. Depreciation, taxes and insurance
   IV. Product deterioration and obsolescence
   V. Spoilage, breakage

Economic order quantity:

How much materials may be ordered at a time. An industry making bolts will definitely like to know the length of steel bars to be purchased at any one time. i.e. called EOQ.

An economic order quantity is one which permits lowest cost per unit and is most advantageous.



Starting from an instant when inventory OA is in the stores, it consumes gradually in quantity from A along AD at a uniform rate. We know it takes L no. of days between initiating order and receiving the required inventory. As quantity reaches point B, purchase requisition is initiated which takes form B to C that is time R. from C to D is the procurement time P. At the point D when only resource stock is left, the ordered material is supposed to reach and again the total quantity shoots to its maximum value i.e. the point A'(A=A')

Maximum quantity- OA is the upper or max limit to which the inventory can be kept in the stores at any time.

Minimum quantity- OE is the lower or minimum limit of the inventory which must be kept in the stores at any time.

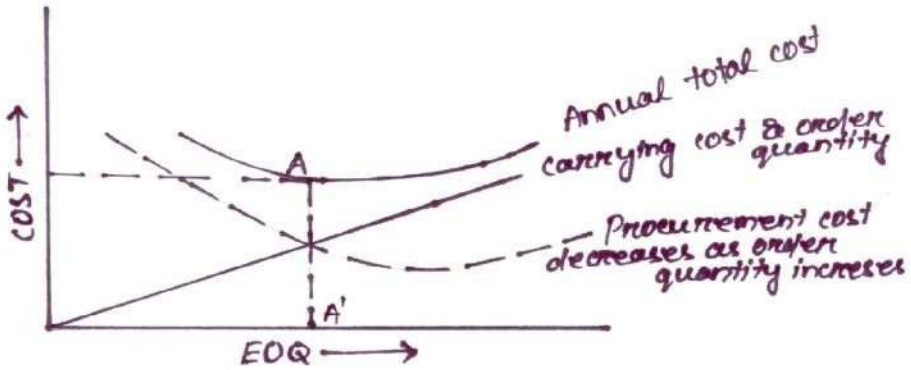
Standard order (A'D) - It is the difference between maximum and minimum quantity and is known as economical purchase inventory size.

Reorder point (B)- It indicates that it is high time to initiate a purchase order if not done so the inventory may exhaust, even reserve stock utilized before the new material arrives.

From B' to D' it is lead time and it may be calculated on the basis of past experience.

It includes-

a) Time to prepare purchase requisition and placing the order.
b) Time taken to deliver purchase order to the seller
c) Time for seller to get or prepare inventory
d) Time for inventory to be dispatched from the vendor's end and to reach the costumer



Inventory procurement cost:

1. Receiving quotations
2. Processing purchase requisition
3. Following up and expediting purchase order
4. Receiving material and then inspect it
5. Processing seller's invoice

Procurement cost decrease as order quantity increases.

Inventory carrying cost:

1. Interest on capital investment
2. Cost of storage facility, up-keep of material, record keeping
3. Cost involving deterioration and obsolescence
4. Cost of insurance, property tax.

Carrying cost directly proportional to the order size or order quantity

Mathematical derivation of EOQ:

Let Q is the economic lot size or EOQ

C is the cost for one item.

I is the cost of carrying inventory in percentage per period

P is the procurement cost associated with one order

U is the total quantity used per period.

No. of purchase orders to be furnished = $\frac{Total\ quantity}{EOQ} = \frac{U}{Q}$

Total procurement cost = No. of orders × cost involved in one order

$$= \frac{U}{Q} \times P$$

Average quantity = Q/2

Inventory carrying cost = average inventory × cost per item × cost of carrying inventory in %

$$= \frac{Q}{2} \times C \times I$$

Total cost (T) = a + b

$$= \frac{U}{Q} \times P + \frac{Q}{2} \times C \times I$$

To minimize cost, $\frac{dT}{dQ} = 0$

$\Rightarrow \frac{d}{dQ}\left(\frac{U}{Q}P + \frac{Q}{2}CI\right) = 0$

$\Rightarrow - UQ^{-2}P + CI/2 = 0$

$\Rightarrow Q^2 = \frac{2UP}{CI}$

$$\Rightarrow \quad Q = \sqrt{\frac{2UP}{CI}}$$

Problem-1:

I. Annual usage (U) = 60 units
II. Procurement cost (P) = Rs 15
III. Cost per price (C) = Rs 100
IV. Cost of carrying inventory (I) = 10 %
Calculate EOQ.

Answer:

$$Q = \sqrt{\frac{2UP}{CI}}$$

$$= \sqrt{\frac{2 \times 60 \times 15 \times 100}{100 \times 10}} = 13.41$$

No. of orders per year $= \frac{60}{13.41} = 4.47 \cong 5$

$\therefore$ EOQ $= \frac{60}{5} = 12$ units (rounded)

Problem-2:

The rate of use of a particular raw material from stores is 20 units per year. The cost of placing and receiving on order is Rs 40. The cost of each unit is Rs 100. The cost of carrying inventory in percent per year is 0.16 and it depends upon the average stock. Determine the order quantity. If the lead time is 3 month, calculate the reorder point.

Answer:

U = 20 units

P = Rs 40 /-

C = Rs 100 /-

I = 0.16

$$EOQ = \sqrt{\frac{2UP}{CI}} = \sqrt{\frac{2 \times 20 \times 40}{100 \times 0.16}} = 10$$

L = 3 months

12 months = 20 units

3 months = $\frac{20}{12} \times 3$ = 5 units

Problem-3:

Find economic order quantity from following data.

Average annual demand = 30000 units

Inventory carrying cost = 12 % of the unit value per year

Cost of unit = Rs 2 /-

Answer:

Given, U = 30000

I = 12 %

P = 70

C = 2 /-

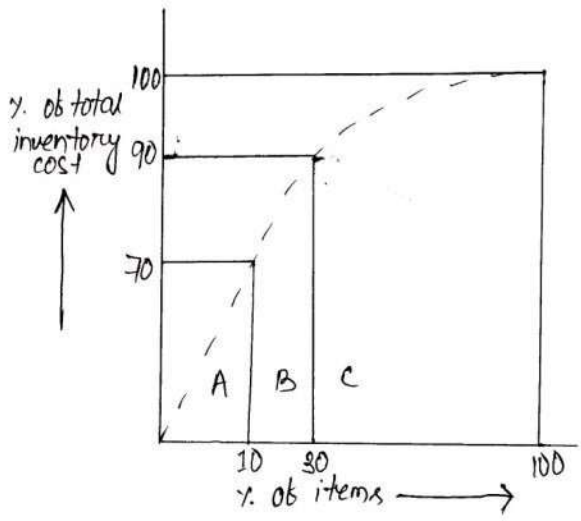
EOQ = $\sqrt{\frac{2UP}{CI}} = \sqrt{\frac{2 \times 30000 \times 70 \times 100}{2 \times 12}}$ = 4183.3

No. of orders = $\frac{30000}{4183.3}$ = 7.17 ≅ 7

EOQ = $\frac{30000}{7}$ = 4285.7 ≅ 4286 (rounded)

ABC analysis:

ABC analysis helps differentiating the item from one another and tells how much valued the item is and controlling it to what extent is in the interest of an organization.



1. A-items:

   A items are high valued but are limited or few in number. They need careful and close inventory control and proper handling and storage facilities should be provided for them.

   A items generally 70-80 % of the total inventory cost and 10 % of the total items.

2. B-items;

   B-items are medium valued and their umber lies in between A and C items. They need moderate control. They are purchased on the basis of past requirements.

   B-items generally 20-15 % of total inventory cost and 15-20 % of the total items.

3. C-items:

   C-items are low valued, but maximum numbered items. These items do not need any control. These are least important items, like clip, all pins, washers, rubber bands. No record keeping is done.

   C-items generally 10-5 % of the total inventory cost and constitute 75 % of the total items

Advantage

I. Better planning and control
II. Increase inventory turn over
III. Effective management and control

Disadvantage

I. Periodic review to be dfdf

Procedure

1. Identify all the items used In industry
2. List all the items as per their value.
3. Count the no. of high valued, medium valued and law valued items
4. Find the % of high, medium and low valued items
   High valued contribute – 70% of total inv. Cost
   Medium valued contribute -20% of total inv. Cost
   Low valued contribute-10% of total inv. Cost
5. A graph can be plotted between % of items and % of total inventory cost

PLANT MAINTENANCE

Plant-

A plant is a place, where men, materials, money, equipment, machinery, etc are brought together for manufacturing products.

Maintenance-

Maintenance of facilities and equipment in good working condition is essential to achieve specified level of quality and reliability and efficient working. It helps in maintaining and increasing the operational efficiency of plant facilities and contributes to revenue by reducing operating of production.

Objectives of plant maintenance-

- To achieve minimum breakdown and to keep the plant in good working condition at the lowest possible cost.
- To keep the m/c in such a condition that permit to use without any interrupter
- To increase functional reliability of production facilities
- To maximize the useful life of the equipment
- To minimize the frequency of interruption to production by reducing breakdown
- To enhance the safety of manpower

IMP of maintenance-

- Equipment breakdown leads to an inevitable loss of production
- An improperly maintained or neglected plant will sooner or later require expensive and frequent repairs, because with the passage of time all machines or other facilities, building, etc wear out and need to be maintained to function properly.
- Plant maintenance plays a prominent in production management because plant breakdown creates problem such as- loss of production time
    - ✓ Rescheduling of production
    - ✓ Spoilt materials (because sudden stoppage of process damages in-process materials)
    - ✓ Failure to recover overheads (because loss in production hours)
    - ✓ Need for overtime
    - ✓ Need for subcontracting work
    - ✓ Temporary work shortage- workers require alteration work

Duties, functions and responsibilities of pant maintenance department-

a) Inspection-

- Inspection is concerned with the routine schedule checks of the plant facilities to examine their condition and to check for needed repairs
- Inspection ensures the safe and efficient operation of equipment and machinery
- Frequency of inspections depends upon the intensity of the use of the equipment
- Items removed during maintenance and overhaul operation are inspected to determine flexibility of repairs
- Maintenance items received from vendors are inspected for their fitness

b) Engineering-

- Engineering involves alterations and improvements in existing equipments and building to minimize breakdowns
- Maintenance department also undertakes engineering and supervision of constructional projects that will eventually become part of the plant.
- Engineering and consulting services to production supervision are also the responsibility of maintenance department.

c) Maintenance –

- Maintenance of existing plant equipment.
- Maintenance of existing plant buildings and other service facilities such as yards, central stress, roadways.
- Minor installation of equipments, building and replacements
- Prevent breakdown by well-conceived plans of inspection, lubrication, adjustments, repair and overhaul.

d) Repair-

- Maintenance department carries corrective repairs to avoid unsatisfactory conditions found during preventive maintenance inspection.
- Such a repair work is of an emergency nature and is necessary to correct breakdowns.

e) Overhaul-

- Overhaul is a planned, schedule reconditioning of plant facilities such as machinery etc.
- It involves replacement, reconditioning, reassembly etc.

f) Construction-

- In some organizations, maintenance department is provided with equipment and personnel and it takes up construction job also.
- It handles construction of wood, brick and steel structures, electrical installation etc.

g) Salvage-

- It may also handle disposition of scrap or surplus materials.
- This involves segregation and disposition of production scrap.

h) Clerical jobs-

- Maintenance department keeps records of cost, of time progress on jobs, electrical installations, water, steams, air and oil lines, transport facilities.

i) Generation and distribution of power.
j) Providing plant protection
k) Establishing and maintaining a suitable store of maintenance materials
l) House keeping
m) Pollution and noise control

Types of maintenance:

Maintenance may be classified as

a) Corrective or breakdown maintenance
b) Scheduled maintenance
c) Preventive maintenance
d) Predictive maintenance

a) 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. Ex – electric motor will not start, a belt is broken.
- Under such conditions, production department calls on the maintenance department to rectify the defect. The maintenance department checks into the difficulty and makes the necessity repairs.
- After removing the fault, maintenance engineers do not attend the equipment again until another failure or breakdown occurs.
- Breakdown maintenance is economical for those equipment whose down time and repair costs are less.
- Breakdown type maintenance involves little administrative work, few records and comparative small staff.

Causes of equipment breakdown:

- Lack of lubrication
- Neglected cooling system
- Failure to replace worn out parts
- External factors (too higher or too voltage)

Disadvantages of breakdown maintenance:

- Breakdowns occur at inopportunity times, which lead to poor, hurried maintenance and excessive delays in production.
- Reduction of output
- More spoilt material
- Increased chances of accidents and less safety to both workers and machines
- Direct loss of profit.
- Breakdown maintenance cannot be employed to cranes, lifts, hoists and pressure vessels.

b) Scheduled maintenance:

- Scheduled maintenance is a stick-in-time procedure aimed at availing breakdowns
- Scheduled maintenance do inspection, lubrication, repair and overhaul of certain equipments are done in predetermined schedule.
- Schedule maintenance practice is generally followed for overhauling of machines, cleaning of water and other tanks, white washing of building etc.

c) Preventive maintenance:

- A system of scheduled, planned or preventive maintenance tries to minimize the problems of breakdown maintenance.
- It is a stich-in-time procedure.
- It locates weak spots (such as bearing surfaces, parts under excessive vibrations etc) in all equipments, proceeds them regular inspection and minor repairs reducing the danger of unanticipated breakdown.
- Preventive maintenance involves.
- Periodic inspection of equipment and machinery to prevent production breakdown an harmful depreciation.
- Upkeep of plant equipment to correct fault.

Objective of FM:

- To minimize the possibility of unanticipated production interruption and major breakdown by locationg the fault.
- To make plant equipment and machinery ready to use
- To maintain the optimum productive efficiency
- To maintain the operational accuracy
- To achieve maximum production and minimum repair cost
- To ensure safety of life and limbs of the workers

Advantages:

- Reduces breakdown and down-time
- Lesser odd-time repairs
- Greater safety for workers
- Low maintenance and repair cost
- Increased equipment life.
- Better product quality.

d) Predictive maintenance:

- It is a newer maintenance technique.
- It uses human senses or other sensitive instruments such as audio gauges, vibration analysers, amplitude meters, pressure, temperature and resistance strain gauges to predict troubles before the equipment fails.
- Unusual sound coming out of a rotating equipment predict an trouble, an electric cable excessively hot at one point predicts an trouble.
- In predictive maintenance, equipment conditions are measured periodically or on a continuous basis enables maintenance men to take timely action such as equipment adjustments, repair and overhaul.

- It extends the service life of an equipment without fear of failure.

Recent developments in plant maintenance:

The management techniques used for plant maintenance to increase maintenance efficiency, reduce maintenance cost and to improve services.

A. Use of work study:

Work study can improve maintenance scheduling and eliminate a great deal of frustration and anxiety on the part of production supervision.

B. Use of network planning techniques:

- CPM has enables some firms to cut their down time by 20 to 30 %
- Maintenance costs have been cut down.
- CPM is useful for large maintenance projects
- 70 % of reduction in time for overhaul by central electricity board in Great Britain using network planning technique.
- PERT reduced shut down time 18 to 16 days 102 and added 90000 barrels to production volume of a refinery.

C. Use of operation research:

Operation research handles maintenance problems such as the economiv level of spare parts or when to replace an item etc.

D. Use of computers;

- More efficient and control over maintenance problems.
- Computer can prepare maintenance work orders giving accurate work order descriptions and job timing.
- Eliminate human error in preparing work order.
- Reduced cost of keeping records of equipments
- Reduced premature replacement of parts.

An **inspection** involves checking something, i.e., examining and assessing something. ... They also have to make sure that whatever they are inspecting is safe. In the world of business, inspection is the critical appraisal of materials, items, or systems involving examination, testing, and gauging.

Quality control is a procedure or set of procedures intended to ensure that a manufactured product or performed service adheres to a defined set of quality criteria or meets the requirements of the client or customer. It may follow ISO standards also.

Objectives of Inspection:

(i) Inspection separates defective com ponents from non-defective ones and thus ensures the adequate quality of products.

(ii) Inspection locates defects in raw materials and flaws in processes which otherwise cause problems at the final stage. For example, detecting the parts not having proper tolerances during processing itself, will minimize the troubles arising at the time of assembly.

(iii) Inspection prevents further work being done on semi-finished products already detected as spoiled.

(iv) Inspection makes sure that the product works and it works without hurting anybody, i.e., its operation is safe.

(v) Inspection detects sources of weak ness and trouble in the finished products and thus checks the work of designers.

(vi) Inspection builds up the reputation of the concern as it helps reducing the number of complaints from the customers.

Quality Control

- Quality control can be defined as that Industrial Management technique by means of which product of uniform acceptable quality is manufactured.

- **Factors Affecting Quality**

(1) Men, Materials and Machines
(2) Manufacturing conditions
(3) Market research in demand of purchases
(4) Money in capability to invest
(5) Management policy for quality level
(6) Production methods and product design
(7) Packing and transportation
(8) After sales service

PROF.SYED MANSUR NOOR
JDIET,YAVATMAL

Kinds of Inspection:

(a) Roving, process, patrolling or floor inspection.

The inspector walks round on the shop floor from machine to machine and checks samples of the work of various machine operators or workers.

(i) Helps catching errors during process itself, i.e., before the final production is ready; and

(ii) It is more effective and desirable because the work need not be transported to a centralized (inspection) place.

Incoming raw materials are inspected in order to:

(i) Eliminate those materials which do not meet specifications and are likely to cause trouble during processing; and to

(ii) Evaluate vendor's quality and ability to supply acceptable materials.

Raw materials involving high transportation charges are checked by the buyer at vendor's end whereas others are inspected as soon as received at purchaser's plant. Inspection of raw materials may involve a visual check up only, a dimensional check, a test of physical properties and chemical composition, etc.

Raw materials depending upon their characteristics and use may require a Sampling Inspection or 100% Inspection (as in purchased aircraft component parts). After inspection, the right quality parts are sent either to stock room or assembly lines.

(b) Fixed Inspection:

The work is brought at intervals for inspectors to check. Fixed inspection discovers defects after the job has been completed. Fixed inspection is used when inspection equipments and tools cannot be brought on the shop floor. It is a sort of centralized inspection, the worker and the inspector do not come in contact with each other; thus it eliminates any chances of passing a doubtful product.

(c) Key-Point Inspection:

Every product (more or less) has a key point in its process of manufacture. A key point is a stage beyond which either the product requires an expensive operation or it may not be capable of rework. Inspection at a key point segregates and thus avoids unnecessary further expenditure on poor and substandard parts, which are likely to be rejected finally.

In process Inspection:

An effective in process inspection eliminates:

(i) Defects so that the subsequent operation is not badly affected;

(ii) A defect which may be concealed in the final product (e.g., after painting, etc.);

(iii) Extra work from being performed on reject able materials.

In-process inspection is carried out by:

(a) Workers doing the job.

(b) Inspectors from the inspection department.

In process inspection may check:

(a) A first few parts of the new machine set up, or a new operation.

(b) A part before it moves for the next operation.

(c) A part before it goes for an expensive operation.

(d) A part after a series of manufacturing operations.

(e) Parts before sub-assembly or final assembly.

(f) A part before it is being sent for plating or painting.

(g) A part before it moves to the next department.

For in process inspection, the inspectors are stationed at specific stages in the manufacturing process.

(d) Final Inspection:

The final inspection of the product may check its appearance and performance. Many destructive and non-destructive inspection and test methods such as tensile, fatigue, impact testing, etc., and ultrasonic inspection, X-ray radiography, etc., respectively, are available for final inspection of the products manufactured. Final inspection is a centralized inspection and it makes use of special equipments.

Inspection of Finished Goods:

An unthorough inspection of finished and final goods may permit

Control Limit Formulas & Constants (A2, D3, & D4)

In Textbook pg. 167

$\bar{x}$ Chart Control Limits

$$UCL = \bar{\bar{x}} + A_2\bar{R}$$

$$LCL = \bar{\bar{x}} - A_2\bar{R}$$

R Chart Control Limits

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

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

Our sample size n= ?

n	A2	D3	D4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74

here N subgroup size is 3

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	11.1	10.1	9.8	11.3	11.2
	9.2	11.2	10.2	10.1	9.4
	11.3	9.9	9.9	10.1	8.9
x-bar	10.5	10.4	10.0	10.5	9.8
R	2.1	1.3	0.4	1.2	2.3

N = 3

R Chart

Centerline = $\bar{R} = \frac{2.1 + 1.3 + 0.4 + 1.2 + 2.3}{5} = \frac{7.3}{5} = 1.46$

Upper Control Limit = UCL = $D_4(\bar{R}) = 2.57(1.46) = 3.75$

Lower Control Limit = LCL = $D_3(\bar{R}) = 0(1.46) = 0$

x-bar Chart

Centerline = $\bar{\bar{x}} = \frac{10.5 + 10.4 + 10.0 + 10.5 + 9.8}{5} = 10.24$

Upper Control Limit = $\bar{\bar{x}} + A_2(\bar{R}) = 10.24 + 1.02(1.46) = 11.73$

Lower Control Limit = $\bar{\bar{x}} - A_2(\bar{R}) = 10.24 - 1.02(1.46) = 8.75$

P-Chart Example: A production manager for a tire company has inspected the number of defective tires in five random samples with 20 tires in each sample. The table below shows the number of defective tires in each sample of 20 tires. Calculate the control limits.

Sample	Number of Defective Tires	Number of Tires in each Sample	Proportion Defective
1	3	20	**.15**
2	2	20	**.10**
3	1	20	**.05**
4	2	20	**.10**
5	2	20	**.05**
Total	9	100	**.09**

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}}$$

$$CL = \bar{p}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}}$$

Solution:

$$\mathbf{CL} = \bar{\mathbf{p}} = \frac{\#\mathbf{Defectives}}{\mathbf{Total\ Inspected}} = \frac{9}{100} = .09$$

$$\sigma_{\mathbf{p}} = \sqrt{\frac{\bar{\mathbf{p}}(\mathbf{1}-\bar{\mathbf{p}})}{\mathbf{n}}} = \sqrt{\frac{(.09)(.91)}{20}} = 0.64$$

$$\mathbf{UCL_p} = \bar{\mathbf{p}} + \mathbf{z}(\sigma) = .09 + 3(.064) = .282$$

$$\mathbf{LCL_p} = \bar{\mathbf{p}} - \mathbf{z}(\sigma) = .09 - 3(.064) = -.102 = 0$$

C-Chart Example: The number of weekly **customer complaints** are monitored in a large hotel using a c-chart. Develop **three sigma control limits** using the data table below.

$UCL = \bar{c} + 3\sqrt{\bar{c}}$

$CL = \bar{c}$

$LCL = \bar{c} - 3\sqrt{\bar{c}}$ or 0 if LCL is negative

Week	Number of Complaints
1	3
2	2
3	3
4	1
5	3
6	3
7	2
8	1
9	3
10	1
Total	**22**

Solution:

$$CL = \frac{\#\,\text{complaints}}{\#\,\text{of samples}} = \frac{22}{10} = 2.2$$

$$UCL_c = \bar{c} + z\sqrt{\bar{c}} = 2.2 + 3\sqrt{2.2} = 6.65$$

$$LCL_c = \bar{c} - z\sqrt{\bar{c}} = 2.2 - 3\sqrt{2.2} = -2.25 = 0$$

How to Implement Total Quality Management?

1. Commitment from Employees
2. Quality Improvement Culture
3. Continuous Improvement in Process
4. Co-operation from Employees
5. Focus on Customer Requirements
6. Effective Control shall be laid down

Definition

- **ISO 9000** is a *series* of standards , development and published by the ISO that define , establish and maintain an effective quality assurance system for manufacturing and service industries.

What is ISO

- ISO is a name used for the International Organization for Standardization
- ISO is not an acronym
- It was formed in 1947 in Geneva Switzerland.
- It is a federation of national standard bodies of 143 countries.

OBJECTIVES

- To Facilitate International Trade Of Goods and Services.
- To obtain competitiveness by obtaining required quality in a cost effective way.
- Promoting a Total Quality Control System(TQC)

PRINCIPLES OF ISO

1. Customer focus
2. Leadership
3. Involvement of people
4. Process approach
5. System approach to management
6. Continual improvement
7. Factual approach to decision making
8. Mutually beneficial supplier relationships

PRINCIPLES OF NEW STANDARD

1.Customer focus

- Organizations depend on their customers and therefore should understand current and future customer needs, should meet customer requirements and strive to exceed customer expectations.
- Key benefits : Increased revenue and market Share obtained through flexible and fast Responses to market opportunities.

2.Leadership

- Leaders establish unity of purpose and direction of the organization. They should create and maintain the internal environment in which people can become fully involved in achieving the organization's objectives.
- Key benefits : People will understand and be motivated towards the organization's goals and objectives.

Activities are evaluated, aligned and implemented in a unified way.

Miscommunication between levels of an organization will be minimized.

3. Involvement of people

- People at all levels are the essence of an organization and their full involvement enables their abilities to be used for the organization's benefit.
- Key benefits : Motivated, committed and involved people within the organization.

Innovation and creativity in furthering the organization's objectives.

People being accountable for their own performance. People eager to participate in and contribute to continual improvement.

4.Process Approach

- A desired result is achieved more efficiently when activities and related resources are managed as a process.
- Key benefits : Lower costs and shorter cycle times through effective use of resources.
  Improved, consistent and predictable results.
  Focused and prioritized improvement opportunities.

5. System Approach to Management

- Identifying, understanding and managing interrelated processes as a system contributes to the organization's effectiveness and efficiency in achieving its objectives.
- Key benefits : Integration and alignment of the processes that will best achieve the desired results.

  Ability to focus effort on the key processes.

  Providing confidence to interested parties as to the consistency, effectiveness and efficiency of the organization.

6.Continual Improvement

- Continual improvement of the organization's overall performance should be a permanent objective of the organization.
- Key benefits : Performance advantage through improved organizational capabilities.

Alignment of improvement activities at all levels to an organization's strategic intent.

Flexibility to react quickly to opportunities.

7.Factual approach to decision making

- Effective decisions are based on the analysis of data and information.
- Key benefits : Informed decisions.

An increased ability to demonstrate the effectiveness of past decisions through reference to factual records.

Increased ability to review, challenge and change opinions and decisions.

8.Mutually beneficial supplier relationships

- An organization and its suppliers are interdependent and a mutually beneficial relationship enhances the ability of both to create value.
- Key benefits : Increased ability to create value for both parties.

Flexibility and speed of joint responses to changing market or customer needs and expectations.

Optimization of costs and resources.

ISO 14000

- INTRODUCTION : In the present day, environmental matter is not limited only in one country or specific area. The environmental impact effects everywhere and leads to problem all over the world.
- Environmental conservation has become so complicated that it causes pressure to all business organizations.
- The International Organization for Standardization had led to the development of the International Standard for environmental management system series (ISO 14000).

ELEMENTS OF ISO 14001

- General Requirements
- Environmental Policy
- Planning
- Implementation & Operation
- Checking & Corrective action
- Management review

Environmental management system model

1. Environmental policy

Initially, the organization's top management should have commitment and define the policy on EMS which is used for the direction of implementing and improving its EMS.

2. Planning

In order to achieve environmental policy, at least, the organization should

Identify the environmental aspects of its activities and specify those which have significant impacts on the environment.

Establish objectives and targets of its activities having impacts to environment.

Establish environmental programs for achieving its objectives and targets.

3. Implementation

•In order to achieve environmental planning, at least, the organization should :

•Define roles, responsibilities and authorities for facilitating EMS effectively.

•Communicate to the staffs at each level for the importance of conformance to the environmental policy; provide appropriate training to personnel performing the tasks to gain their knowledge and competence.

•Identify potential accidents and emergency situations for preventing and mitigating the environmental impacts that may be associated with them and periodically test such procedures where practicable.

4. Checking and corrective action

- To ensure that the organization is performing in accordance with the stated EMS programmes, at least, the organization should:
- Monitor and measure its operations and activities against the organization's plans.
- Record the on-going activities of the EMS.
- Conduct periodic EMS audits.

5. Management review

- The organization's top management should review and continually improve its EMS, with the objective of improving its overall environmental performance.

CONCLUSION

- It can be applied to any type of organization
- It help in maintaining an efficient quality system in an organization
- It creates confidence in customer on quality of product supplied
- It act as competitive barrier

What is Just-in-Time (JIT)?

- Supplies and products are pulled through system to arrive where they are needed, when they are needed
- A management philosophy of continuous and forced problem-solving via a focus on throughput time and reduced inventory
- JIT's mandate: *Eliminate all waste!*

Just in Time (JIT) – a Business Philosophy

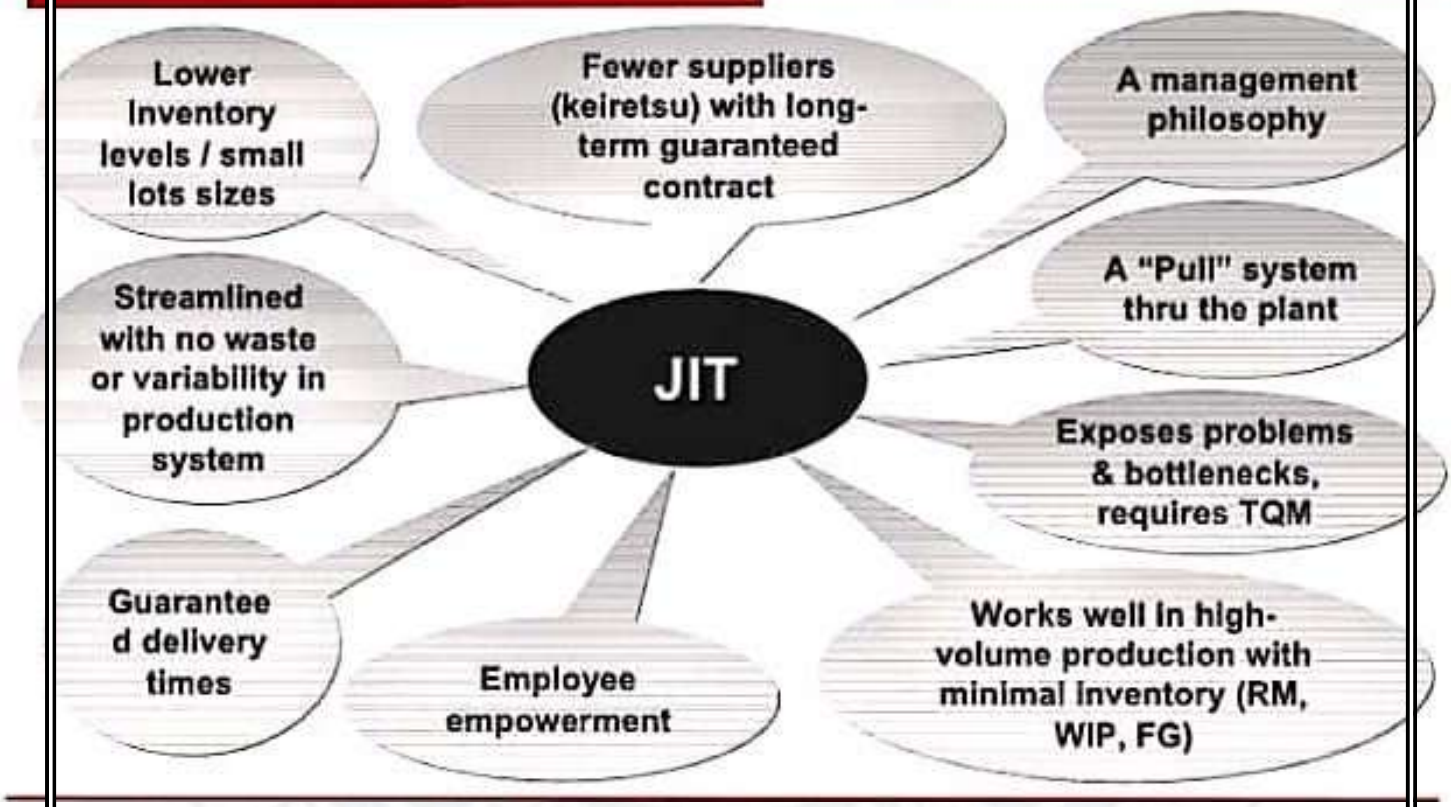
- Production system: manufacturing & movement of materials and goods occur just when they are needed, usually in small batches
- JIT operates with very little "fat" (waste)
- Defines waste in terms of customer value

JIT Goals

- Eliminate disruptions
- Make system flexible by reduce setup and lead times
- Eliminate waste, especially excess inventory

What is JIT Inventory?

- The minimum amount of inventory necessary to keep a perfect system running smoothly
- Objective is to minimize the stock of parts and components by having them delivered just in time for production and to limit the inventory of finished goods by producing them just in time to fill demand


JIT
Lower inventory levels / small lots sizes
Fewer suppliers (keiretsu) with long-term guaranteed contract
A management philosophy
Streamlined with no waste or variability in production system
A "Pull" system thru the plant
Exposes problems & bottlenecks, requires TQM
Guarantee d delivery times
Employee empowerment
Works well in high-volume production with minimal inventory (RM, WIP, FG)

- Smooth flow of work (the ultimate goal)
- Elimination of waste
- Continuous improvement
- Eliminating anything that does not add value
- Simple systems that are easy to manage
- Use of product layouts to minimize moving materials and parts
- Quality at the source

Benefits of JIT

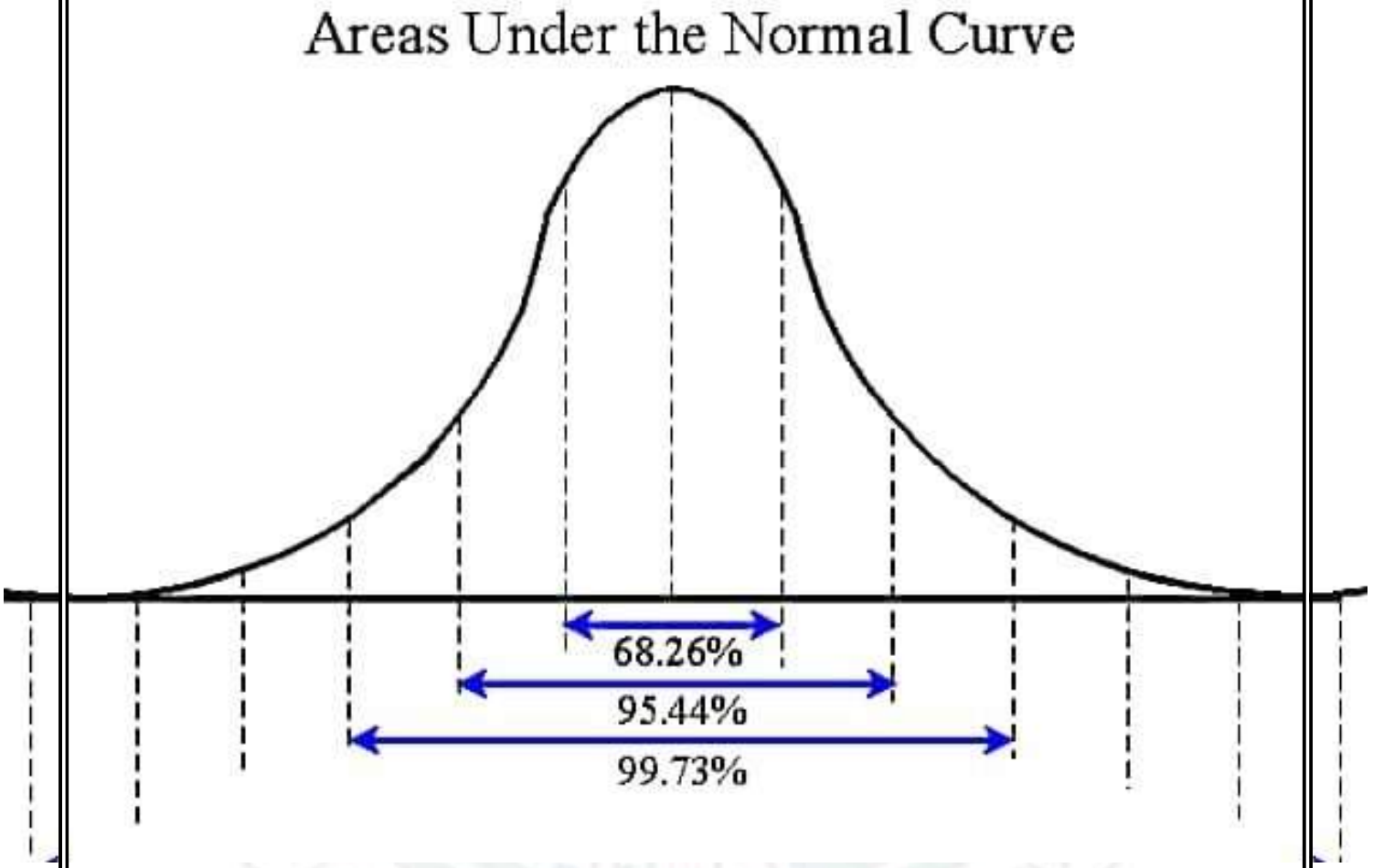
1. Reduced inventory
2. Improved quality
3. Lower costs
4. Reduced space requirements
5. Reduced lead times
6. Increased productivity
7. Greater flexibility
8. Reduced scrap and rework
8. Better relations with suppliers
9. Simplified scheduling and control activities
10. Increased capacity
11. Increased equipment utilization
12. Better use of human resources
13. More product variety
14. Reduced need for indirect labor

What is six sigma..????

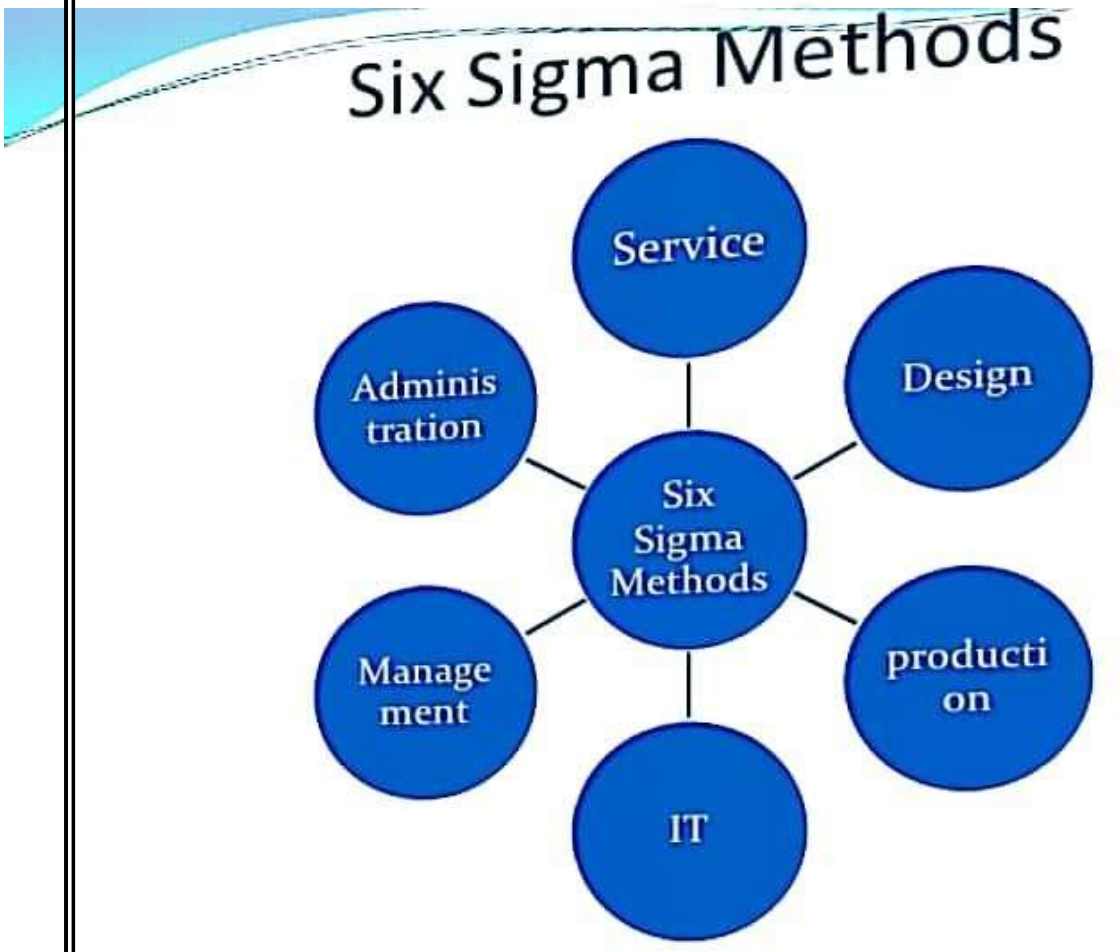
- Six sigma is a business statistical Strategy.
- Is to identifying defects and removing them from the process of products to improve quality.
- A defect is defined as any process output that does not meet customer specifications.
- Statistical measure to objectively evaluate processes.

History of six sigma

- The Six sigma was founded by Motorola in the 1970s.
- Out of senior executive Art Sundry's criticism of Motorola's bad quality.
- They founded a connection between increases in quality and decreases in costs of production.
- **Bill Smith,** "Father of six sigma" introduce this quality improvement Methodology to Motorola.


Areas Under the Normal Curve
68.26%
95.44%
99.73%

Sigma Level	DPMO Defects per Million Opportunities
2 σ	308'537.0
3 σ	66'807.0
4 σ	6'210.0
5 σ	233.0
6 σ	3.4


Six Sigma Methods
Service
Design
production
IT
Management
Administration
Six Sigma Methods

APPROACHES OF SIX SIGMA

- **DMAIC APPROACH**

THIS IS ORGANIZATIONAL BASED

- **DMADV APPROACH**

THIS IS BASED ON CUSTOMER NEEDS AND SATIFACTIONS

DMAIC APPROACH

6σ

It approach undertaken to improve existing business process

CONTINUE...

6σ

1.***Define*** high-level project goals and the current process.

2.***Measure*** key aspects of the current process and collect relevant data.

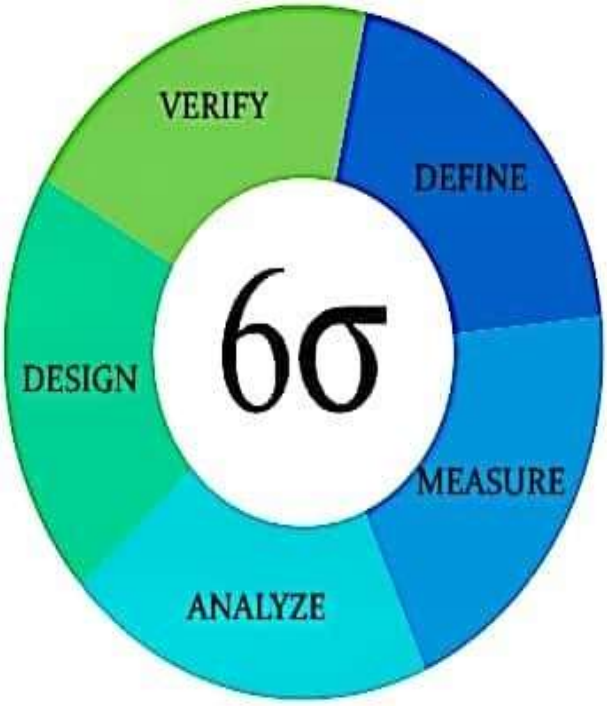
3.***Analyze*** the data to verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered.

4.***Improve*** or optimize the process based upon data analysis using various tools

5.***Control*** to ensure that any deviations from target are corrected before they result in defects.

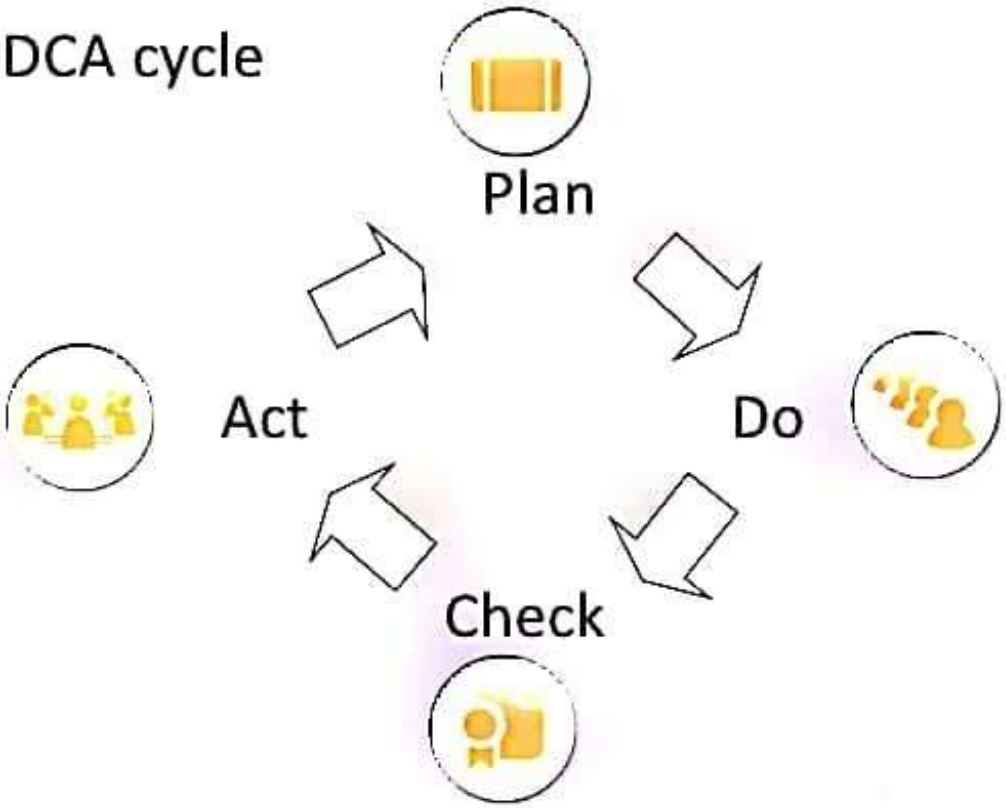
DMADV APPROACH 6σ

This approach is undertaken when there is a need to create new design or product:



Improvement cycle

- PDCA cycle




SORT:
Eliminate what is not needed.
SET IN ORDER:
Organize what remains.
SHINE:
Clean work area.
STANDARDIZE:
Schedule cleaning and maintaining.
SUSTAIN:
Make 7s a way of life.
SPIRIT:
Employee engagement across all levels.
SAFETY:
Create a safe work environment.
7S

7S

1. **Sort** - All unneeded tools, parts and supplies are removed from the area
2. **Set in Order** - A place for everything and everything is in its place
3. **Shine** - The area is cleaned as the work is performed
4. **Standardize** - Cleaning and identification methods are consistently applied
5. **Sustain** - 7S is a habit and is continually improved
6. **Safety** - Improved safety
7. **Spirit** - Reliance on the people factor

Lean Manufacturing Definition

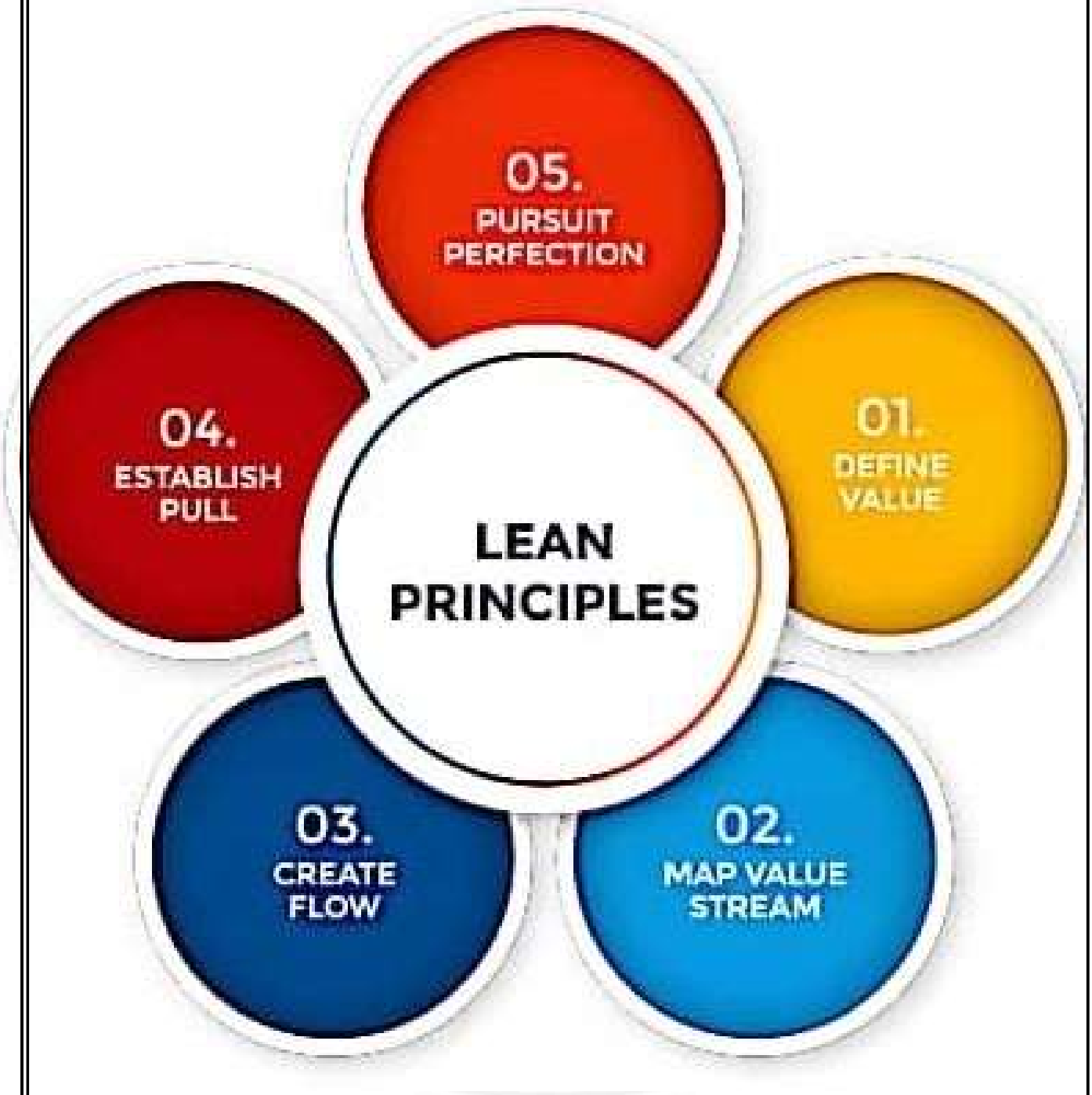
"A philosophy of production that emphasizes the minimization of the amount of all the resources (including time) used in the various activities of the enterprise. It involves identifying and eliminating non-value-adding activities in design, production, supply chain management, and dealing with the customers. . ."

– APICS

Lean Manufacturing System (LMS)

The Lean Manufacturing system has been described as one,

- which seeks to eliminate unnecessary wasteful processes,
- to align processes in a continuous flow
- to use resources in order to solve problems in a never-ending process.


05.
PURSUIT
PERFECTION
04.
ESTABLISH
PULL
01.
DEFINE
VALUE
LEAN
PRINCIPLES
03.
CREATE
FLOW
02.
MAP VALUE
STREAM

1 Specifying Value

Value can only be defined by the ultimate customer

"Value is only meaningful when expressed in terms of a specific product or service which meets the customer needs at a specific price at a specific time"

2 Identify and create value streams

"A value stream is all the actions currently required to bring a product from raw materials into the arms of the customer"

3 Making value flow

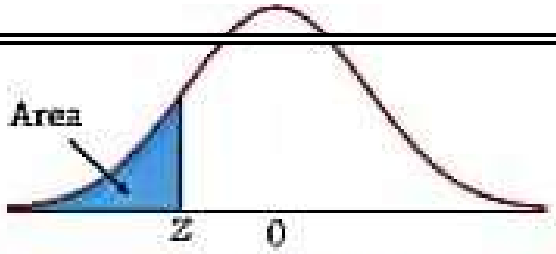
"Products should flow through a lean organisation at the rate that the customer needs them, without being caught up in inventory or delayed"

4 Pull production not push

"Only make as required. Pull the value according to the customer's demand"

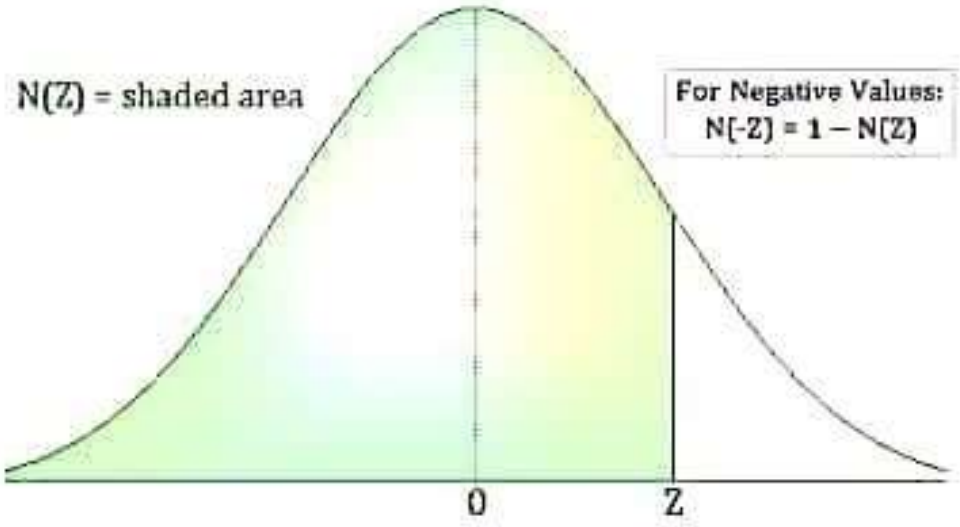
5 Striving for perfection

Perfection does not just mean quality. It means producing exactly what the customer wants, exactly when the customer requires it, at a fair price and with minimum waste.

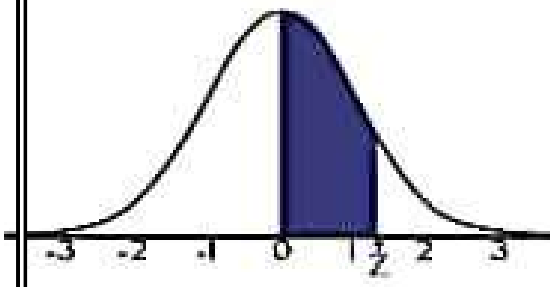


z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
-3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
-3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
-0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641

Table of Values for N(Z)



Tenths Digits	Hundredths Digits									
	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998



STANDARD NORMAL TABLE (Z)

Entries in the table give the area under the curve between the mean and z standard deviations above the mean. For example, for $z = 1.25$ the area under the curve between the mean (0) and z is 0.3944.

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0190	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2969	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3513	0.3554	0.3577	0.3529	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990
3.1	0.4990	0.4991	0.4991	0.4991	0.4992	0.4992	0.4992	0.4992	0.4993	0.4993
3.2	0.4993	0.4993	0.4994	0.4994	0.4994	0.4994	0.4994	0.4995	0.4995	0.4995
3.3	0.4995	0.4995	0.4995	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996	0.4997
3.4	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4998