ST.ANNE'S

COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

ME8691 -COMPUTER AIDED DESIGN AND MANUFACTURING

UNIT-1

INTRODUCTION

PRODUCT LIFE CYCLE (PLC)

Every product goes through a cycle from birth, followed by an initial growth stage, a relatively stable matured period, and finally into a declining stage that eventually ends in the death of the product as shown schematically in *Figure.*

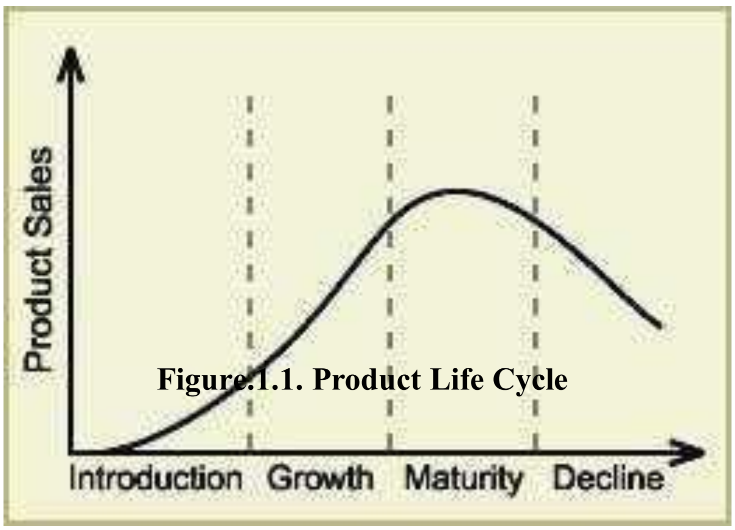
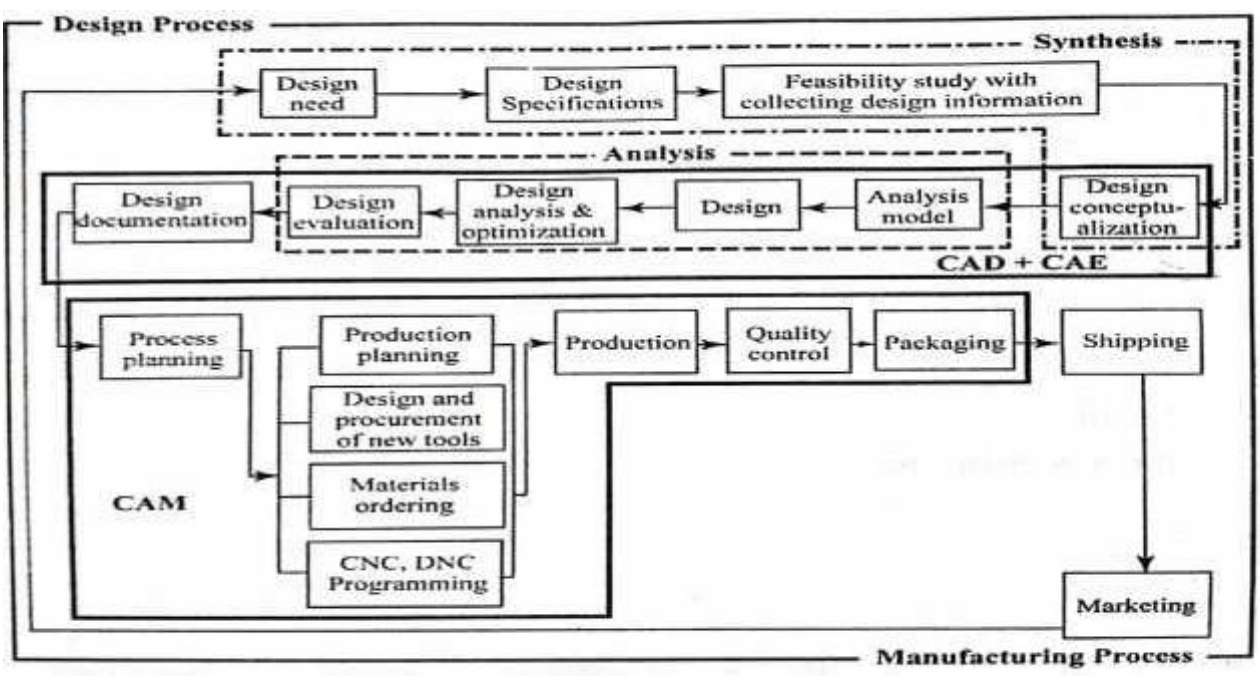


Figure.1.1. Product Life Cycle



(1) *Introduction stage*: In this stage the product is new and the customer acceptance is low and

hence the sales are low.

(2) *Growth stage*: Knowledge of the product and its capabilities reaches to a g rowing number of customers.

(3) *Maturity stage*: The product is widely acceptable and sales are now stable , and it grows with the same rate as the economy as a whole grows.

(4) *Decline stage*: At some point of time the product enters the decline st age. Its sales start decreasing because of a new and a better product has entered the market to fulfill the same customer requirements.

PRODUCT LIFE CYCLE (PLC) FOR CONTINUOUS IMPROVEMENT

Product Life Cycle for continuous Improvement (Basic)

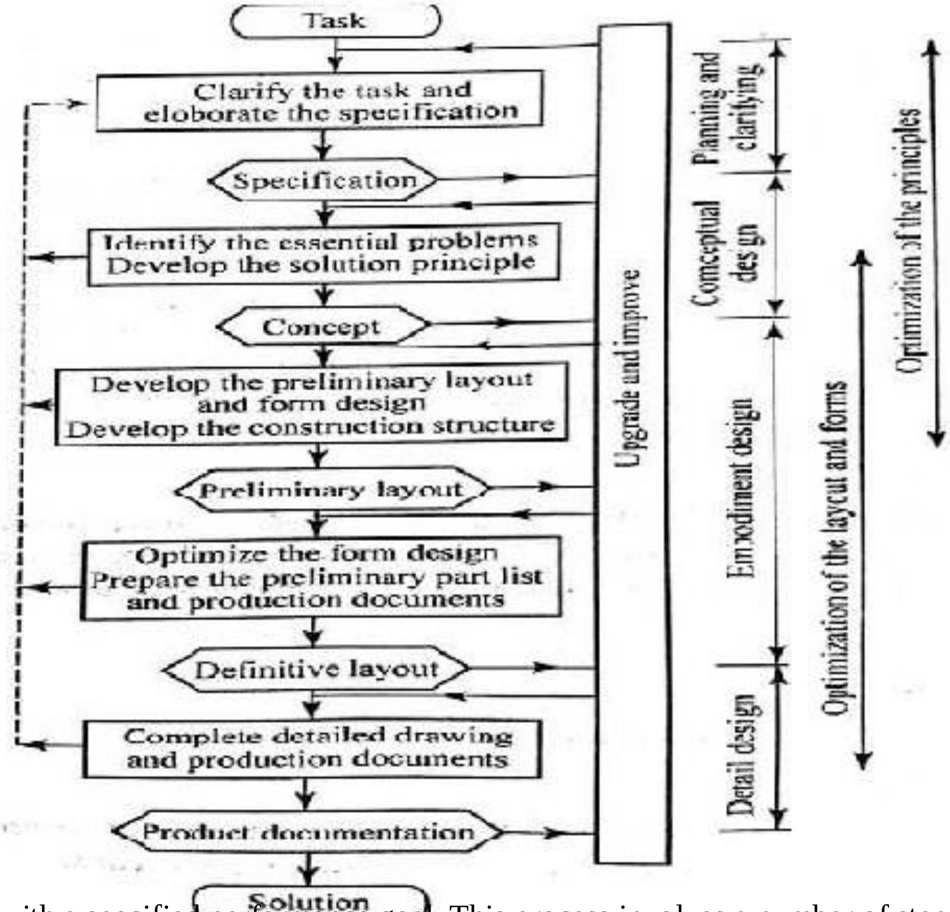
DESIGN PROCESS

Design is an activity that needs to be well organized and should take into account all influences that are likely to be responsible for the success of the product under development. The following models are considered in design purpose

1. Shigley
2. Pahl and Beitz
3. Ohsuga
4. Earle

THE DESIGN PROCESS - INTRODUCTION

The **Engineering Design Process** is the formulation of a plan to help an engineer build a

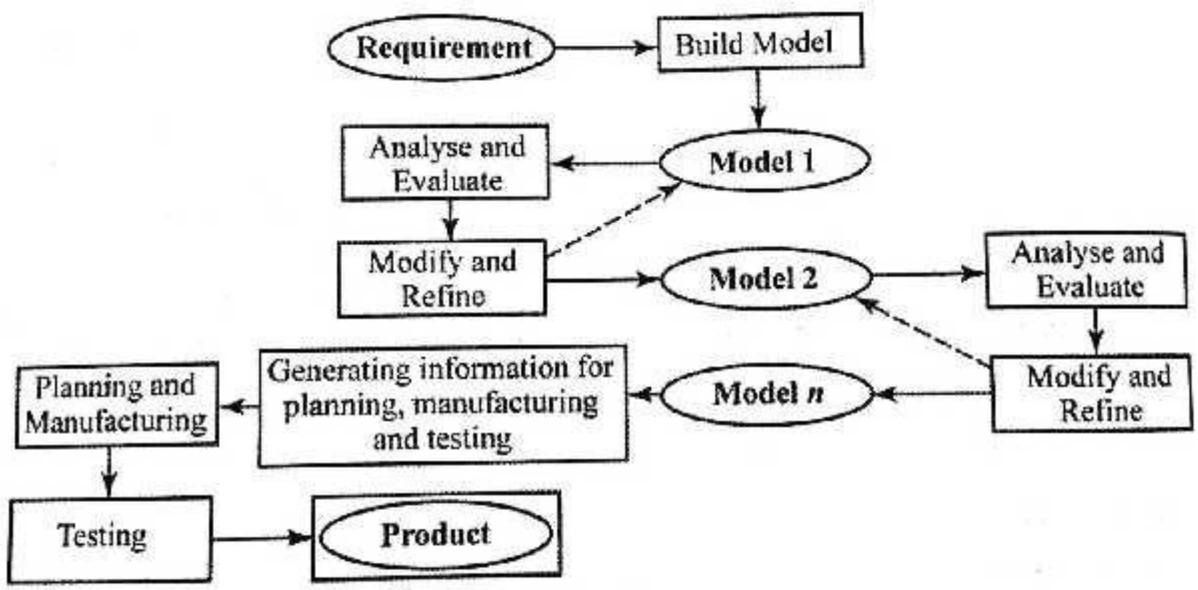


product with a specified performance goal. This process involves a number of steps, and parts of the process may need to be repeated many times before production of a final product can begin.

It is a decision making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

The Engineering Design process is a multi-step process including the research, conceptualization, feasibility assessment, establishing design requirements, preliminary design, detailed design, production planning and tool design, and finally production.

Ohsuga design Process:



Conceptual Design

It is a process in which we initiate the design and come up with a number of design concepts and then narrow down to the single best concept. This involved the following step s.

(1) *Identification of customer needs*: The mail objective of this is to completely understand the customers' needs and to communicate them to the design team

(2) *Problem definition*: The mail goal of this activity is to create a statement that describes what all needs to be accomplished to meet the needs of the customers' requirements.

(3) *Gathering Information*: In this step, we collect all the information that can be helpful for developing and translating the customers' needs into engineering design.

(4) *Conceptualization*: In this step, broad sets of concepts are generated that can potentially satisfy the problem statement

(5) *Concept selection*: The main objective of this step is to evaluate the various design concepts, modifying and evolving into a single preferred concept.

Embodiment Design

It is a process where the structured development of the design concepts takes place. It is in this phase that decisions are made on strength, material selection, size shape and spatial compatibility. Embodiment design is concerned with three major tasks - product architecture, configuration design, and parametric design.

(1) *Product architecture*: It is concerned with dividing the overall design system into small subsystems and modules. It is in this step we decide how the physical components of the design are to be arranged in order to combine them to carry out the functional duties of the design.

(2) *Configuration design*: In this process we determine what all features are required in the various parts / components and how these features are to be arranged in space relative to each other.

(3) *Parametric design*: It starts with information from the configuration design process and aims to establish the exact dimensions and tolerances of the product. Also, final decisions on the material and manufacturing processes are done if it has not been fixed in the previous process. One of the important aspects of parametric designs is to examine if the design is robust or not.

Detail Design

It is in this phase the design is brought to a state where it has the complete engineering description of a tested and a producible product. Any missing information about the arrangement, form, material, manufacturing process, dimensions, tolerances etc of each part is added and detailed engineering drawing suitable for manufacturing are prepared.

Models of the Design Process

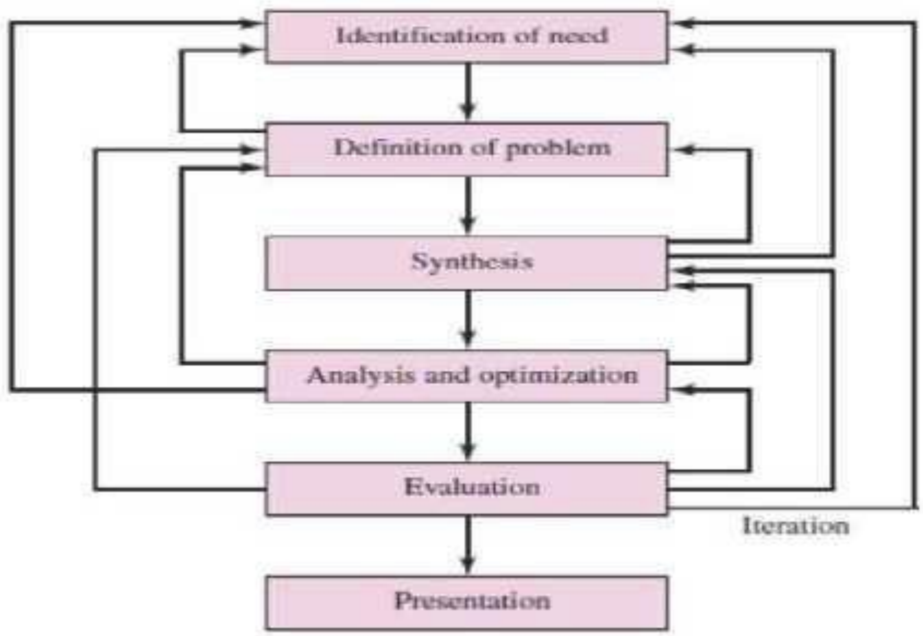
Designers have to:

Explore - the problem territory
Generate - solution concepts
Evaluate - alternative solution concepts
Communicate - a final proposal

DESIGN PROCESS MODELS

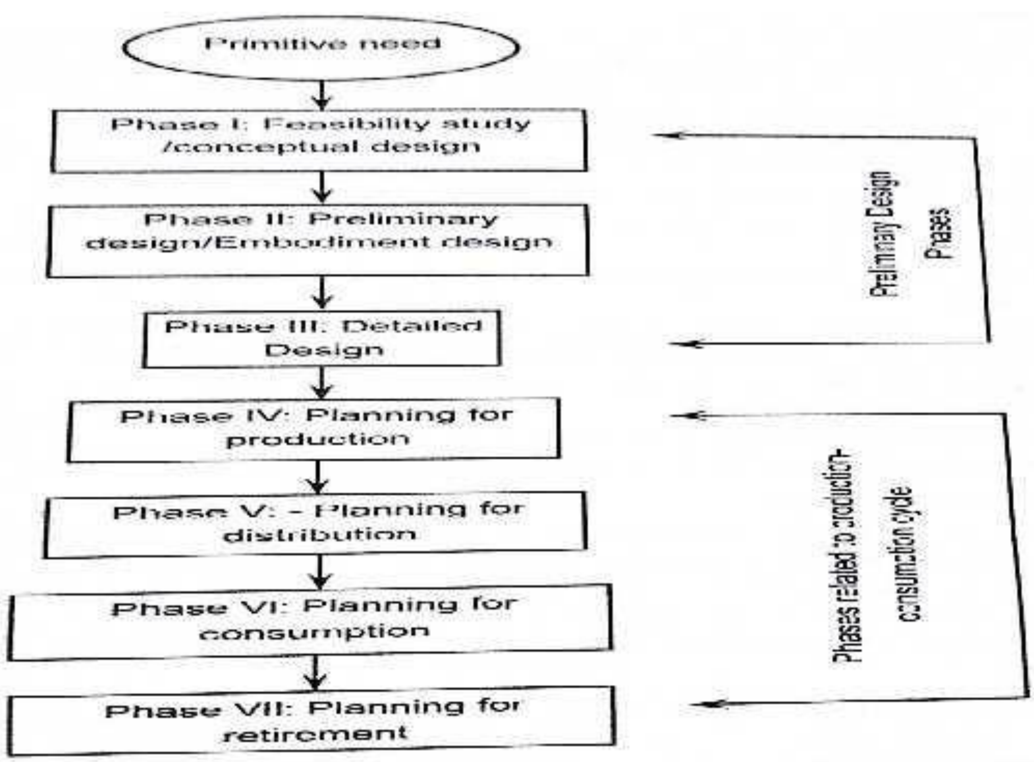
Ohsuga Model

Earle Model

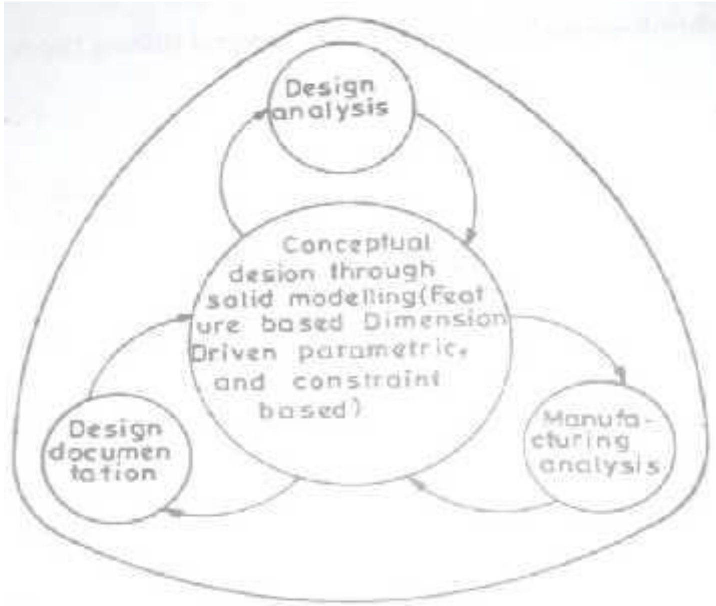


MORPHOLOGY OF DESIGN:

- Morphology design refers to the study of the chronological structure of design projects.
- It is defined by seven phases and their sub steps. Out of seven phases, the first three phases belong to the design the proposed by asimow and the remaining four phases belong to production, distribution, consumption and retirement.



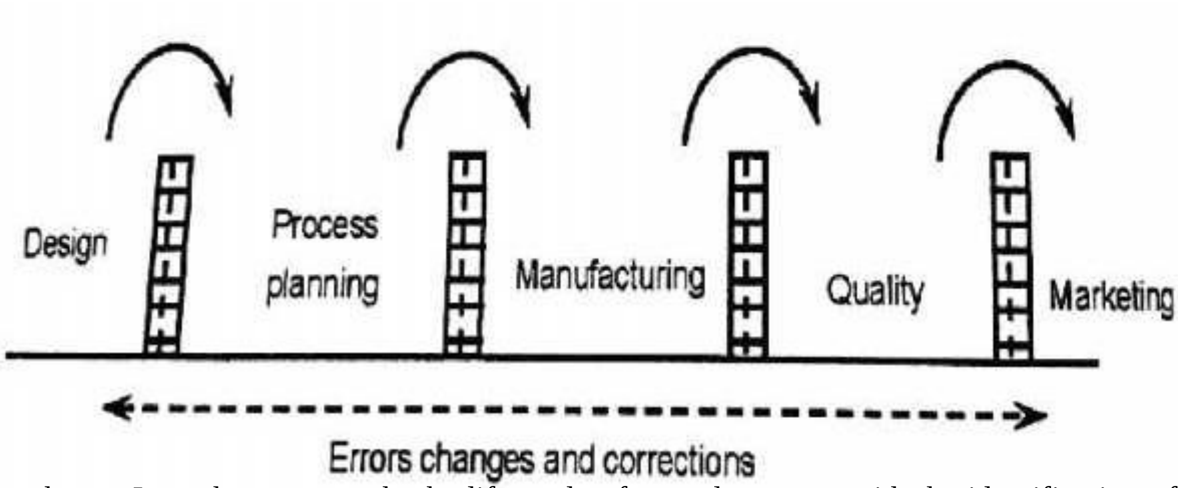
CONCURRENT ENGIN EERING DESIGN



SEQUENTIAL AND CONCURRENT ENGINEERING

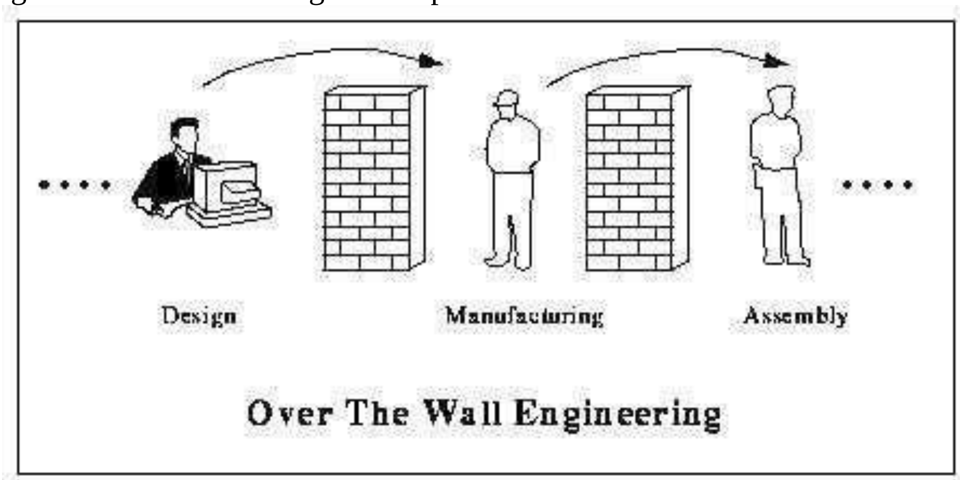
With today's marketplace becoming more and more competitive, there is an ever- increasing pressure on companies to respond quickly to market needs, be cost effective, reduce lead-times to market and deliver superior quality products.

Traditionally, design has been carried out as a sequential set of activities with d istinct non-

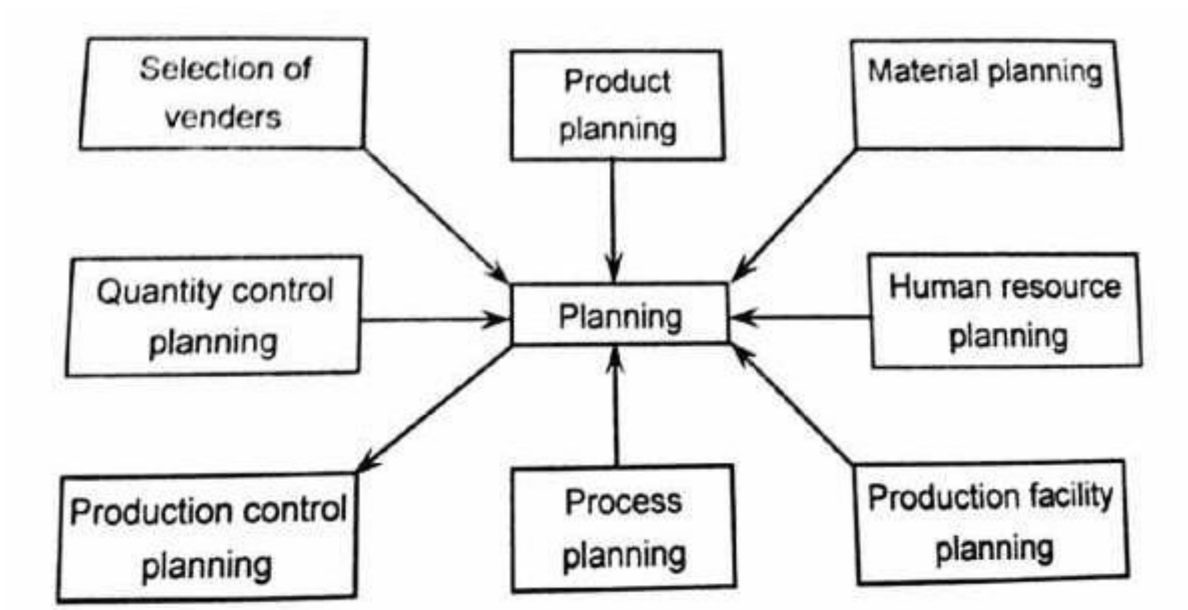


overlapping phases. In such an approach, the life-cycle of a product starts with the identification of the need for that product. These needs are converted into product requirements which are passed on to the design department. The designers design the product's form, fit, and function to meet all the requirements, and pass on the design to the manufacturing department.

After the product is manufactured it goes through the phases of assembly, testing, and installation. This type of approach to life-cycle development is also known as `over the wall' approach, because the different life-cycle phases are hidden or isolated from each other. Each phase receives the output of the preceding phase as if the output had been thrown over the wall. In such an approach, the manufacturing department, for example, does not know what it will actually be manufacturing until the detailed design of the product is over.

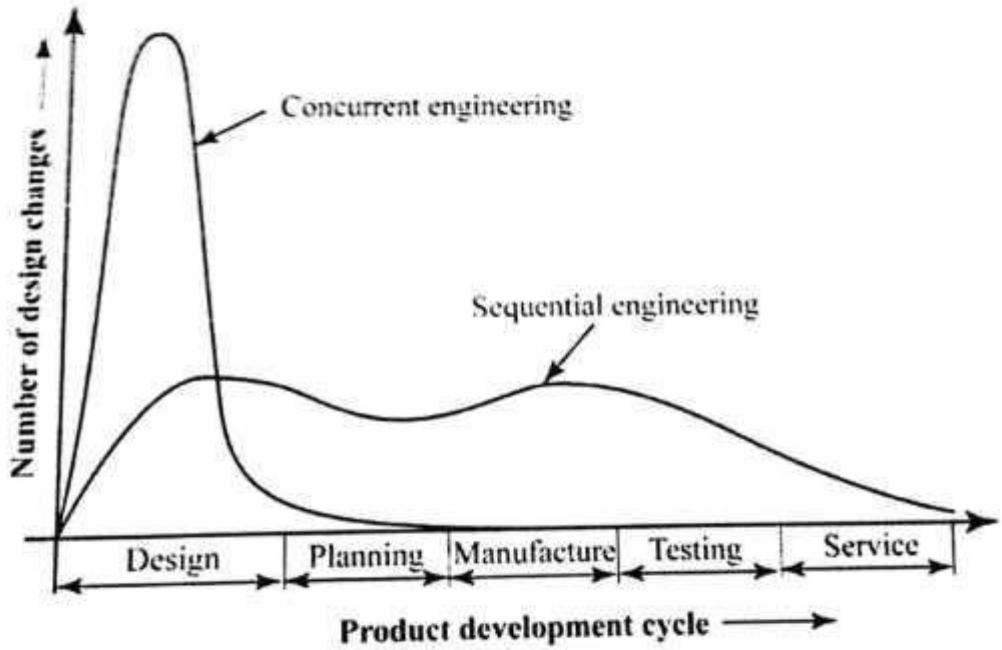


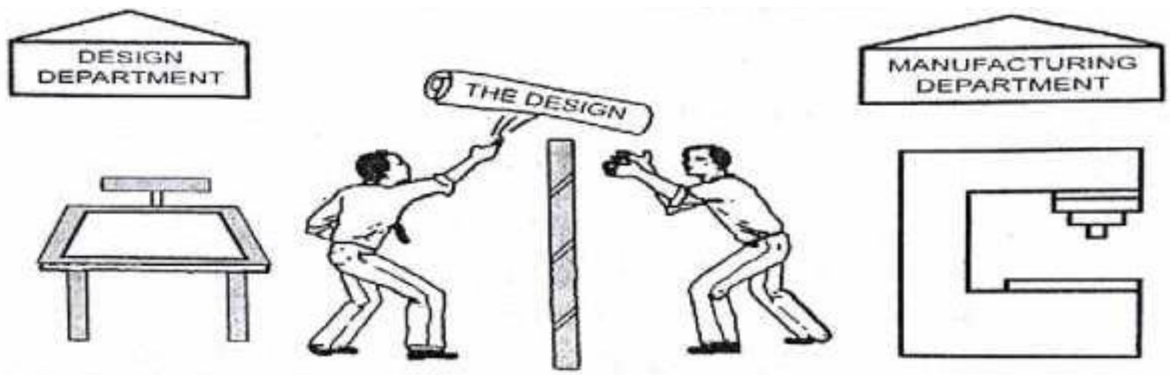
Over the Wall Engineering (Sequential Engineering)



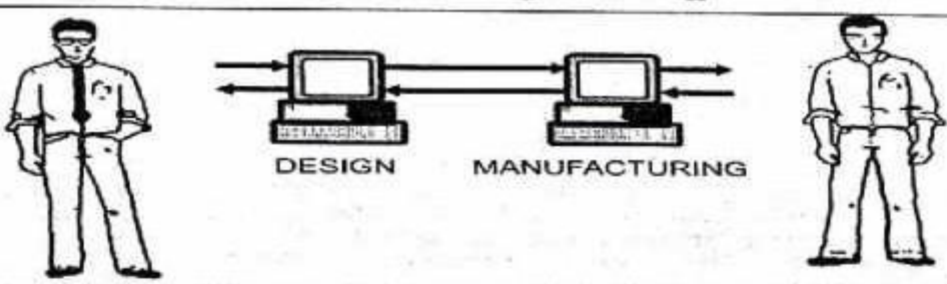
COMPARISION BETWEEN SEQUENTIAL AND CONCURRENT ENGINEERING

 Product development cost
 Number of design changes
 Lead time for product development
Customer satisfaction
 Coordination between departments



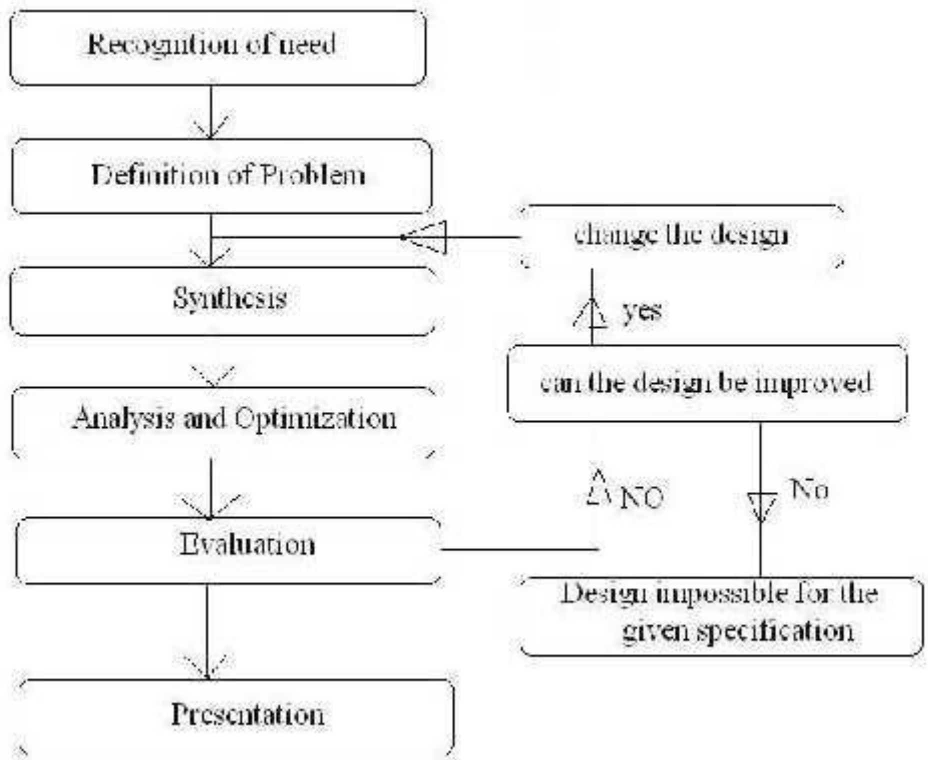


(a) Traditional design/manufacturing communication in sequential engineering

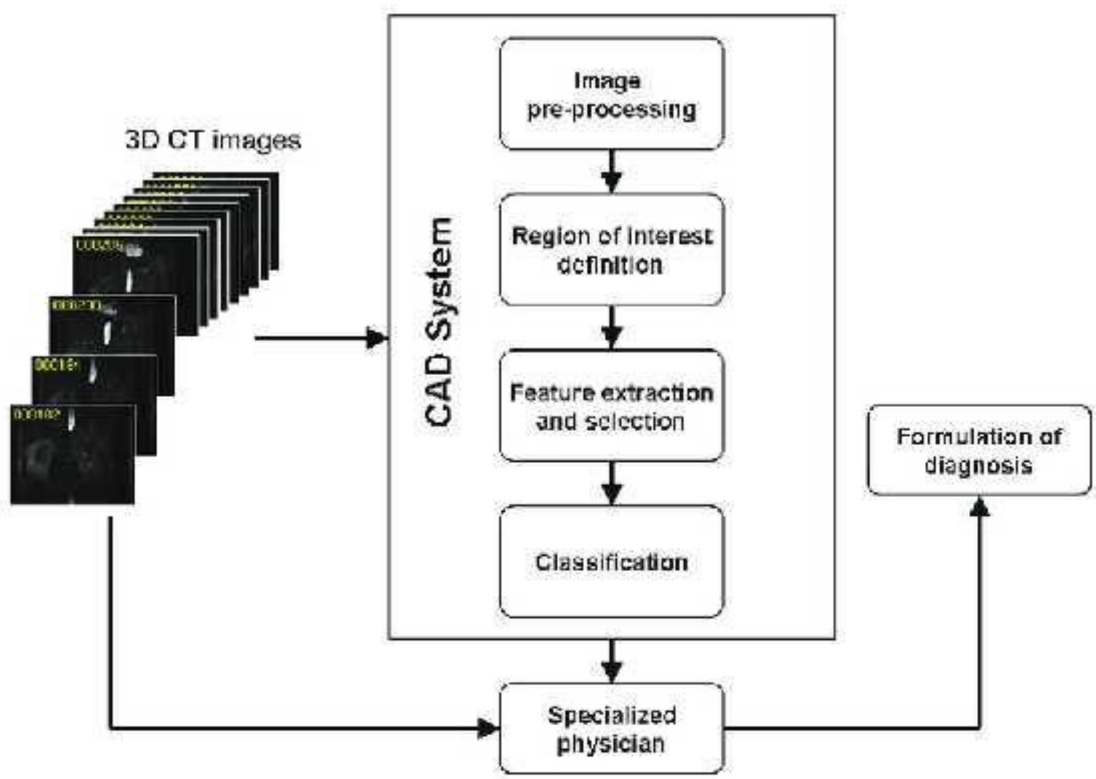


(b) Design/Manufacturing communication with CAD/CAM in concurrent engineering

ROLE OF COMPUTERS IN DESIGN

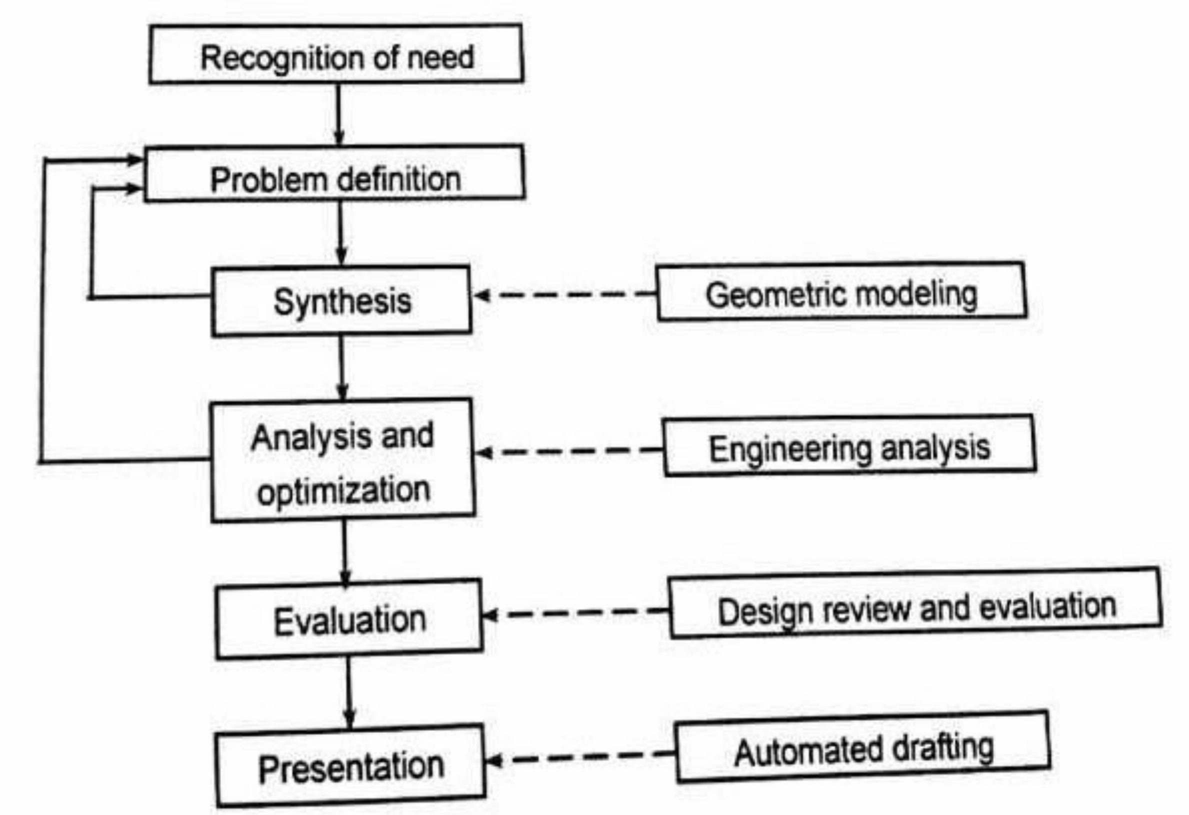


CAD SYSTEM ARCHITECTURE



Roles of CAD in Design

- Accurately generated and easily modifiable graphical representation of the product.
- User can nearly view the actual product on the screen, make any modification to it and present his ideas on screen without any prototype, especially during the early stages of the design process.
- Complex design analysis in short time. By implementing Finite Element Analysis (FEA) methods user can perform as follows
- Static, dynamic & natural frequency analysis
Heat transfer analysis
- Fluid flow analysis
- Plastic analysis
- It records and recalls information with consistency and speed
- Use of Product Data Management (PDM) systems can store the whole design and processing history of a certain product for future reuse and upgrade.



APPLICATION OF CAD

- Mechanical engineering
- Civil engineering
- Electrical and electronics engineering
- Textile industry

ADVANTAGES OF CAD

- Easy editing
- High quality
- Compact storage
- 3D Drawing

APPLICATION OF COMPUTERS TO DESIGN

- Modeling of the Design
- Engineering design and analysis
- Evaluation of Prototype through Simulation and
- Testing Drafting and Design Documentation

BENEFITS OF CAD

1. Productivity Improvement in Design
   Depends on Complexity of drawing,
   Degree of repetitiveness of features in the designed parts, Degree of symmetry in the parts,
   Extensive use of library of user defined shapes and commonly use d entities
2. Shorter Lead Times
3. Flexibility in Design
4. Design Analysis
5. Fewer Design Error
6. Standardization of Design, Drafting and Documentation
7. Drawings are more understandable
8. Improved Procedures of Engineering Changes
9. Benefits in Manufacturing :
   a. Tool and fixture design for manufacturing
   b. Computer Aided process planning
   c. Preparation of assembly lists and bill of materials
   d. Computer aided inspection
   e. Coding and classification of components
   f. Production planning and control
   g. Preparation of numerical control programs for manufacturing the parts on CNC machines
   h. Assembly sequence planning

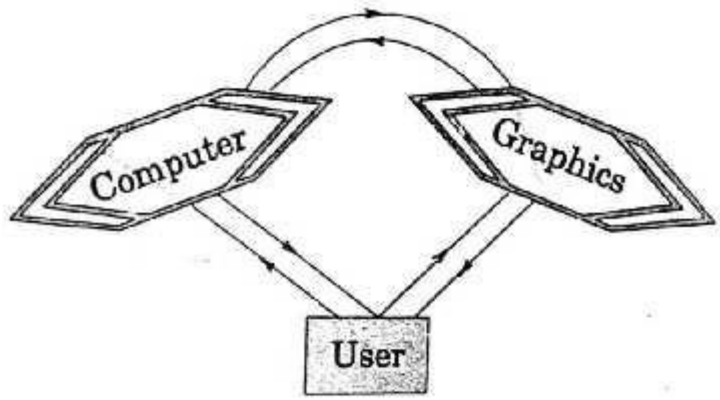
REASONS FOR IMPLEMENTING CAD

- To increase the productivity of the designer
- To improve the Quality of Design
- To improve Documentation
- To create a Database for manufacturing

COMPUTER GRAPHICS or INTERACTIVE COMPUTER GRAPHICS

- Computer Graphics is defined as creation, storage, and manipulation of pictures and drawings by means of a digital computer
- It is an extremely effective medium for communication between people and computers
- Computer graphics studies the manipulation of visual and geometric information using computational techniques

- It focuses on the mathematical and computational foundations of image generation and processing rather than purely aesthetic issues



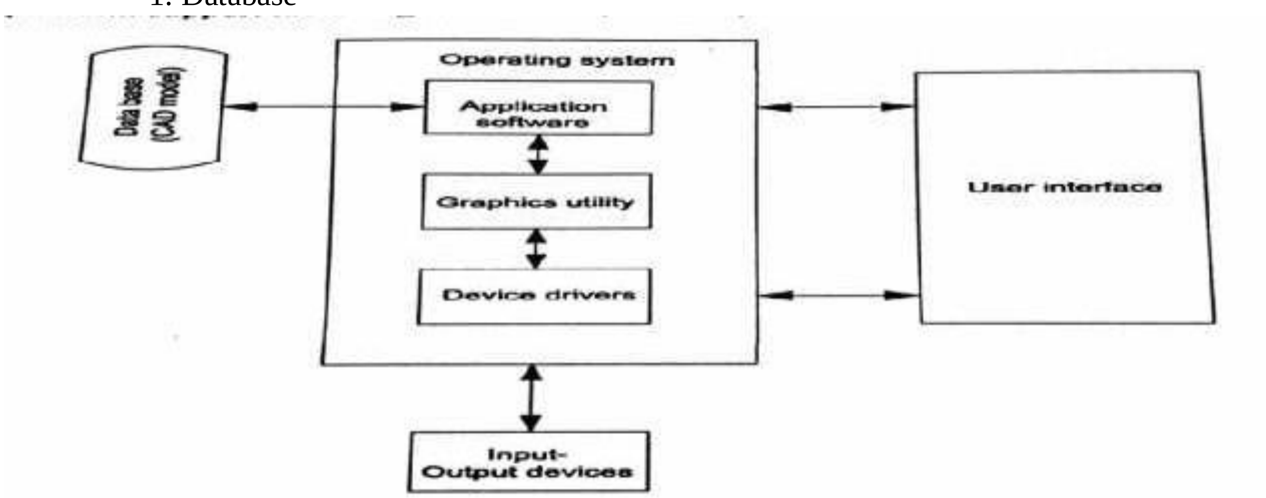
Concept of Interactive computer Graphics

In Interactive Computer Graphics (ICG) the user interacts with the compute and comprises the following important functions:

A coordinate system is o ne which uses one or more numbers, or coordinates, to uniquely determine the position of a point or other geometric element on a manifold such as Euclidean space.

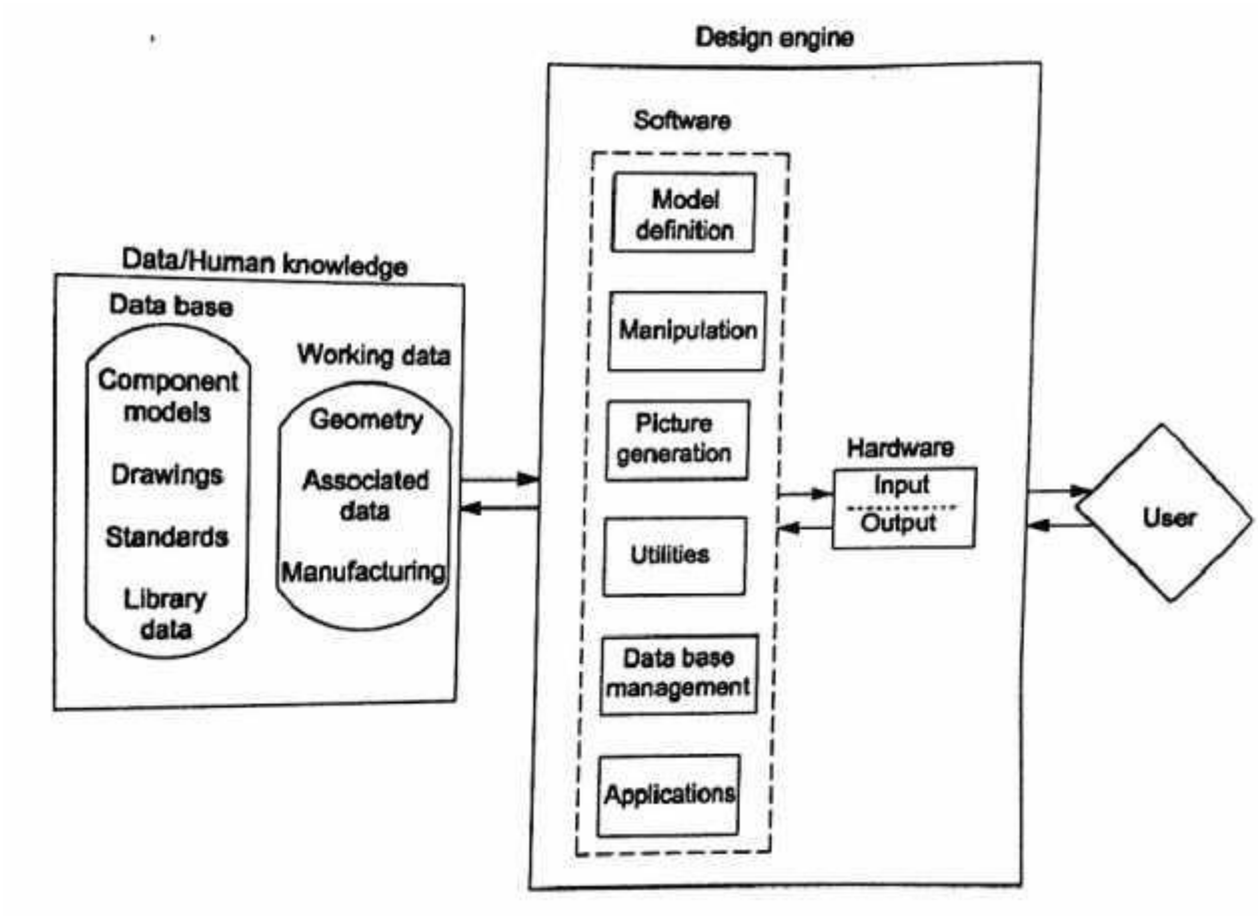
CAD SYSTEM ARCHITECTURE

- It is an early model which was used for the basic geometry construction and modelling purpose.
- Four major components of *CAD System Architecture are*
    1. Database



2. Operating system
3. Input/output devices
4. User interface

COMPUTER GRAPHICS (CG) COMPUTER GRAPHICS (CG) COMPUTER GRAPHICS (CG) COMPUTER GRAPHICS (CG)

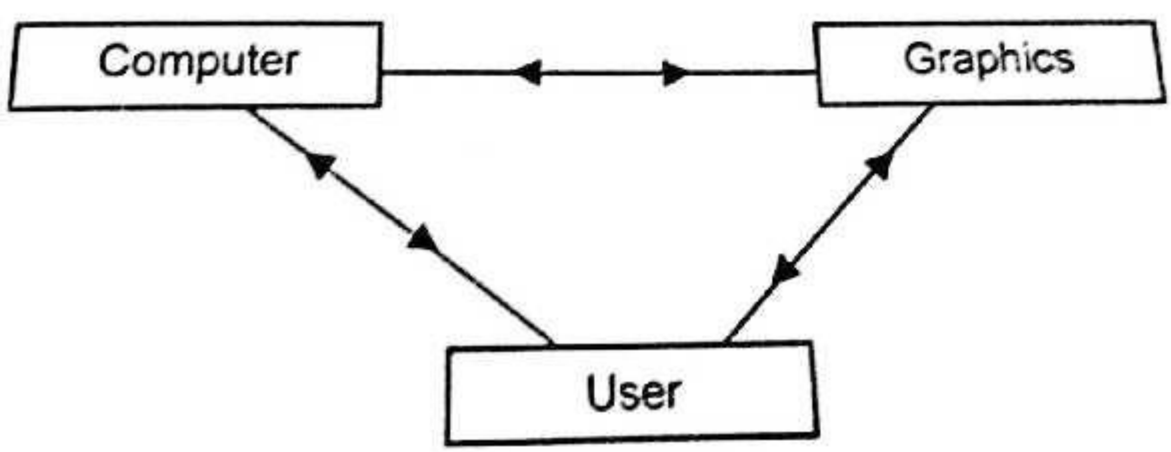


COMPUTER GRAPHICS (CG)

- Computer graphics is a technology which uses the display of the drawing or the geometric model of the component in CAD.
- CG may be defined as the process of creation, storage and manipulation of drawings and pictures with aid of a computer.
- It is an extremely effective medium for communication between users and computers.

There are two types

1. Passive CG



2. Interactive CG

The following functions of the ICG

- Modelling
- Storage
- Manipulation
- Viewing

ADVANTAGES OF COMPUTER GRAPHICS

- The object drawings can be denoted by its geometric model in three dimensions. i.e. X, Y, Z coordinates.
- Accurate drawings can be made.
- Sectional drawings can be easily created.
- Modification of geometric model of objects is easy.
- It is easy storage and retrieval of drawings.

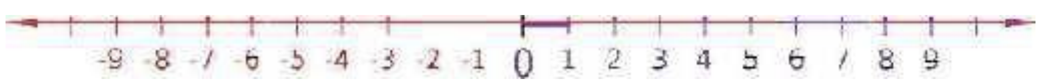
APPLICATIONS OF COMPUTER GRAPHICS

- Paint programs
- Design programs
- Presentation graphics software
- Animation software
- CAD software
- Desktop publishing
- Education and training
- Image processing

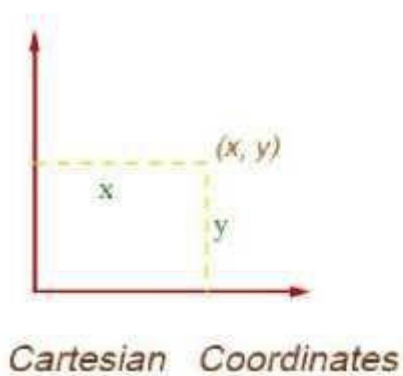
Common coordinate systems are:

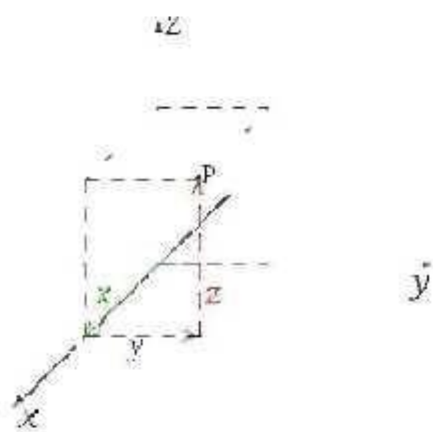
- **Number line**

The simplest example of a coordinate system is the identification of points on a line with real numbers using the number line. In this system, an arbitrary point O (the origin) is chosen o n a given line. The coordinate of a point P is de fined as the signed distance from O to P, where the signed distance is the distance taken as positive or negative depending on which side of the line P lies. Each point is given a unique coordinate and each real number is the coordinate of a unique point



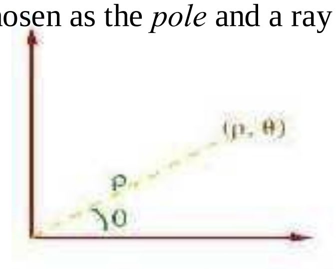
- **Cartesian coordinate system [(x,y) and (x,y,z)]**





Polar coordinate system (ρ,θ)

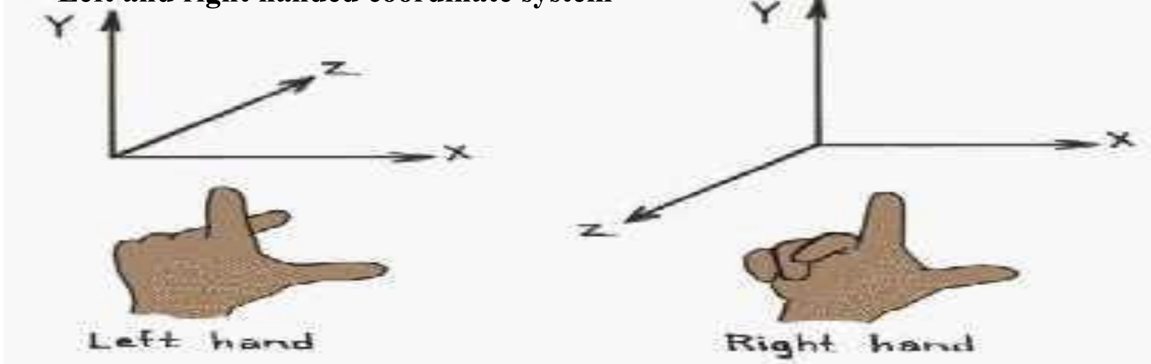
Another common coordinate system for the plane is the *polar coordinate system*. A point is chosen as the *pole* and a ray from this point is taken as the *polar axis*.



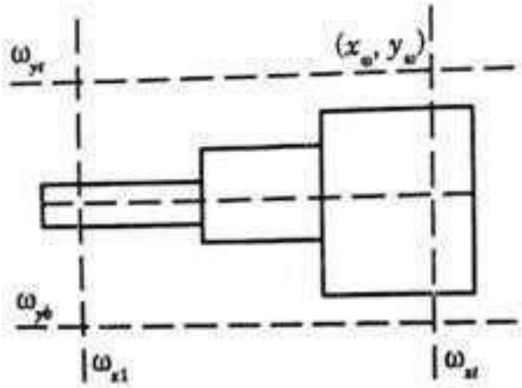
Polar Coordinates

ρ = r

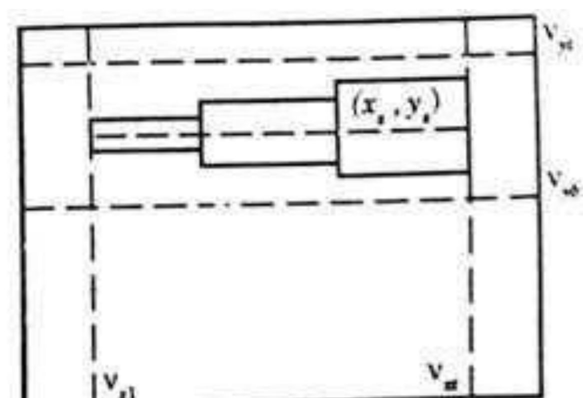
Left and right handed coordinate system



2. Windowing Transformation



Window



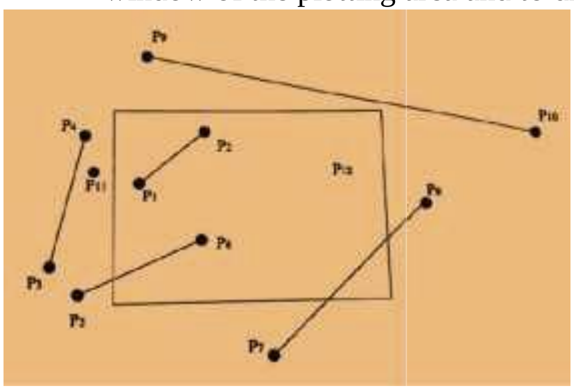
Viewport

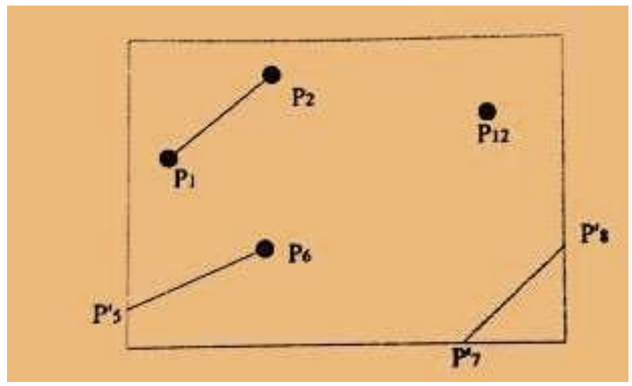
When it is necessary to examine in detail a part of a picture being displayed, a window may be placed around the desired part and the windowed area magnified to fill the whole screen and multiple views of the model may also be shown on the same screen.

The window is a rectangular frame or boundary through which the user looks onto the model. The viewport is the area on the screen in which the contents of the window are to be presented as an image.

Clipping Transformation

The clipping is an operation to plot part of a picture within the given window of the plotting area and to discard the rest.





2- D TRANSFORMATIONS

i. Scaling
ii. Translation
iii. Reflection with mirror
iv. Rotation

2. Scaling

Scaling is the transformation applied to change the scale of an entity. As shown in following figure, this alters the size of the entity by the scaling factor applied. For Example, in following figure, to achieve scaling, the original coordinates would be multiplied uniformly by the scaling factor.

$$P' = [X', Y'] = [S_x \times X, S_Y \times dY] \quad \text{-------(6)}$$

This equation can also be represented in a matrix form as follows.

$$[P'] = \begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad \text{-------(7)}$$

$$[P'] = [T_s] \cdot [P] \quad \text{-------(8)}$$

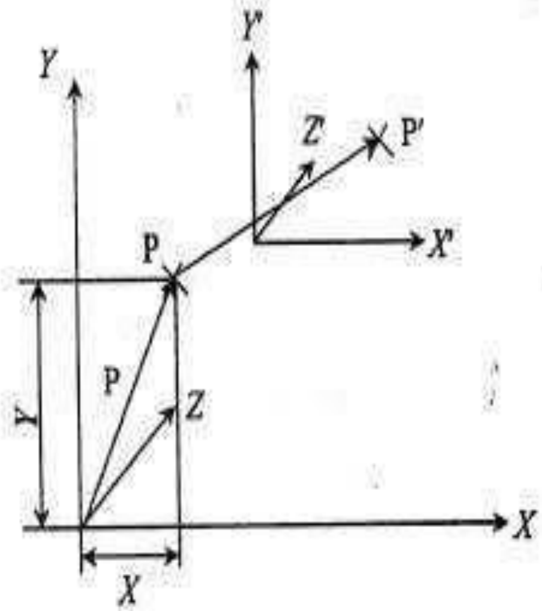
Translation

It is the most common and easily understood transformation in CAD. This moves a geometric entity in space in such a way that the new entity is parallel at all points to the old entity. A representation is shown in following figure for an object. Let us now consider a point on the object, represented by P which is translated along X and Y axes by dX and dY to a new position P'. The new coordinates after transformation are given by following equations.

$P' = [x', y']$ ------(1)

$x' = x + dX$ ------(2)

$y' = y + dY$ ------(3)



Translation of the Point

Putting equations (3) back into equations (1) we can write

$$[P'] = \begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x + dX \\ y + dY \end{bmatrix}$$ -------(4)

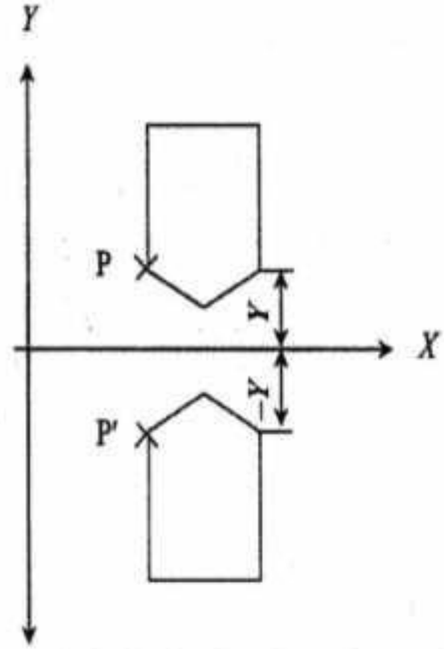
This can also be written in matrix form as follows.

$$[P'] = \begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x + dX \\ y + dY \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} dX \\ dY \end{bmatrix}$$ -------(5)

this is normally the operation used in the CAD systems as MOVE command.

3. Reflection or Mirror

Reflection or mirror is a transformation, which allows a copy of the object to be displayed while the object is reflected about a line or a plane.



Example for Reflection Transformation

The transformation required in this case is that the axes coordinates will get negated depending upon the reflection required. For example from following figures, the new

$P' = [X', Y'] = [X, -Y]$ -------(10)

This can be given a matrix form as

$$[P'] = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad \text{-------(11)}$$

$[P'] = [T_m] \cdot [P]$

where

$$[T_m] = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \quad \text{-------(12)}$$

Thus the general transformation matrix will be

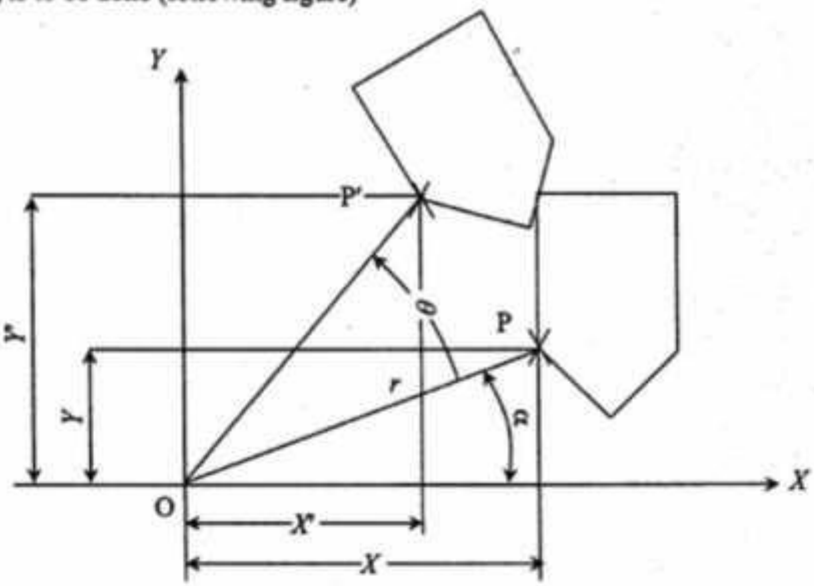
$$[M] = \begin{bmatrix} \pm 1 & 0 \\ 0 & \pm 1 \end{bmatrix} \quad \text{-------(13)}$$

Here, −1 in the first position refers to reflection about *Y*-axis where all the *X* coordinate values get negated.

When the second term becomes −1 the reflection will be about the *X*-axis with all *Y* coordinate values getting reversed. Both the values are −1 for reflection about *X* and *Y*-axes.

4. **Rotation**

Rotation is another important geometric transformation. The final position and orientation of a geometric entity is decided by the angle of rotation (θ) and the base point about which the rotation, is to be done (following figure)



To develop the transformation matrix for transformation, consider a point P located in XY plane, being rotated in the counter clockwise direction to the new position, P' by an angle θ as shown in following figure, The new position P' is given by

$P' = [x', y']$

From the following figure, the original position is specified by

$x = r\cos\alpha$

$y = r\sin\alpha$

The new position, P' is specified by

$$\begin{aligned} x' &= r\cos(\alpha+\theta) \\ &= r\cos\theta\cos\alpha - r\sin\theta\sin\alpha \\ &= x\cos\theta - y\sin\theta \end{aligned}$$

$$\begin{aligned} y' &= r\sin(\alpha+\theta) \\ &= r\sin\theta\cos\alpha + r\cos\theta\sin\alpha \\ &= x\sin\theta + y\cos\theta \end{aligned}$$

This can be written in a matrix form as

$$[P'] = \begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad \text{--------(14)}$$

$[P'] = [T_R] \cdot [P]$

$$[T_R] = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \qquad \text{-------(15)}$$

HOMOGENEOUS CO-ORDINATES

Homogeneous Representation

In order to concatenate the transformation as shown in equation (16), all the transformation matrices should be multiplicative type. However, as seen earlier, the translation matrix (equation (5)) is vector additive, while all others are matrix multiplications. The following form should be used to convert the translation into a multiplication form.

$$[P'] = \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & dX \\ 0 & 1 & dY \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \qquad \text{--------(17)}$$

Hence the translation matrix in multiplication form can be given as

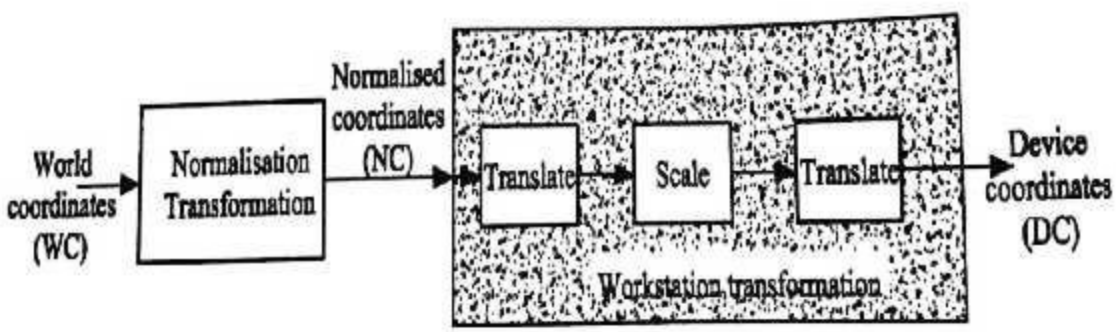
$$[MT] = \begin{bmatrix} 1 & 0 & dX \\ 0 & 1 & dY \\ 0 & 0 & 1 \end{bmatrix} \qquad \text{--------(18)}$$

This is termed as homogeneous representation. In homogeneous representation, an n-dimensional space is mapped into $(n+1)$ dimensional space. Thus a 2 dimensions point $[x \;\; y]$ is represented by 3 dimensions as $[x \;\; y \;\; 1]$.

This greatly facilities the computer graphics operations where the concatenation of multiple transformations can be easily carried out. This can be experienced in the following situations

VIEWING TRANSFORMATIONS

- Displaying an image of a picture involves in mapping the co-ordinates of the picture into the appropriate coordinates on the device where the image is to be displayed.



Elements of CAD system

Functional areas of a CAD design Process

Geometric modelling

Design analysis and optimization

Design review and evaluation

Documentation and drafting

The **manufacturing control applications of CAM** are concerned with developing computer systems for implementing the manufacturing control function.

- The important manufacturing planning applications of CAM includes:
  Process monitoring and control
- Quality control
- Shop floor control
- Inventory control
- Just in time production systems

CIM

- CAD+CAM = CIM
- CIM is the total integration of all components involved in converting raw materials into finished
  products and getting the products to the market.
- CIM is the integration of the total manufacturing enterprise through the use of integrated systems
  and data communications coupled with new managerial philosophies that improve organisational
  and personnel efficiency.

Types of production systems

- Job shop production

Meaning: Job or unit production involves the manufacturing of a single complete unit as per the customer's order. This is a special order type of production. Each job or product is different from others and no repetition is involved.

Three types of job production

A small number of pieces produced once

A small number of pieces produced intermittently when the need arises

A small number of pieces produced periodically at known time intervals

- Batch production

Meaning: In this type, the products are made in small batches and in large variety. Each batch contains identical items but every batch is different from the others.

Three types of batch production are

A batch produced only once.

A batch produced repeatedly at irregular intervals, when the need arises.

A batch produced periodically at known intervals, to satisfy continuous demand.

- Mass production

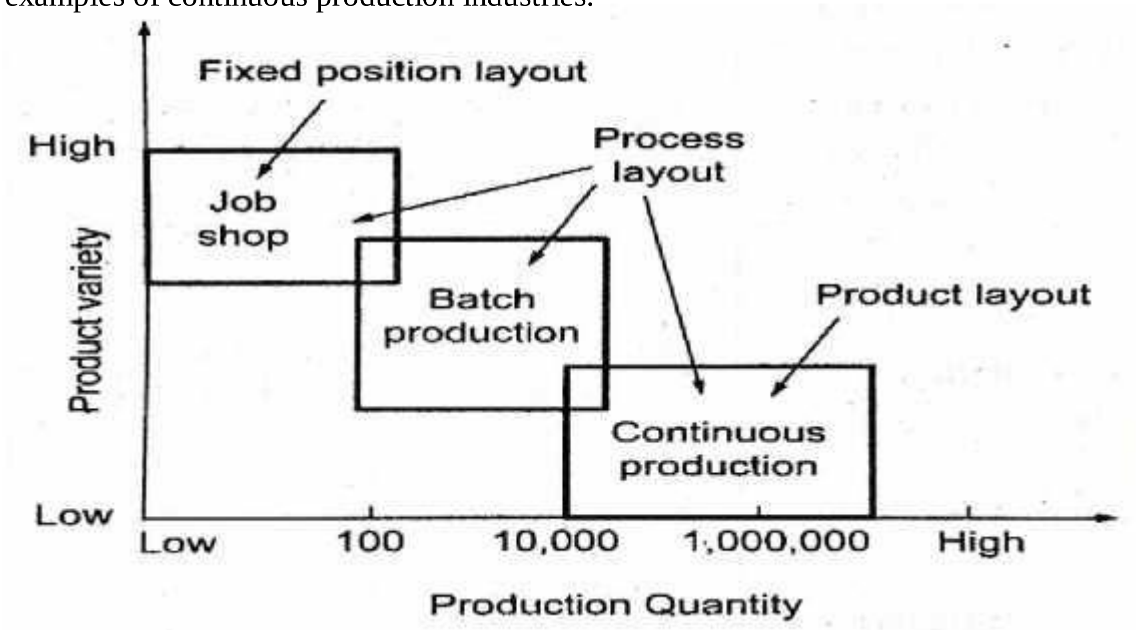
Meaning: In this type of production, only one type of product or maximum 2 or 3 types are manufactured in large quantities. Standardisation of products, process, materials, machines and uninterrupted flow of materials are the basic features of this system. Mass production system offers economics of scale as the volume of output is large.

 Process or continuous production

Meaning: This type of production is used for manufacture of those items whose demand is continuous and high. Here single raw material can be transformed into different kind of products at different stages of production processes. E.g., in processing of crude oil in refinery one gets kerosene, gasoline, etc., at different stage of production.

The characteristics, merits and demerits of continuous production system are the same as that of the mass production system.

Suitability: the industries like paper, textiles, cement, chemicals, automobiles, etc., are a few examples of continuous production industries.



Manufacturing Models and Metrics:

 Manufacturing metrics are used to quantitatively measure the performance of the production facility or a manufacturing company.

 Manufacturing metrics is a system of related measures that facilitates the quantification of some particular characteristics of production.

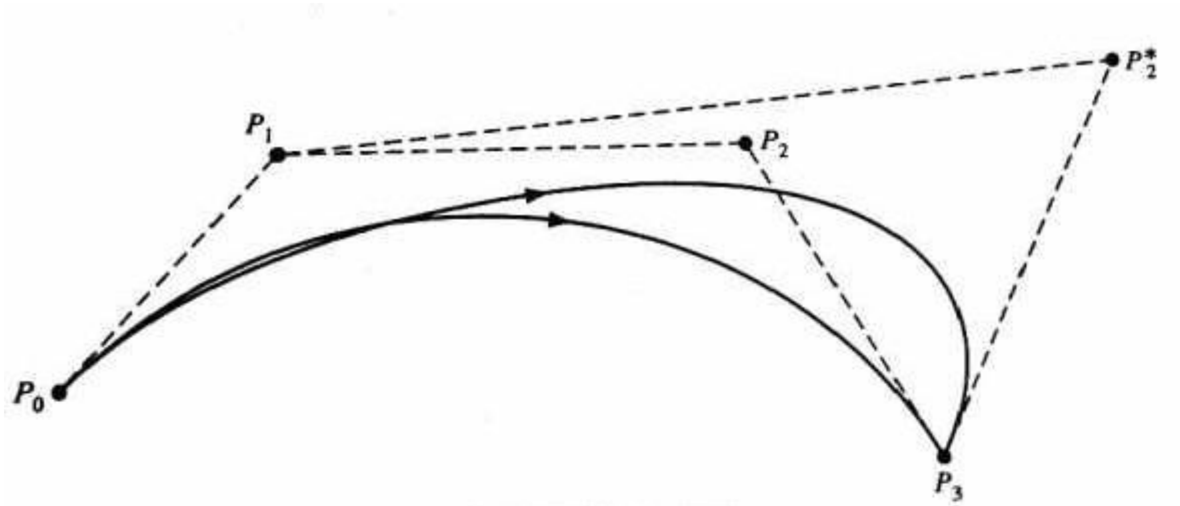
Why use manufacturing metrics?

- To track performance of the production system in successive periods.
- To determine the merits, and demerits of the potential new technologies and system.
- To compare alternative methods
- To make good decisions

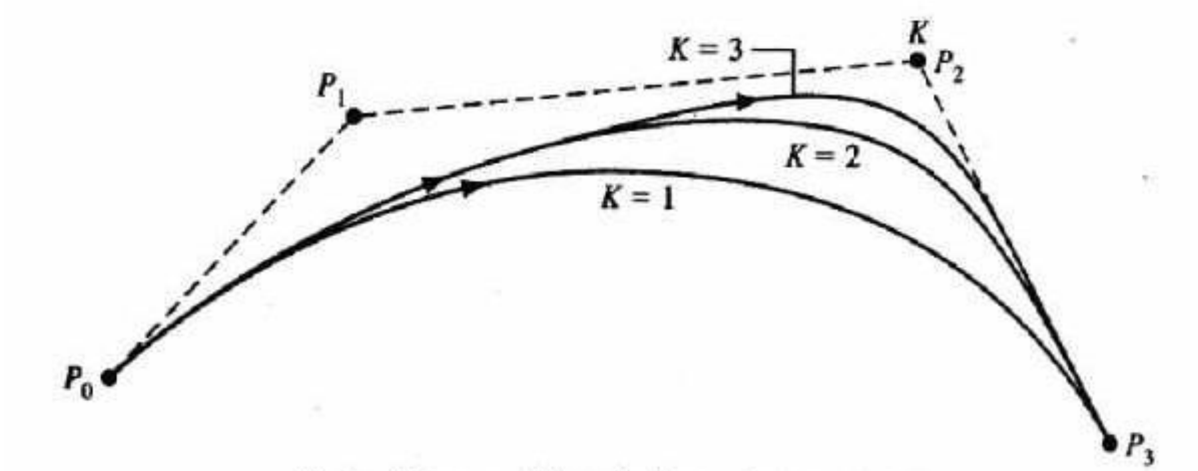
UNIT-II- GEOMETRIC MODELING

CHARACTERISTICS OF BEZIER CURVE

- The curve interpolates the first and last control points.
- The curve is tangent to the first and last segments of characteristics polygon.
- The curve shape can be modified by either changing one or more vertices of its polygon or by keeping the polygon fixed and specifying multiple coincident points at a vertex as shown in figure.



(a) Changing a vertex



(b) Specifying multiple coincident points at a vertex

PRE-REQUISITE DISCUSSION

CURVE REPRESENTATIO N

(1) Parametric equation x, y, z coordinates are related by a parametric variable (u or θ)

(2) Nonparametric equation x, y, z coordinates are related by a function

Example: Circle (2-D)

Parametric equation

$$x = R\cos\theta, \quad y = R\sin\theta \quad (0 \le \theta \le 2\pi)$$

Nonparametric equation

$$x^2 + y^2 - R^2 = 0 \quad \text{(Implicit nonparametric form)}$$

$$y = \pm\sqrt{R^2 - x^2} \quad \text{(Explicit nonparametric form)}$$

TYPES OF CURVES USED IN GEOMETRIC MODELLING

- Hermite curves
- Bezeir curves
- B-spline curves
  - NURBS

curves

HERMITE CURVES

$$\mathbf{P}(u) = \mathbf{a}_0 + \mathbf{a}_1 u + \mathbf{a}_2 u^2 + \mathbf{a}_3 u^3 \quad (0 \le u \le 1)$$

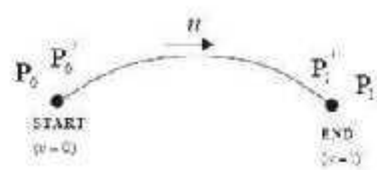
Instead of algebraic coefficients, let's use the position vectors and the tangent vectors at the two end points!

Position vector at starting point: $\mathbf{P}_0 = \mathbf{P}(0) = \mathbf{a}_0$

Position vector at end point: $\mathbf{P}_1 = \mathbf{P}(1) = \mathbf{a}_0 + \mathbf{a}_1 + \mathbf{a}_2 + \mathbf{a}_3$

Tangent vector at starting point: $\mathbf{P}_0' = \mathbf{P}'(0) = \mathbf{a}_1$

Tangent vector at end point: $\mathbf{P}_1' = \mathbf{P}'(1) = \mathbf{a}_1 + 2\mathbf{a}_2 + 3\mathbf{a}_3$



Blending functions

$$\mathbf{P}(u) = \begin{bmatrix} 1-3u^2+2u^3 & 3u^2-2u^3 & u-2u^2+u^3 & -u^2+u^3 \end{bmatrix} \begin{bmatrix} \mathbf{P}_0 \\ \mathbf{P}_1 \\ \mathbf{P}_0' \\ \mathbf{P}_1' \end{bmatrix}$$

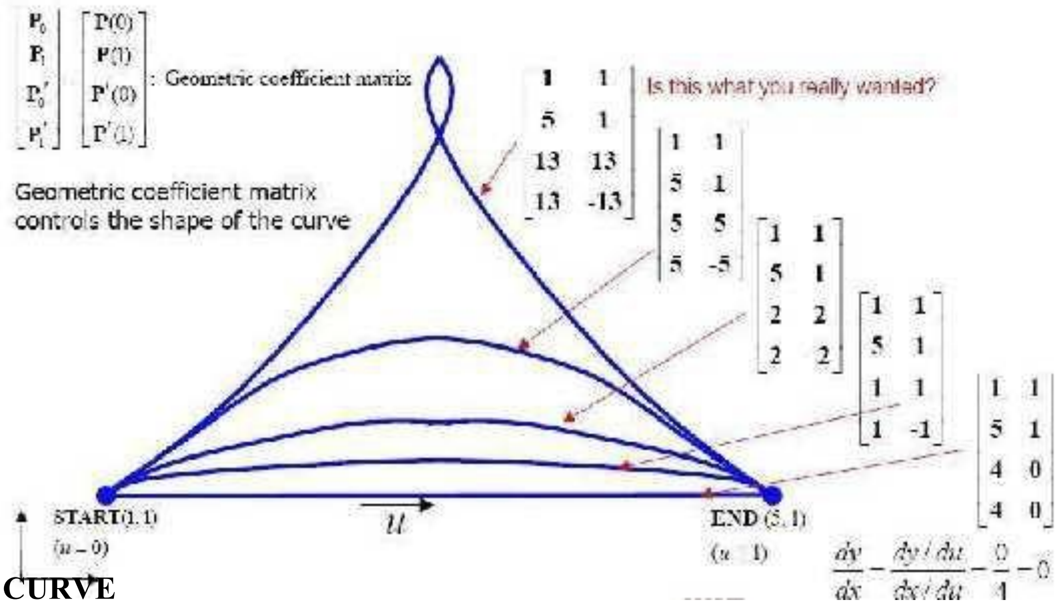
: Hermit curve

No algebraic coefficients

$\mathbf{P}_0, \mathbf{P}_0', \mathbf{P}_1, \mathbf{P}_1'$: Geometric coefficients

➡ The curve's shape change can be intuitively anticipated from changes in these values

Effect of tangent vector on t he curve's shape



BEZIER CURVE

Properties

- The curve passes through the first and last vertex of the polygon.

-The tangent vector at the starting point of the curve has the same direction as the first segment of the polygon.

- The nth derivative of the curve at the starting or ending point is determined by the first or last (n+1) vertices.

Two Drawbacks of Bezier Curves

(1) For complicated shape representation, higher degree Bezier curves are needed.

→ Oscillation in curve occurs, and computational burden increases.

(2) Any one control point of the curve affects the shape of the entire curve.

→ Modifying the shape of a curve locally is difficult.

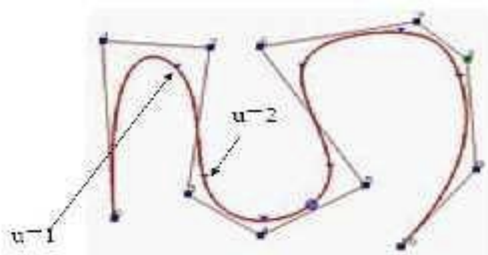
(Global modification property)

Desirable properties :

1. Ability to represent complicated shape with low order of the curve
2. Ability to modify a curve's shape locally

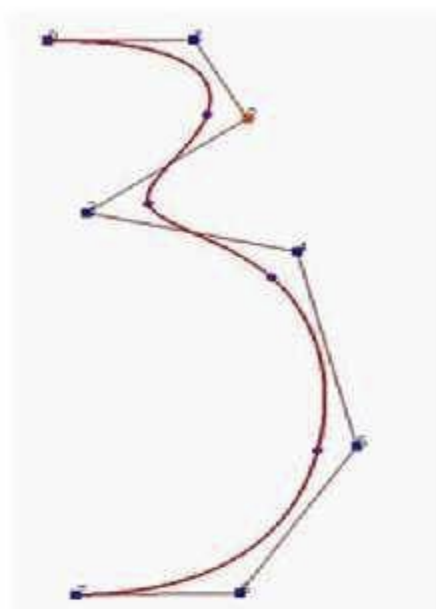
Properties of B-Spline

1. The m degree B-Spline function are piecewise polynomials of degree m → have C^{m-1} continuity. →e.g B-Spline degree 3 have C^2 continuity.

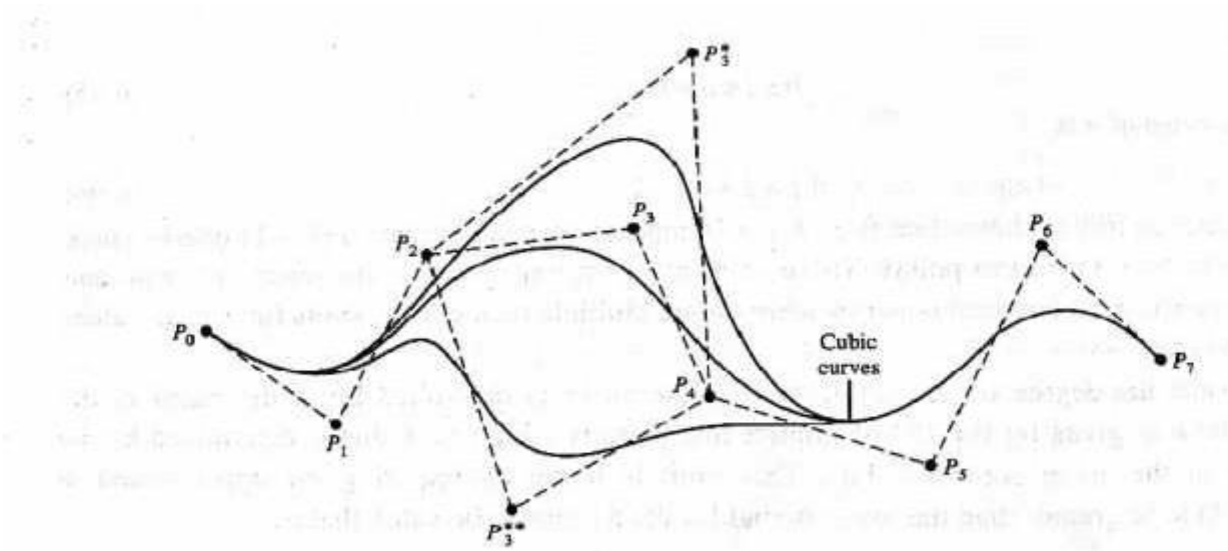


B-Spline

- Motivation (recall bezier curve)
  - moving a control point affects the shape of the entire curve- (*global modification property*) – undesirable.
  - Thus, the solution is B-Spline – the degree of the curve is independent of the number of control points
  - E.g - right figure – a B-spline curve of degree 3 defined by 8 control points



NURBS curve



$$P(u) = \frac{\sum_{i=0}^{n} h_i P_i N_{i,k}(u)}{\sum_{i=0}^{n} h_i N_{i,k}(u)} \qquad \left(\text{B-spline}: \ P(u) = \sum_{i=0}^{n} P_i N_{i,k}(u) \right)$$

P_i : Position vector of the ith control point

h_i : Homogeneous coordinate

* If all the homogeneous coordinates (h_i) are 1, the denominator becomes 1

  If $h_i = 0 \ \forall i$, then $\sum_{i=0}^{n} h_i N_{i,3}(u) = 1$.

* B-spline curve is a special case of NURBS.

* Bezier curve is a special case of B-spline curve.

Advantages of B-spline curves and NURBS curve

(1) More versatile modification capacity

- Homogeneous coordinate h_i, which B-spline does not have, can change.

- Increasing h_i of a control point → Drawing the curve toward the control point.

(2) NURBS can exactly represent the conic curves - circles, ellipses, parabolas, and hyperbolas (B-spline can only approximate these curves)

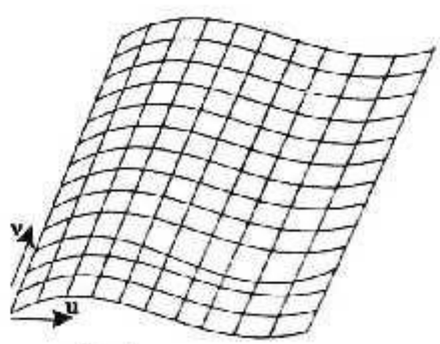
(3) Curves, such as conic curves, Bezier curves, and B-spline curves can be converted to their corresponding NURBS representations.

TECHNIQUES IN SURFACE MODELLING

i. Surface Patch
ii. Coons Patch
iii. Bicubic Patch
iv. Be'zier Surface
v. B-Spline Surface

i. Surface Patch

The patch is the fundamental building block for surfaces. The two variables *u* and *v* vary across the patch; the patch may be termed *biparametric.* The parametric variables often lie in the range 0 to 1. Fixing the value of one of the parametric variables results in a curve on the patch in terms of the other variable (*Isoperimetric curve*). Figure shows a surface with curves at intervals of *u* and *v* of 0 : 1.



Surface patch.

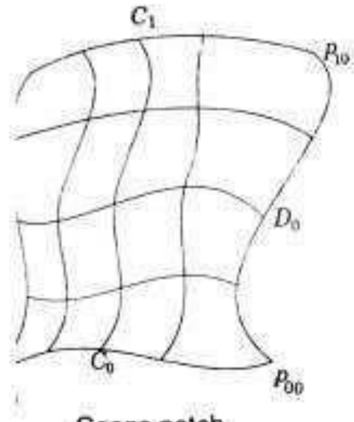
ii. Coons Patch

The sculptured surface often involve interpolation across an intersecting mesh of curves that in effect comprise a rectangular grid of patches, each bounded by four boundary curves. The linearly blended coons patch is the simplest for interpolating between such boundary curves. This patch definition technique blends for four boundary curves C $i(u)$ and $D_j(v)$ and the corner points p *ij* of the patch with the linear blending functions,

$$f(t) = 1 - t$$
$$g(t) = t$$

using the expression

$$\vec{p}(u, v) = \vec{C}_0(u)\, f(v) + \vec{C}_1(u)\, g(v) + \vec{D}_0(v)\, f(u) + \vec{D}_1(v)\, g(u) - \vec{p}_{00}\, f(u)\, f(v) - \vec{p}_{01}\, f(u)\, g(v) - \vec{p}_{10}\, g(u)\, f(v) - \vec{p}_{11}\, g(u)\, g(v)$$



Coons patch

iii. Bicubic Patch

The bi-cubic patch is used for surface descriptions defined in terms of point and tangent vector information. The general form of the expressions for a bi-cubic patch is given by:

$$\vec{p}(u, v) = \sum_{i=0}^{3} \sum_{j=0}^{3} \vec{k_{ij}}\, u^i\, v^j$$

This is a vector equation with 16 unknown parameters k_{ij} which can be found by Lagrange interpolation through 4 x 4 grid.

iv. Be'zier Surface

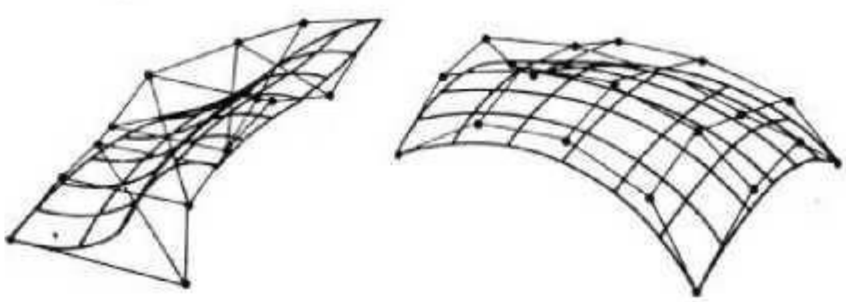
- The Be'zier surface formulation use a characteristic polygon
- Points the Bezier surface are given by

$$\vec{p}(u, v) = \sum_{i=0}^{m} \sum_{j=0}^{n} \vec{B}_{i,m}(u)\, \vec{B}_{j,n}\, \vec{p}_{ij};\ u, v, \epsilon\ [0, 1]$$

Where,

$\vec{p}_{ij}$ - Vertices of the characteristic polygon

$\vec{B}_{j,n}$, $\vec{B}_{i,m}$ - Blending functions



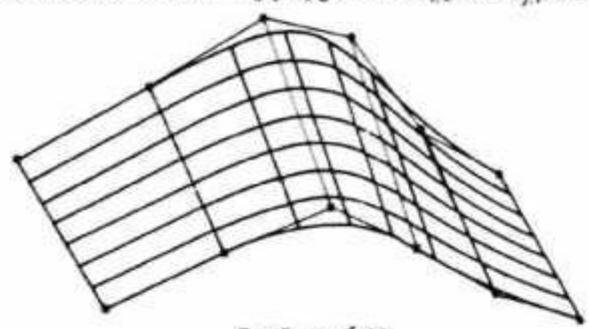
v. B-Spline Surfaces

- The B-spline surface approximates a characteristics polygon as shown and passes through the corner points of the polygon, where its edges are tangential to the edges of the polygon
- This may not happen when the control polygon is closed
- A control point of the surface influences the surface only over a limited portion of the parametric space of variables u and v.

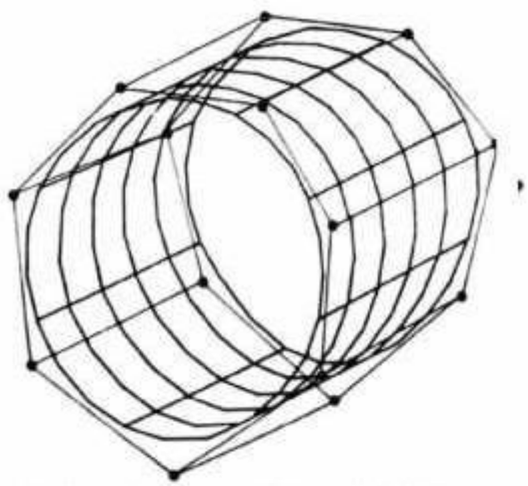
The expression for the B-spline surfaces is given by

$$\vec{p}(u,v) = \sum_{i=0}^{m} \sum_{j=0}^{n} N_{i,k}(u)\, N_{j,l}(v)\, \vec{p}_{ij}$$

p_{ij} are the vertices of the defining polygon and $N_{i,k}$ and $N_{j,l}$ are blending functions



. B-spline surface



B-spline surface for a closed control polygon

GEOMETRIC MODELLING

Geometric modeling is the starting point of the product design and manufacture process. Functions of Geometric Modeling are:

Design Analysis

Evaluation of area, volume, mass and inertia properties
Interference checking in assemblies
Analysis of tolerance build-up in assemblies
Kinematic analysis of mechanisms and robots
Automatic mesh generation for finite element analysis

Drafting

Automatic planar cross-sectioning
Automatic hidden lines and surface removal
Automatic production of shaded images
Automatic dimensioning
Automatic creation of exploded views of assemblies

Manufacturing

Parts classification
Process planning
NC data generation and verification
Robot program generation

Production Engineering

Bill of materials
Material requirement
Manufacturing resource requirement
Scheduling

Inspection and quality control

Program generation for inspection machines
Comparison of produced parts with design

PROPERTIES OF A GEOMETRIC MODELING SYSTEM

The geometric model must stay invariant with regard to its location and orientation
The solid must have an interior and must not have isolated parts
The solid must be finite and occupy only a finite shape
The application of a transformation or Boolean operation must produce another solid The solid must have a finite number of surfaces which can be described
The boundary of the solid must not be ambiguous

WIRE FRAME MODELING

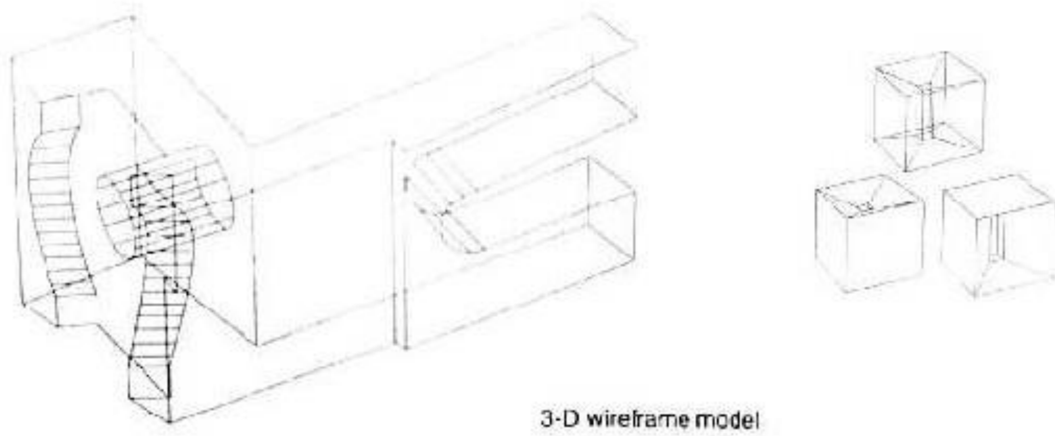
It uses networks of interconnected lines (wires) to represent the edges of the physical objects being modeled

Also called ‗Edge-vertex' or ‗stick- figure' models
Two types of wire frame modeling:

1. 2 ½ - D modeling
2. 3 - D modeling

3-D Wire frame models: These are

Simple and easy to create, and they require relatively little computer time and memory; however they do not give a complete description of the part. They co ntain little information about the surface and volume of the part and cannot distinguish the inside from the outside of part surfaces. They are visually ambiguous as the model can be interpreted in many different ways because in many wire frame models hidden lines cannot be removed. Section property and mass calculations are impossible, since the object has no faces attached to it. It has limited values a basis for manufacture and analysis



3-D wireframe model

TECHNIQUES IN SURFACE MODELLING

The various methods for representing the solids are:

1. Half-space method
2. Boundary representation method (B-rep)
3. Constructive solid geometry (CSG and C-rep)
4. Sweep representation
5. Analytical solid modeling (ASM)
6. Primitive instancing
7. Spatial partitioning representation
    a. Cell decomposition
    b. Spatial occupancy enumeration

Boundary representation method (B-rep)

- In solid modeling and computer-aided design, boundary representation often abbreviated as B-rep or BREP—is a method for representing shapes using the limits.

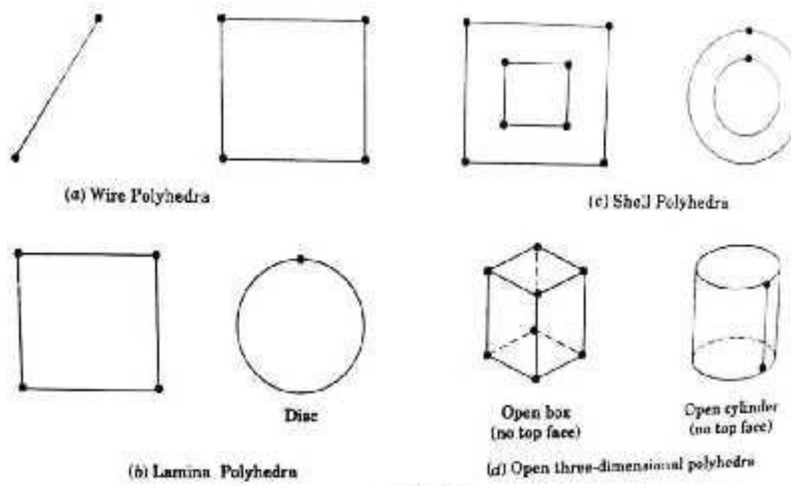
- A solid is represented as a collection of connected surface elements, the boundary between solid and non-solid.

- Boundary representation models are composed of two parts:

    O Topology, and
    O Geometry (surfaces, curves and points).

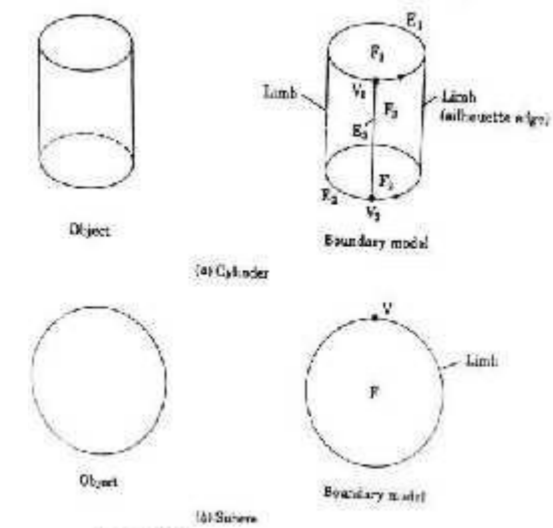
- A minimum body is a point; topologically this body has one face, one vertex, and no edges. It is called a seminal or singular body

Open polyhedral objects



Open polyhedral objects.

Curved Objects



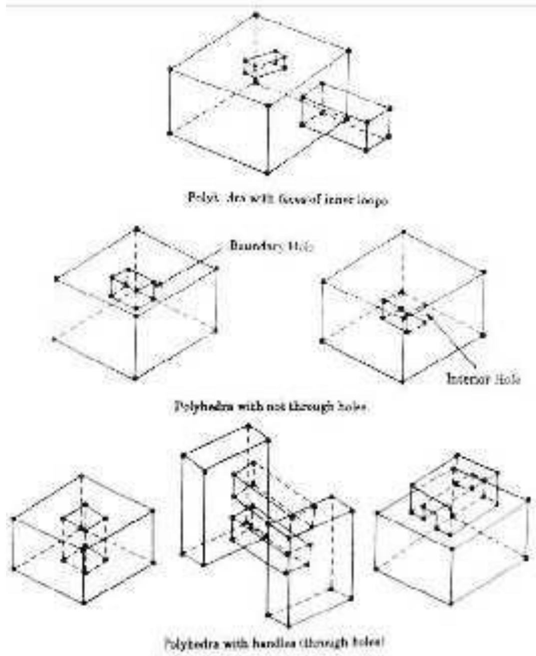
Exact B-rep of a cylinder and a sphere.

Euler's formula

Euler - Poincare Law for closed objects : $F - E + V - L = 2(B - G)$

Euler - Poincare Law for open objects : $F - E + V - L = B - G$

Solid Model Generation using B-rep



Advantages of b-rep

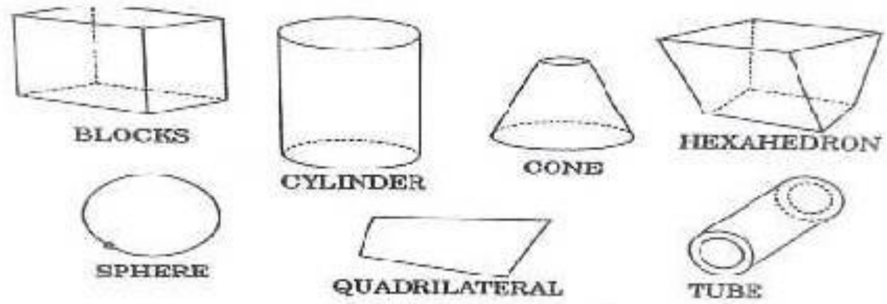
- O Appropriate to construct solid models of unusual shapes
- O Relatively simple to convert a b-rep model to wireframe model

Disadvantages of b-rep

- O Requires more storage
- O Not suitable for applications like tool path generation
- O Slow manipulation

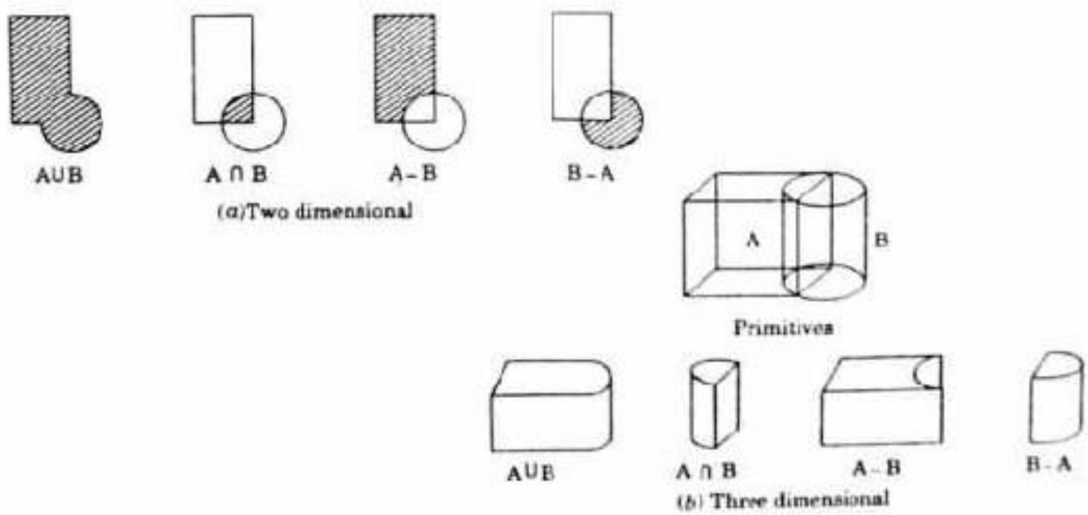
CONSTRUCTIVE SOLID GEOMETRY (CSG and C-rep)

- Constructive solid geometry (CSG) (formerly called computational binary solid geometry) is a technique used in solid modeling.
- Constructive solid geometry allows a modeler to create a complex surface or object by using Boolean operators to combine objects.
- Often CSG presents a model or surface that appears visually complex, but is actually little more than cleverly combined or de-combined objects
- The simplest solid objects used for the representation are called **primitives**. Typically they are the objects of simple shape:
    - O cuboids
    - O cylinders
    - O prisms
    - O pyramids
    - O spheres
    - O cones

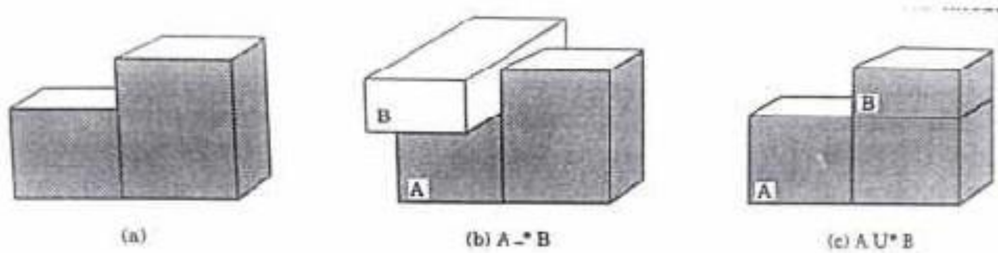


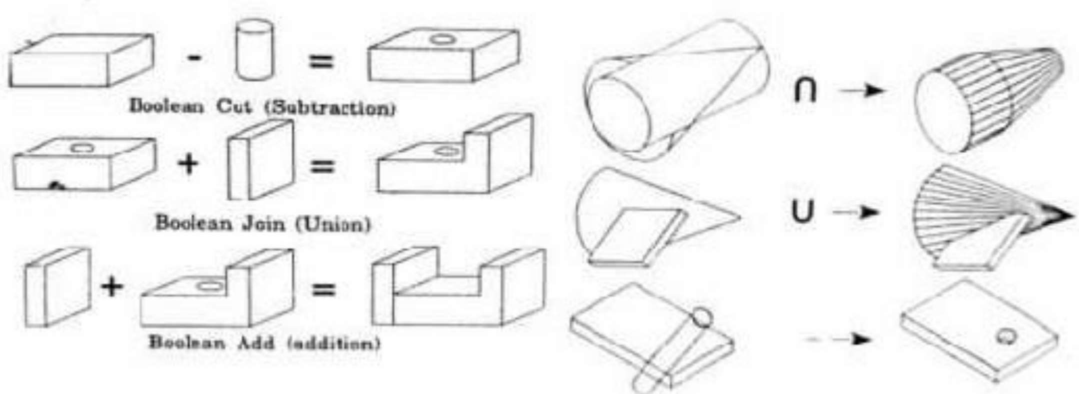
Solid primitives

Boolean Operations

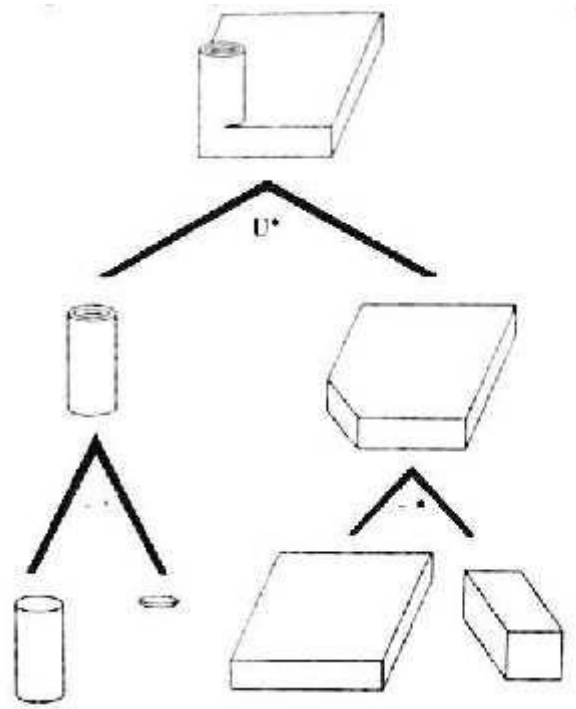


Boolean operations of a block *A* and cylinder *B*.





CSG Tree



An object defined by CSG and its tree.

UNIT III

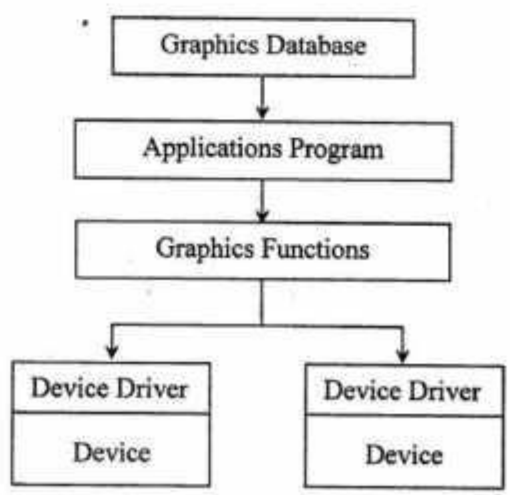
CAD STANDARDS

PRE-REQUISITE DISCUSSION

With the proliferation of computers and software in the market, it became necessary to standardize certain elements at each stage, so that investment made by companies in certain hardware or software was not totally lost and could be used without much modification on the newer and different systems. Standardization in engineering hardware is well known. Further, it is possible to obtain hardware and software from a number of vendors and then be integrated into a single system. This means that there should be compatibility between various software elements as also between the hardware and software. This is achieved by maintaining proper interface standards at various levels. Following are some of them.

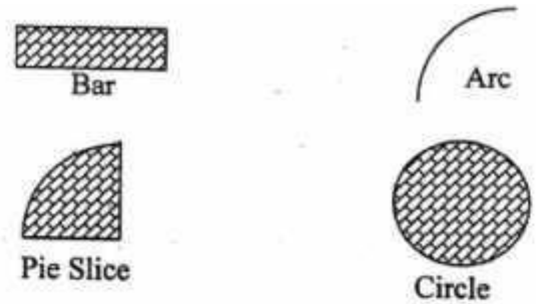
- **GKS** (Graphical Kernel Systems)
- **PHIGS** (Programmer's Hierarchical Interface for Graphics)
- **CORE** (ACM-SIGGRAPH)
- **GKS-3D**
- **IGES** (Initial Graphics Exchange Specification)
- **DXF** (Drawing Exchange Format)
- **STEP** (Standard for the Exchange of Product Model Data)
- **DMIS** (Dimensional Measurement Interface Specification)
- **VDI** (Virtual Device Interface)
- **VDM** (Virtual Device Metafile)
- **GKSM** (GKS Metafile)
- **NAPLPS** North American Presentation Level Protocol Syntax)

Schematically, the operation of these standards with application programs is depicted in Figure. Details of some of these standards are discussed in the following sections.



Various Standards in Graphics Programming

GRAPHICAL KERNEL SYSTEM (GKS)



Graphics Primitives in IBM GKS

For drawing lines, the concept of PEN is used. PEN has the attributes of colour, thickness and line type. Lines can be drawn with any PEN that can defined. The basic graphic primitives that were made available are.

- **POLYLINE** for lines after specifying in the line type, line width and line colour.
- **POLYMARKER** for specific marker types after specifying the type, size and colour.
- **GENERALISED DRAWING PRIMITIVES (GDP)** for specific graphic primitives such as arc, circle, ellipse, spline, etc.
- **TEXT** after specifying font type, precision, colour, height of the box, expansion factor , spacing up vector and the path (left, right, up or down).
- **FILL AREA** for hatching and filling of areas.

In essence, the GKS is essentially a set of procedures that can be called by user programs for carrying out certain generalised functions. In the interest of interchangeability, ISO has identified certain calling conventions for all these functions in various languages in order to take care of the variability of the programming languages.

GKS is defined in terms of a number of levels describing the level of support in terms of facilities. The highest level is 2c, though level 2b is the most commonly available facility with marginal difference in terms of the length of input queue (5 in case of 2c and 0 in case of 2b). A number of implementations are available for GKS on all types of computer starting from the micros to the main frame computers.

DATA EXCHANGE STANDA RDS

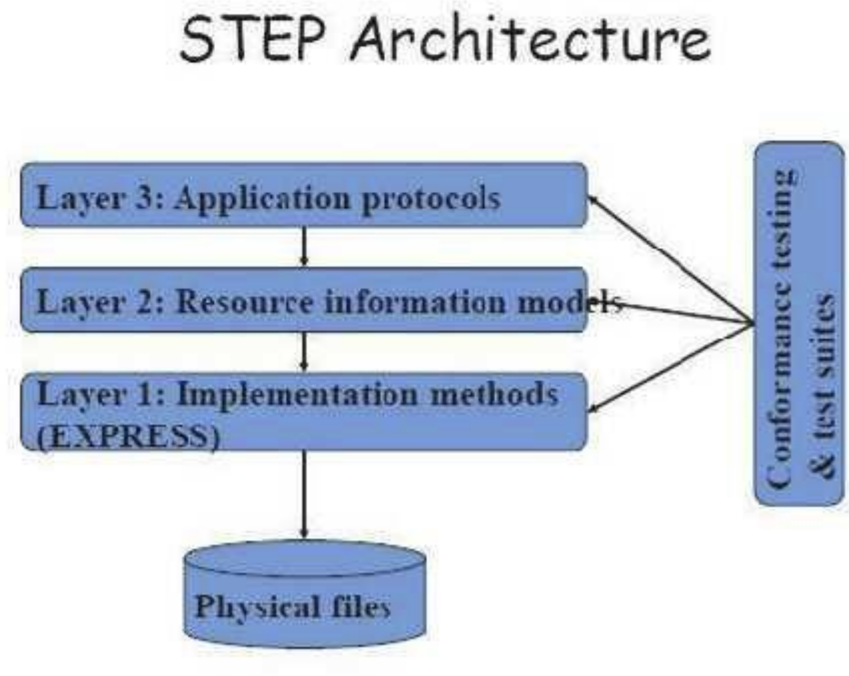
IGES STANDARD

However, the IGES is the most comprehensive standard and *is designed to transmit the entire product definition including that of manufacturing and any other associated information.* A brief description of the IGES version 3.0 is given below highlighting the philosophy of the conversion methodology.

In IGES the records are present with 80 column fields, with columns 1 to 72 providing the data and columns 73 to 80 providing a sequence number for the record with identification as to the location of the sub-section. This sequence number is utilized as a pointer for the data. The IGES file consists of the following 6 sub-sections.

STEP (Standard for the Exchange of Product model Data)

- Standard for Exchange of Product Model Data
- Uses a formal model f or data exchange
- Information is modeled using the EXPRESS language
- EXPRESS has elements of Pascal, C, and other languages
- It contains constructs for defining data types and structures, but not fo r processing data
- EXPRESS describes geometry and other information in a standard, unambiguous way



Classes of STEP Parts

•Introductory
•Description methods
•Implementation methods
•Conformance testing methodology and Framework
•Integrated resources
•Application proto cols
•Abstract test suites
•Application interpreted constructs

Status of STEP

•STEP has been under development for many years, and will continue for many more

•Over a dozen STE P parts have been approved as international standards
•Many others are under development

CONTINUOUS ACQUISITION AND LIFE-CYCLE SUPPORT (CALS)

•Developed by US Department of Defense

•Prescribes formats for storage and exchange of technical data
•Technical publications an important focus

Important CALS Standards

• Standard Generalized Markup Language (SGML) -developed in 1960s IBM

i. document description language
ii. separates content from structure (formatting)
iii. uses ―tags‖ to define headings, sections, chapters, etc.
iv. HTML is based on SGML

• Computer Graphics Metafile (CGM)

i. Developed in 1986
ii. vector file format for illustrations and drawings
iii. All graphical elements can be specified in a textual source file that can be compiled into a binary file or one of two text representations

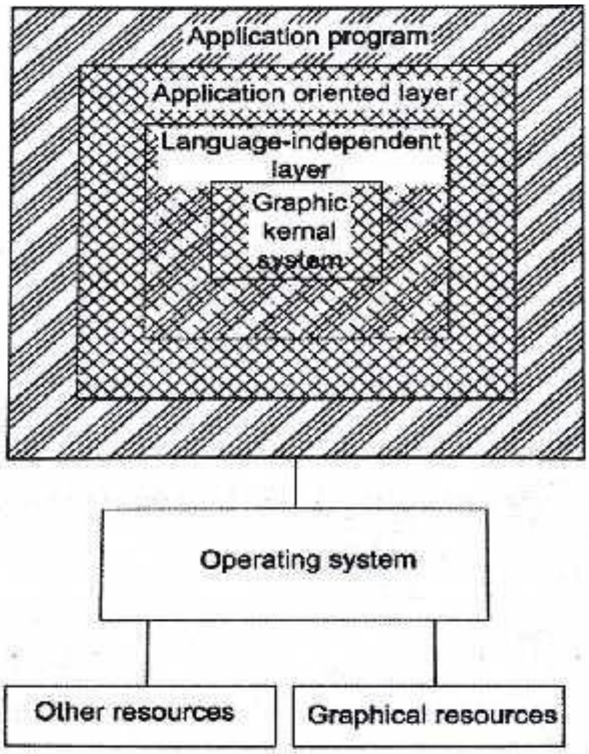
OpenGL (**Open Graphics Library**)

OpenGL is a cross- language, multi-platform application programming interface (API) for rendering 2D and 3D vector graphics. The API is typically used to interact with a graphics processing unit (GPU), to achieve hardware-accelerated rendering.

The OpenGL specification describes an abstract API for drawing 2D and 3D graphics. Although it is possible for the API to be implemented entirely in software, it is designed to be implemented mostly or entirely in hardware.

The API is defined as a number of functions which may be called by the client program, alongside a number of named integer constants (for example, the constant G L_TEXTURE_2D, which corresponds to the decimal number 3553). Although the function definitions are superficially similar to those of the C programming language, they are language- independent. As such, OpenGL has many language bindings, some of the most noteworthy being the Java Script binding Web GL (API, based on OpenGL ES 2.0, for 3D rendering from within a web browser); the C bindings WGL, GLX and CGL; the C binding provided by iOS; and the Java and C bindings provided by Android.

In addition to being language- independent, OpenGL is also platform- independent. The specification says nothing on the subject of obtaining, and managing, an OpenG L context, leaving this as a detail of the underlying windowing system. For the same reason, OpenGL is purely concerned with rendering, providing no APIs related to input, audio, or windowing.

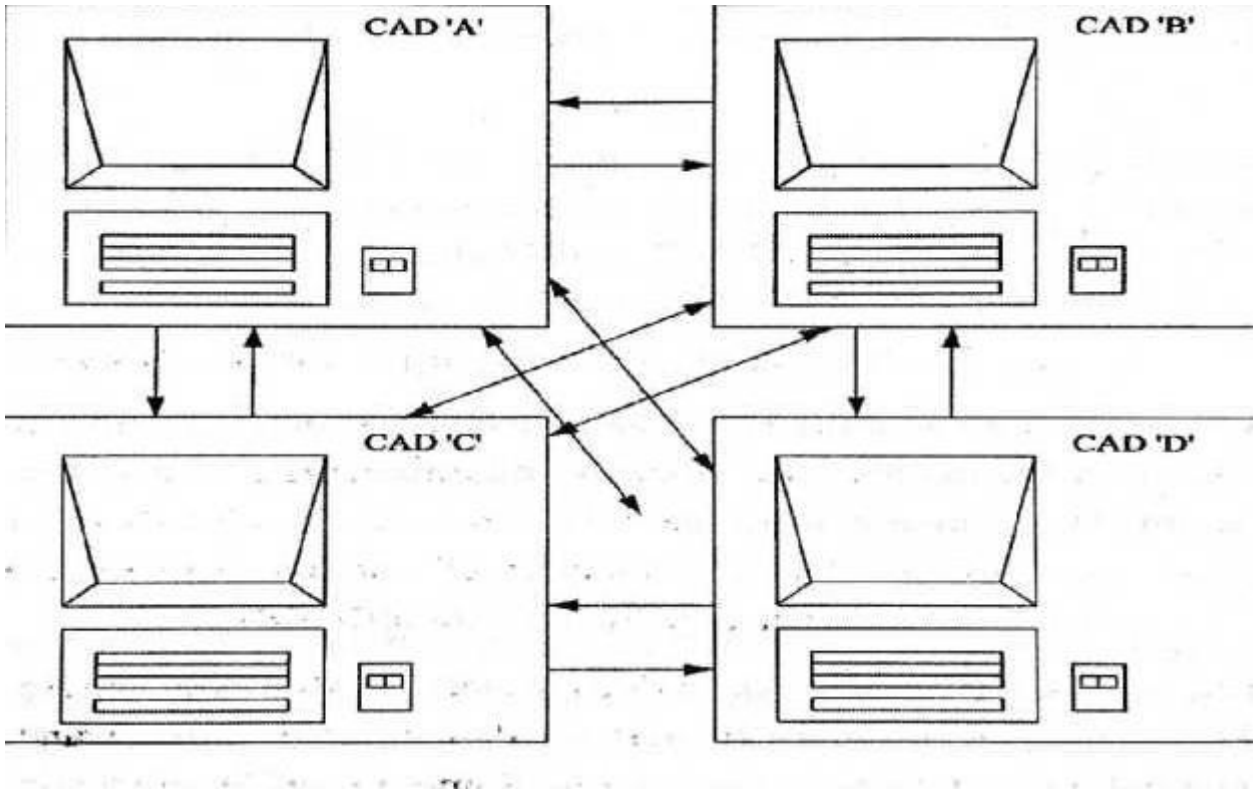


STANDARDS FOR EXCHANGE IMAGES:

- The purpose of GKS and other similar standards is to allow graphics to be drawn on a display device by an application program.
- The model is converted by the series of graphics primitives, and these are then displayed on the screen using the graphics procedures, typically by setting the values of the pixels in a rectangular raster array.
- The raster array is represented by a region of computer memory is known as bitmap.

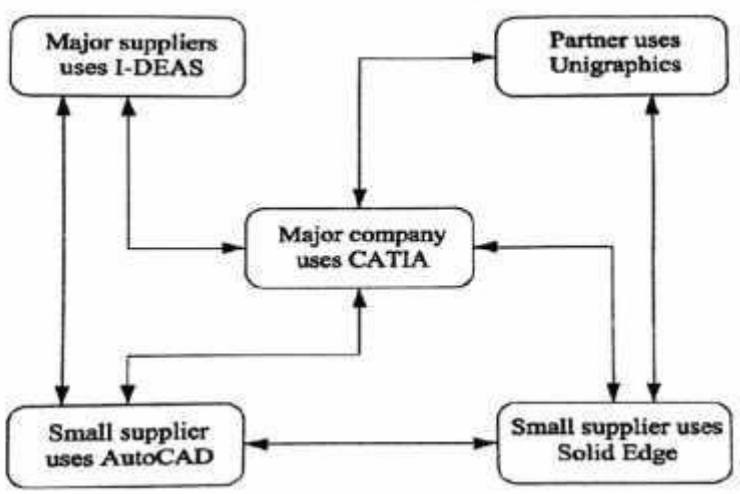
<u>Data exchange standards:</u>

- CAD data exchange involves a number of software technologies and methods to translate data from one Computer-aided design system to another CAD file format.
- The recent decades, the data transfer of data between the system has been made possible by the neutral format of data exchange.



The following reasons for exchanging the data are that

- All use the same cad package
- Special translator applications are used to change the data from one format to another format needed.
- A neutral format is used for data exchange.



IGES has three types of entity:

- Geometric - it defines the product shape and include curves, surface and solids
- Annotation - it included various types of dimensions (linear, angular, ordinate), centre line , notes, general labels, symbols and cross hatching
- Structure - it includes views, drawing , attributes(such as line and text fonts, colors and layers), properties (mass), subfigures and external cross reference entities (for surface and assemblies)

Entity number	Entity description	Entity number	Entity description
100	Circular arc	132	Connect point
102	Composite curve	136	Finite element
104	Conic arc	138	Nodal display and rotation
106	Copious data	140	Offset surface
108	Plane	142	Curve on a parametric surface
110	Line	144	Trimmed parametric surface
112	Parametric spline curve	146	Nodal results
114	Parametric spline surface	148	Element results
116	Point	150	Block
118	Ruled surface	152	Right angular wedge
120	Surface of revolution	154	Right circular cylinder
122	Tabulated cylinder	156	Right circular cone
124	Transformation matrix	158	Sphere
125	Flash	160	Torus
126	Rational B-spline curve	162	Solid of revolution
128	Rational B-spline surface	164	Solid of linear extrusion
130	Offset curve	186	Ellipsoid

Error handling

- While importing IGES file, error handling is very important
- There are two major error sources when processing IGES files
  - Program errors in the processors
  - Misinterpretation of the IGES standard itself.
- The way an IGES processor report error is - the processor should report the entity type, number of unprocessed entries, reason for un-processing and other relevant database information of these unprocessed entities.

- IGES should also report any invalid or missing data encountered in reading IGES files especially those that were edited.

STEP:

- STEP (standard for Exchange of Product Data) is an exchange for product data in support of industrial automation

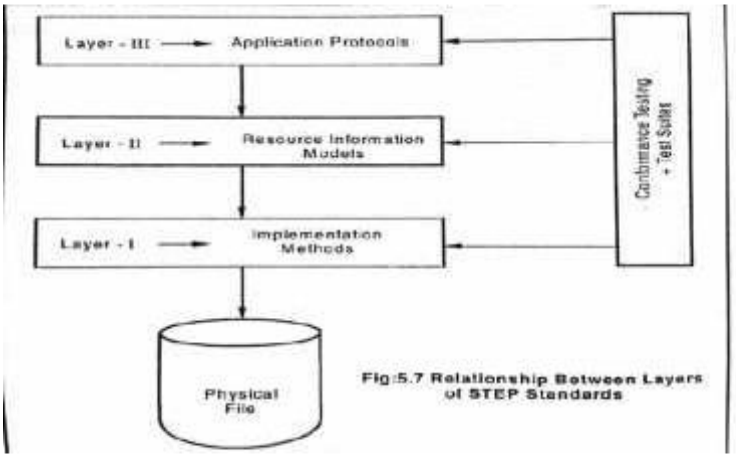
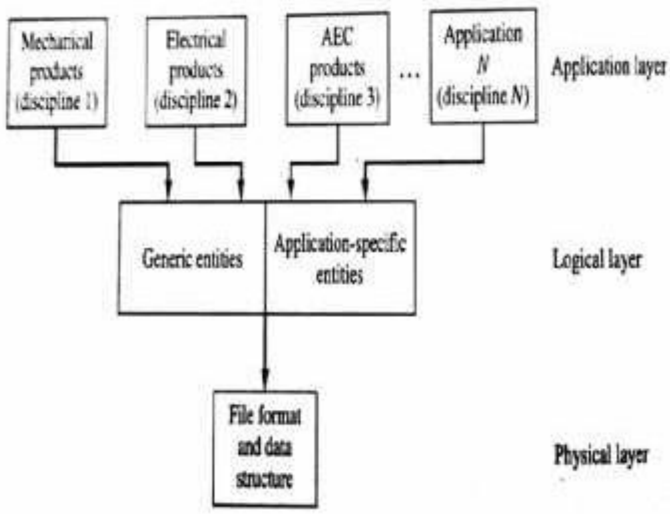


Fig:5.7 Relationship Between Layers of STEP Standards

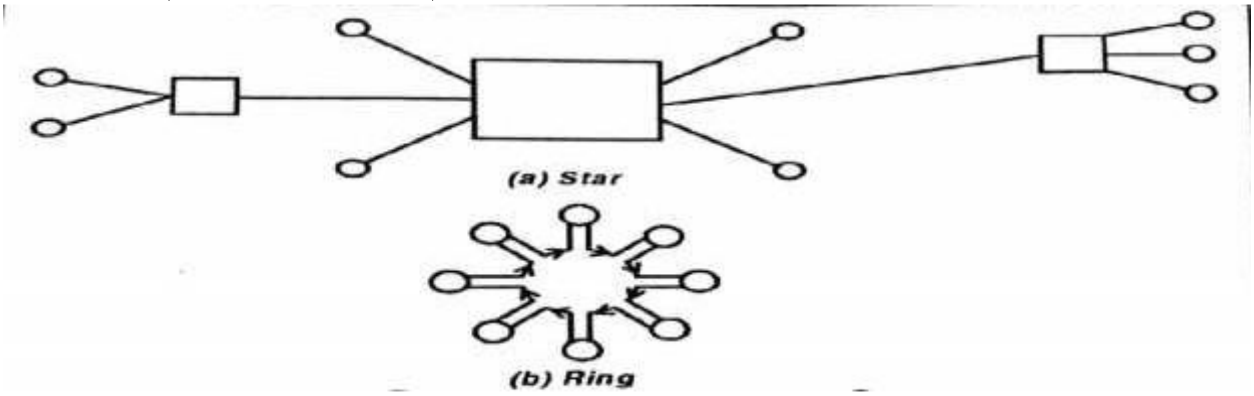


CALS:

- Continuous Acquisition and Life cycle support is CALS.
- CALS was originally called Computer Aided Acquisition and Logistics Support.

COMMUNICATION STANDARDS:

- Data exchange depends not only on the compatibility of the applications data formats between the communicating systems.
    - LAN (Local area networks)
    - WAN (Wide area networks)



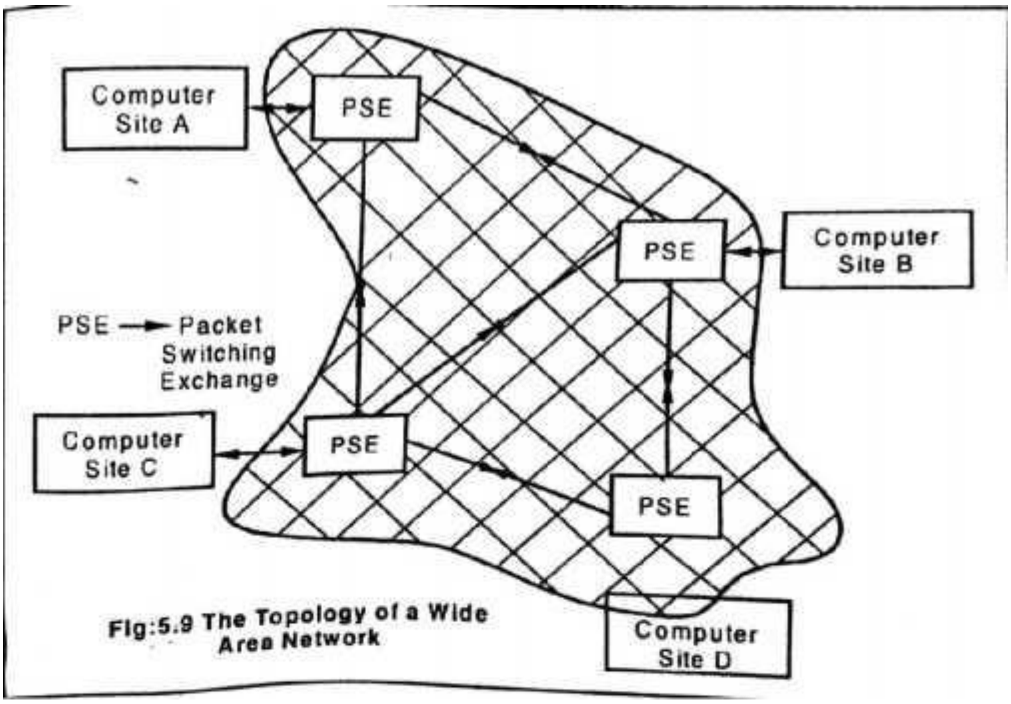
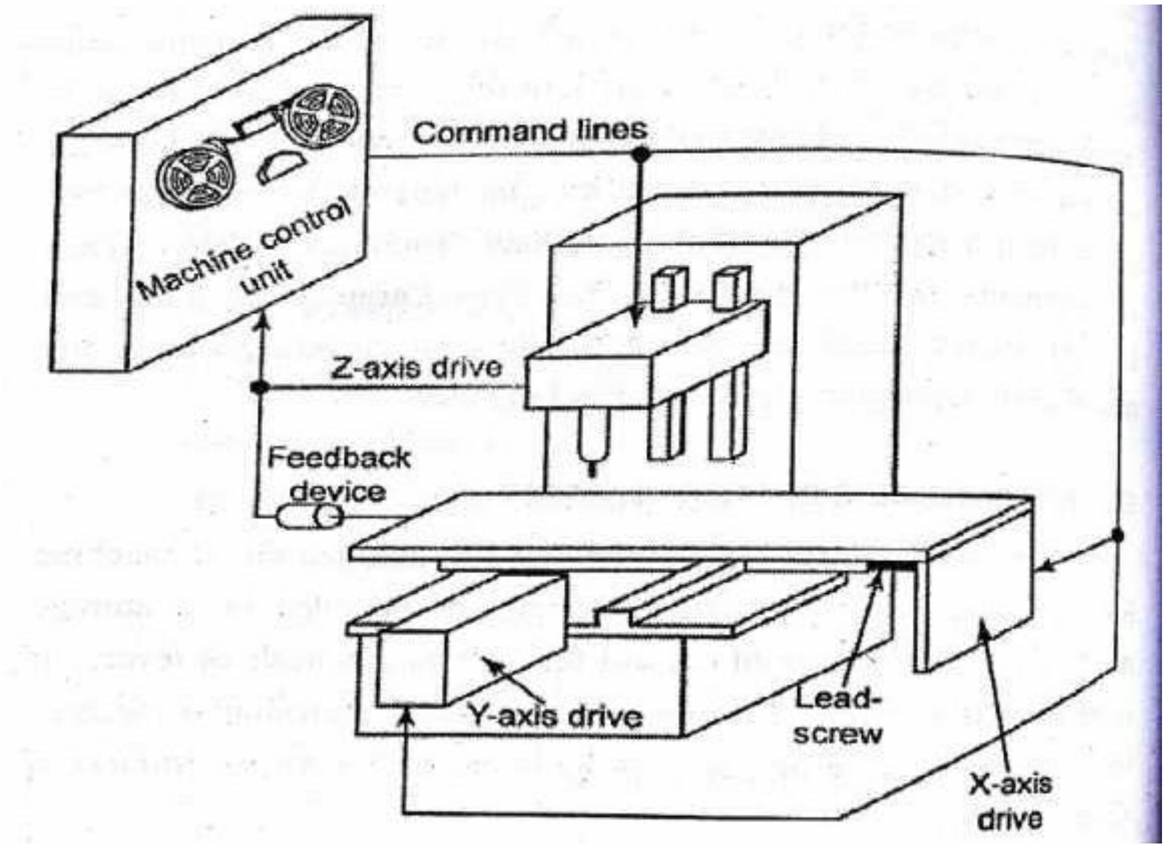


Fig:5.9 The Topology of a Wide Area Network

UNIT IV
FUNDAMENTAL OF CNC AND PART PROGRAMING

Definition of NC System:

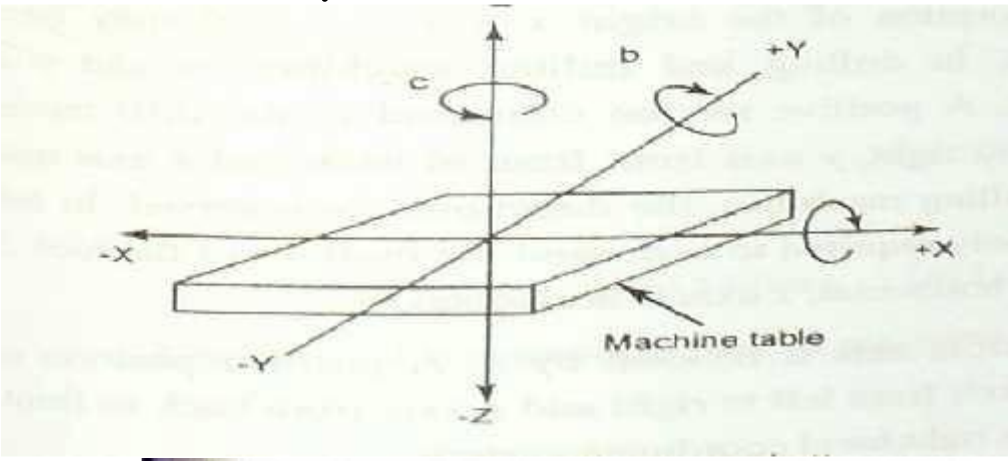
- A system in which actions are controlled by the direct insertion of numerical data at some point is known as NC system.

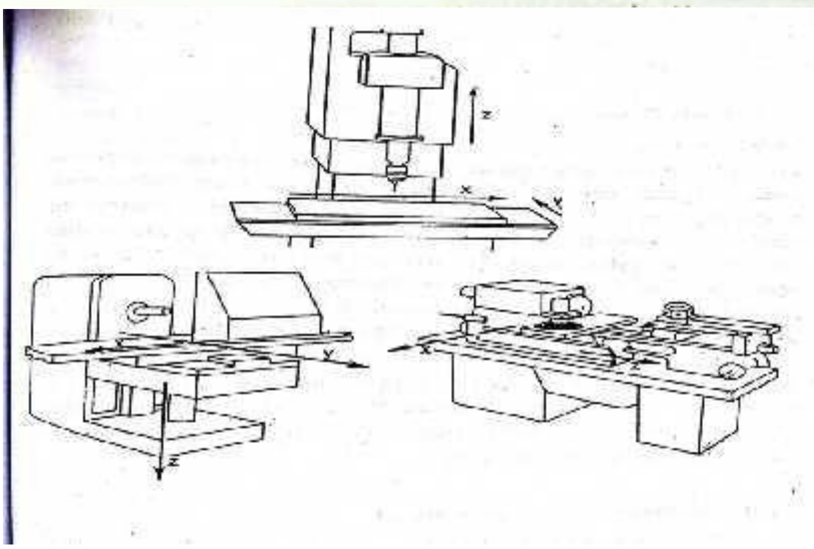


TYPES OF NC SYSTEM:

- Traditional numerical control (NC)
- Computer numerical control (CNC)
- Distributed numerical control (DNC)

Controlled axes in NC systems:

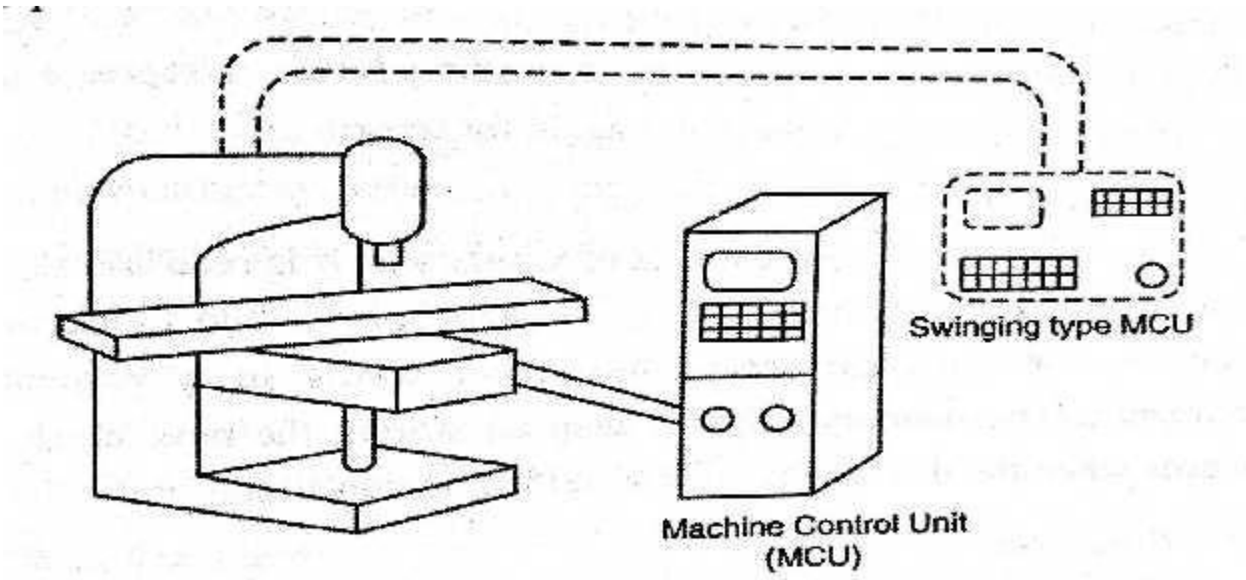




Basic components of NC:

- Software
- Machine Control Unit (MCU)
- Machine tool

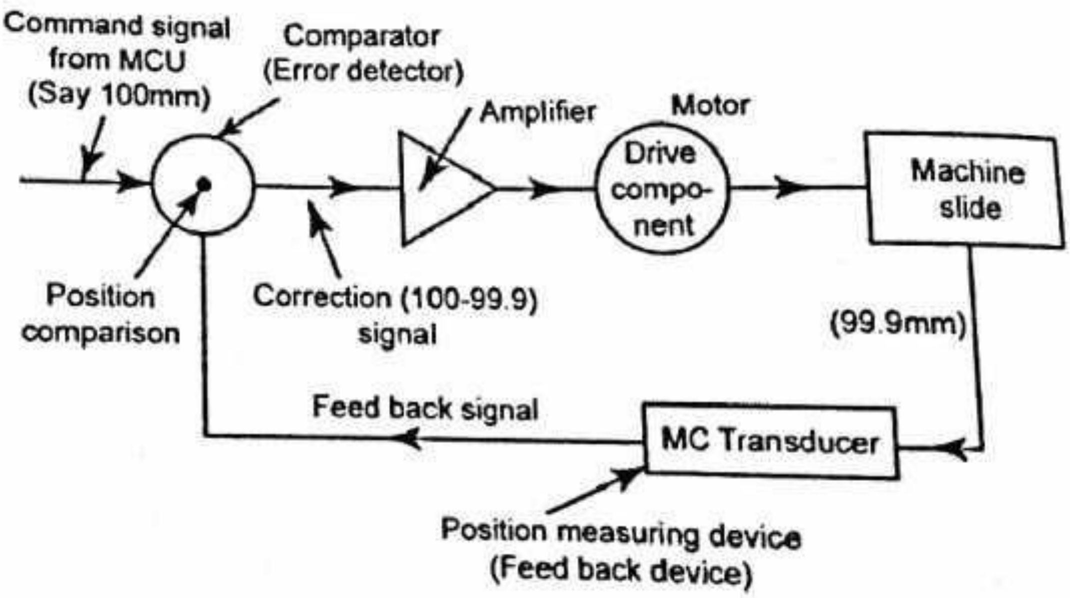
Machine Control Unit

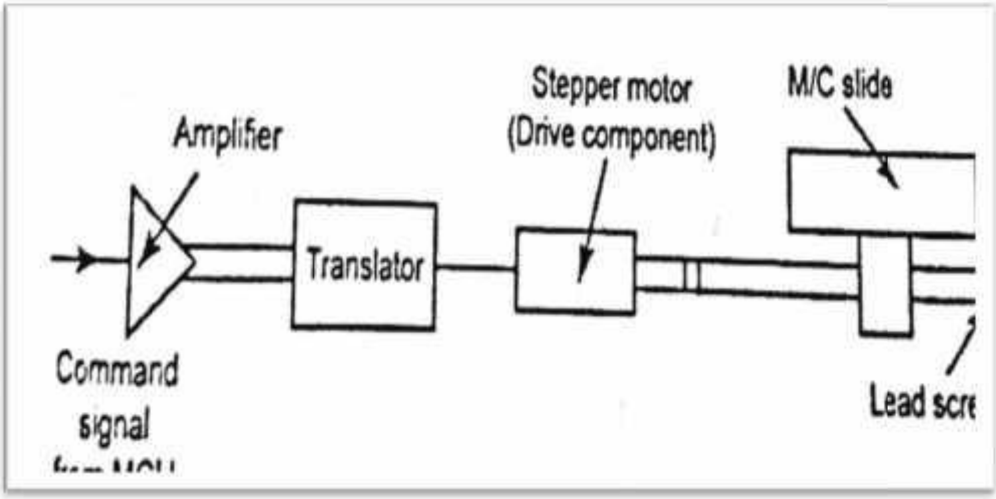


CLASSIFICATION NC MACHINES BASED ON CONTROL SYSTEM

- Open- loop system in NC machines
- Closed loop system in NC machines

Open- loop system in NC machines





Closed loop system in NC machines

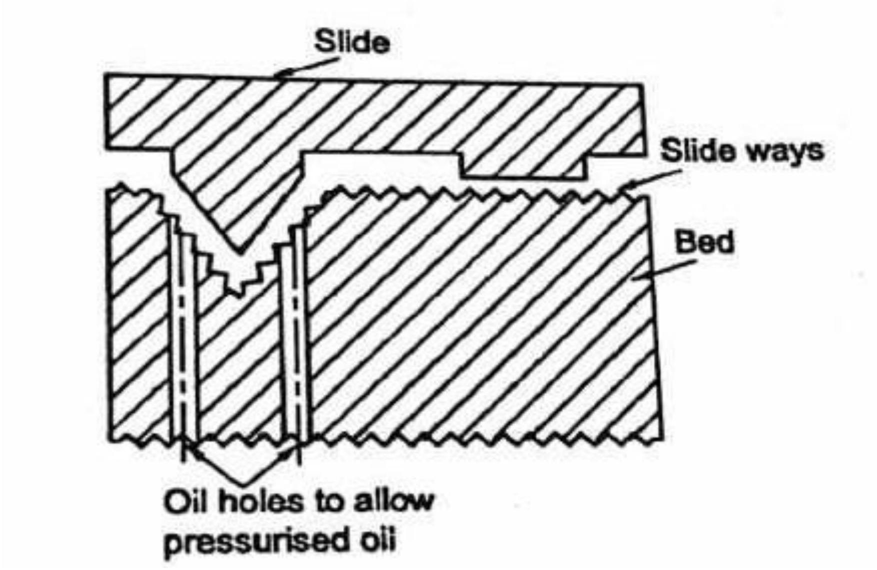
The type of CNC used in these above- said fields are given below

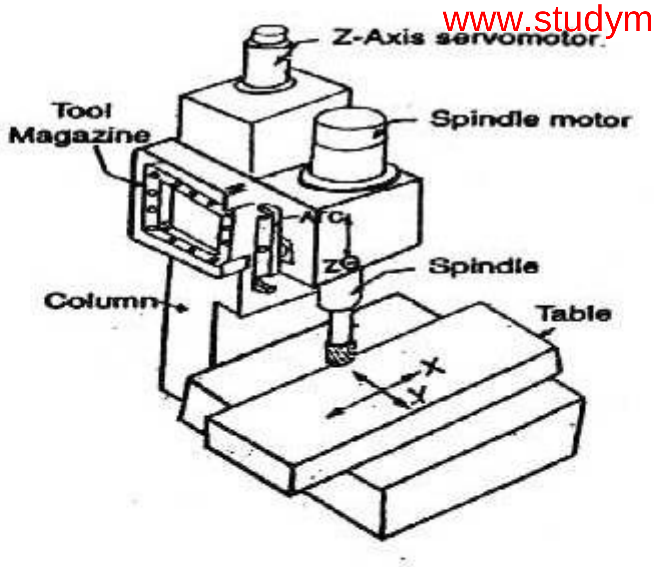
- CNC lathes

- CNC turning centres
- Gear hobbing machines
- Gear shaping machines
- Tube bending
- Electron beam welding
- Press brakes
- Abrasive water jet machines
- Coordinate measuring machines

Special features of CNC machines

- CNC drive systems
- Feed drive
- Slide movement element
- coolant control
- Working of automatic tool changer
- Work holding system
- CNC controller
- Type of CNC machines





MACHINING CENTRES

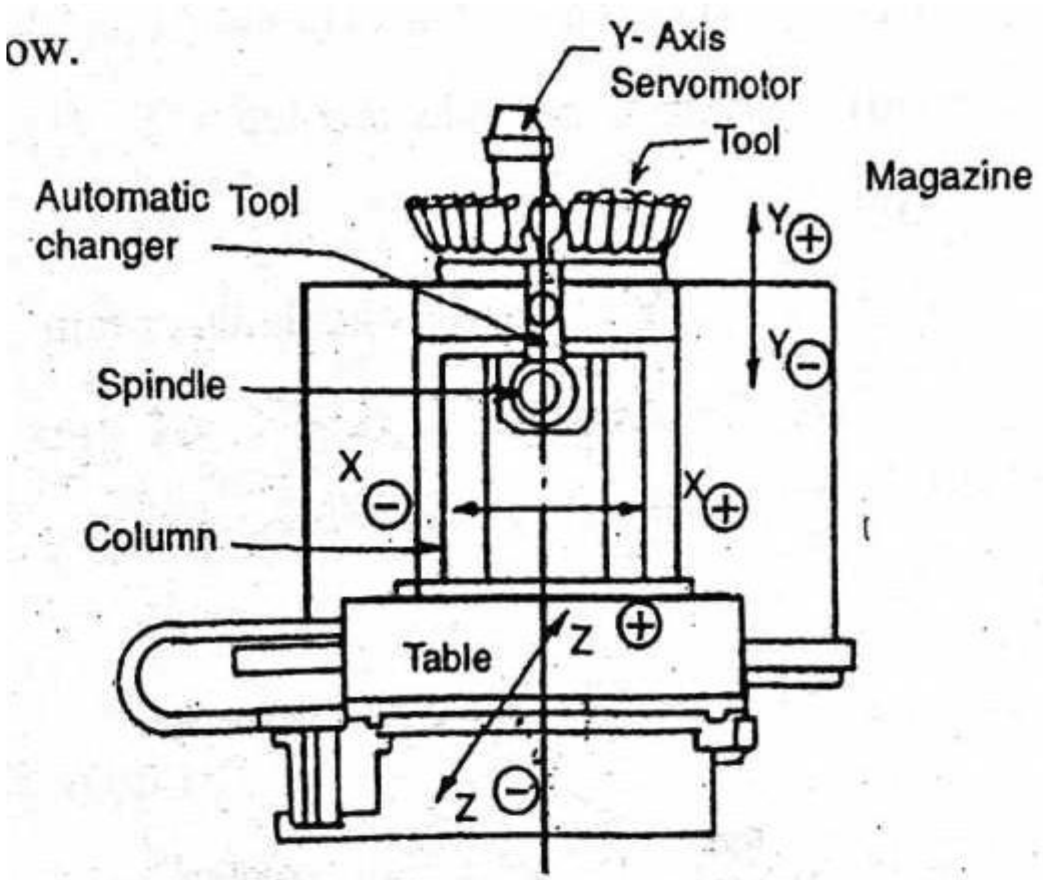
The following operations are carried out

- Milling
- Drilling
- Reaming
- Boring
- Tapping

Classification of machining centres

Horizontal spindle machining centres

Vertical spindle machining centre



APPLICATION OF CNC MACHINES:

- Metal cutting industry for processes
- In addition to metal cutting machines, CNC has also been applied to the following
  - Press working machine tools
  - Welding machines
  - Inspection machines
  - Assembly machines
  - Industrial robots
  - Cloth cutting

ADVANTAGES OF CNC MACHINES

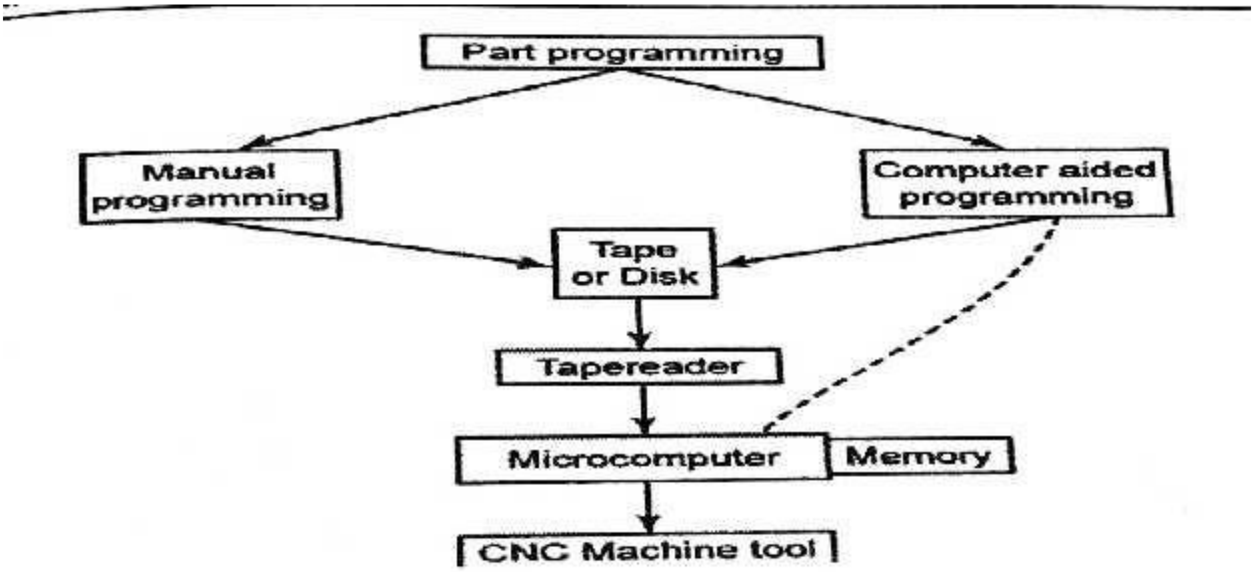
- It increases in capacity for storing large part programs
- It increases the memory for part programme processing
- It is easy to edit the part programs on the control console
- CNC is more compatible

DISADVANTAGES OF CNC MACHINES

- Costly setup and skilled operators are required
- Computer programming knowledge is essential
- Maintenance is difficult
- Machines have to be installed in air conditioned places

Part program:

– The part programme is a set of instructions proposed to get the machined part starting with the desired blank and NC machine tool.



Methods of creating part programming:

- Manual part programming
- Computer assisted part programming (CAD/CAM)
- Manual data input
- Computer automated part programming

CNC MANUAL PART PROGRAMMING:

- To prepare a part programme using a manual method, the programmer writes the machining instructions on a special format called part programming manuscript.
- The manual programming jobs can be divided into two categories
    - Point to point jobs
    - Contouring jobs

DATA REQUIRED FOR PART PROGRAMMING

– Job dimensions/workpiece
- Work holding
- Feed/cutting speed
- Finished dimension with tolerance
- Sequence of operation
- Types of tools

5.18.6. Part Programme Format and Symbols

The programme format is N4/G2/X43/Y43/F03/S200/M03. From the above format, the following should be understood.

(i) N indicates the *block number* which has the number 1 to 9999.

(ii) G denotes the *preparatory function* having two digits 00 to 99.

(iii) X and Y co-ordinates may have up to seven digits each 1234567.

(iv) F indicates the *Feed* given.

(v) S indicates the speed of work (or) spindle.

(vi) M denotes miscellaneous functions.

(vii) Enter or end of the block (for each line it should be given).

- Mounting of tools

PREPARATORY FUNCTIONS (G) IN PART PROGRAMMING

- Preparatory commands which prepare the machine or tool for different modes of movement positioning.

Function codes	*Meaning*
G00	Point to point positioning
G01	Linear interpolation
G02	Circular interpolation, clockwise
G03	Circular interpolation, anticlockwise
G04	Dwell
G06	Parabolic interpolation
G08	Acceleration
G09	Deceleration
G17	XY plane selection
G18	XZ plane selection
G19	YZ plane selection
G25, G29	Unassigned
G33	Tread cutting, constant lead
G34	Tread cutting, increasing lead
G35	Tread cutting, decreasing lead
G36, G39	Unassigned
G40	Tool offset cancel

G41 G42	Tool offset
G54, G59	Linear shift
G60	Fine positioning
G61	Medium positioning
G62	Coarse positioning (fast)
G63	Tapping
G70	Inch programming
G71	Metric (mm)
G80	Canned cycle cancel
G81, G89	Canned cycles
G90	Absolute dimension
G91	Incremental dimension
G92	Position pre-set
G93	Inverse time, feed rate
G94	Feed/minute
G95	Feed/revolution
G96	Constant surface speed
G97	Spindle speed

MISCELLANEOUS FUNCTION IN PART PROGRAMMING

- The function not relating the dimensional movement of the machine but it denotes the auxiliary or switching information is called miscellaneous functions.
- For example coolant on/off, spindle speed

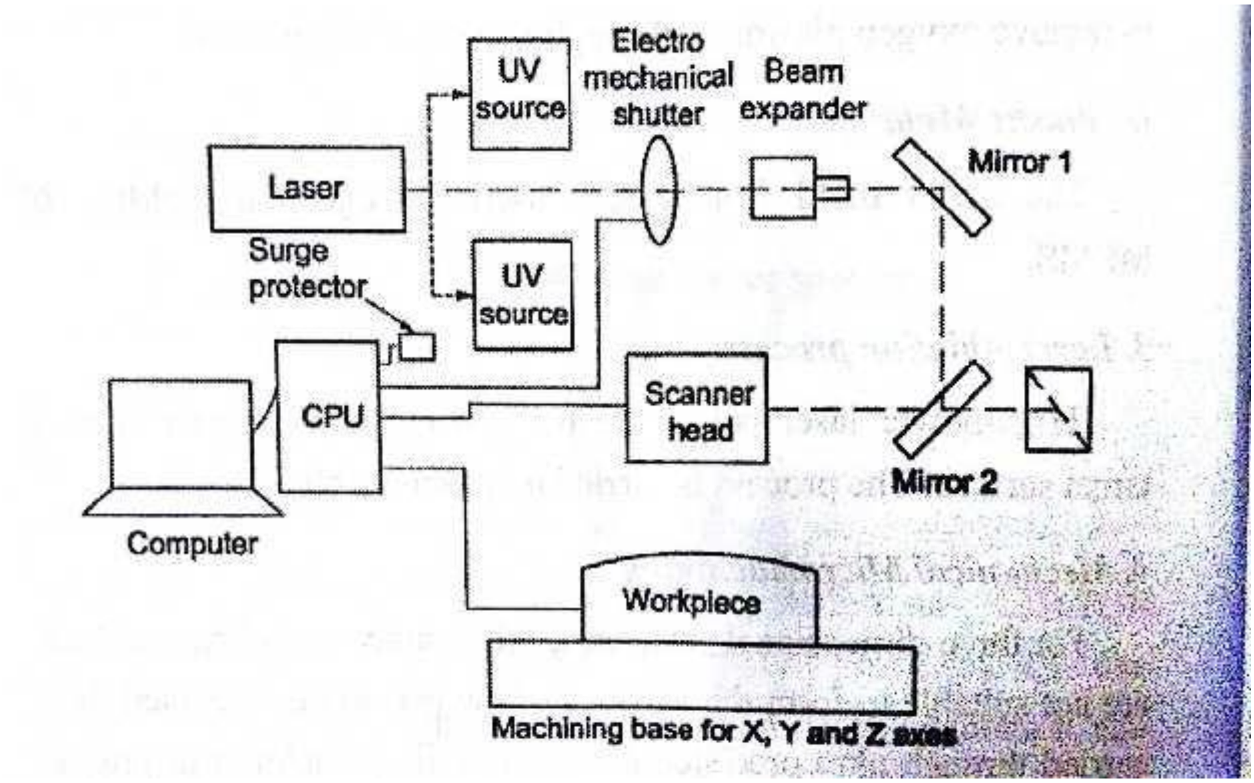
Function codes	*Meaning*
M00	Programmed stop
M01	Optional stop
M02	End of programmewithout skip back
M03	Spindle clockwise
M04	Spindle anticlockwise
M05	Spindle stop
M06	Tool change
M07	high pressure coolant ON
M08	Low pressure coolant ON
M09	Coolant OFF
M10	Clamp workpiece
M11	Release workpiece
M12	Hydraulic power rotary table ON
M13	Last replacement tool
M14	Oil hole frill coolant ON
M16	Heavy tool change
M17	Tap cycle confirmation
M18	Tap cycle cancel
M19	Spindle orientation
M20	Coolant nozzle up
M21	Coolant nozzle middle
M22	Coolant nozzle down
M23	Detection of contact in – X
M24	Detection of contact in +X
M25	Detection of contact in –Y
M26	Detection of contact in +Y
M27	Tool breakage detection
M28	Quill forward
M29	Quill back
M30	End of programme with skip back
M31	Delete block 'off'
M35	Transition taper ON while threading
M36	Transition taper ON while threading
M40	Transmission stage I

INTERPOLATION IN PART PROGRAMMING

- It is the process of developing coordinate points in between start and finish coordinates.
- Interpolation in NC machining is required to calculate the intermediate points of a curve or straight line when its start and end coordinates are given. Interpolation may be linear, circular or cubic/parabolic.

MICROMACHINING

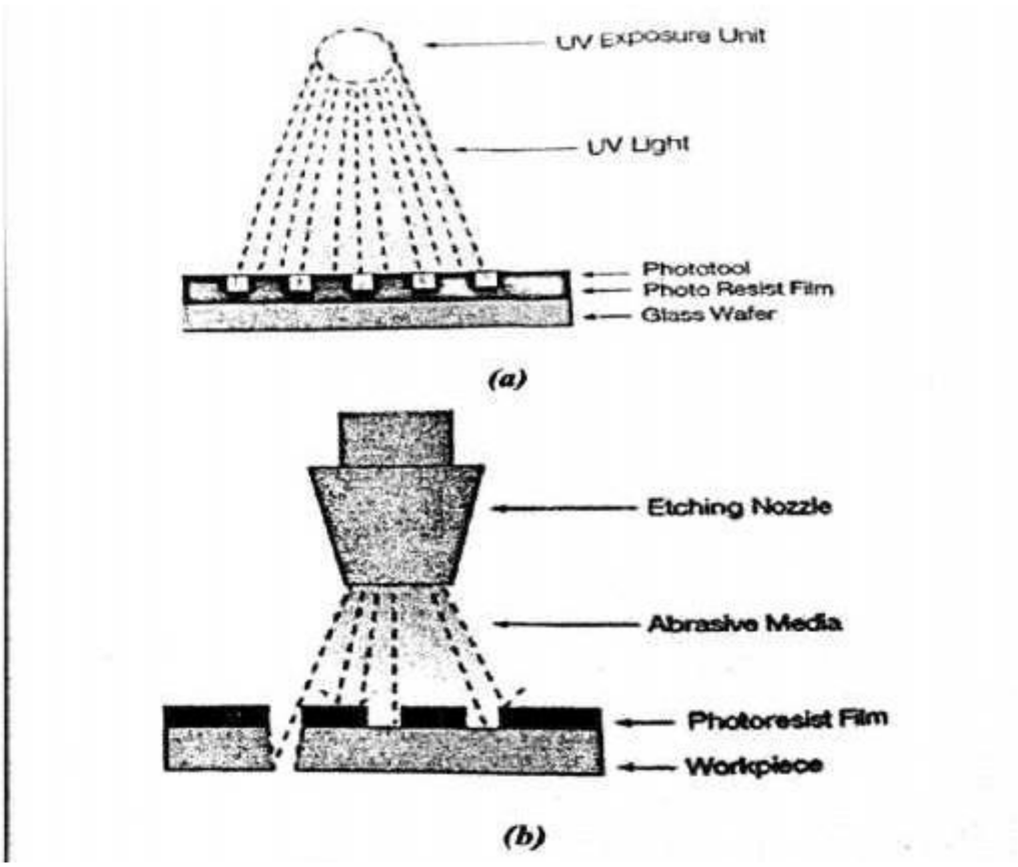
- Micromachining refers of the technique for the fabrication of 3D structure on the micrometer scale. Micromachining refers the super finishing, a metalworking process for producing very fine surface finishes.
- The various types of micromachining process are given below
  - Bulk micromachining
  - Surface micromachining



SURFACE MICROMACHINING

- In surface machining process, the structures are created on top of a substrate. In this case, a silicon substrate (wafer) is selectively etched to produce structures.
- In this machining the microstructures are built by deposition and etching of different structural layers on top of the substrate.

WAFER MACHINING



UNIT V

CELLULAR MANUFACTURING AND FLEXIBLE MANUFACTURING SYSTEM (FMS)

GROUP TECHNOLOGY:

- It's the manufacturing philosophy to increase the production efficiency by grouping a variety of parts having similarities of shape, dimension, and/or process route.
- It justifies batch production by capitalizing on design and/or manufacturing similarities among components parts.

Role of GT in CAD/CAM

- For closer dimensional tolerances
- More economical in higher accuracy
- Increased variety of materials , by manufacturing needs. ❧

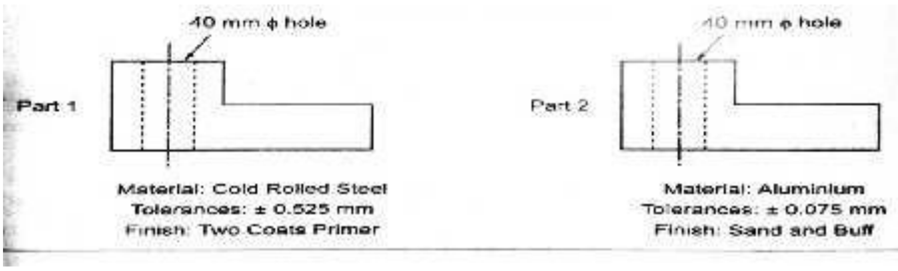
Lowering scrap rates

Important Elements of CAD/CAM Integration

- It provides a common data base for effective integration of CAD & CAM for successful implementation of CIM
- GT provides a common language for users
- It gives a information about Design, Manufacturing Attributes, Processes & Capabilities

Part Families

- A part family is a collection of parts which are similar in geometric shape and size or processing steps are required in their manufacture.
- It may be a similar in their Design, Manufacturing characteristics are grouped and referred as Design part family & Manufacturing part family
- The characteristics used are known as Attributes



METHODS FOR PART FAMILY FORMATION

1.Visual inspection

2. part classification & Coding Methods

3.production flow analysis

Design & Manufacturing Attributes

1.System based on Part Design Attributes

2.System based on Manufacturing Attributes

3.System based on Both Design & Manufacturing Attributes

Part design attributes	Part manufacturing attributes
Basic external shape	Major production processes
Basic internal shape	Minor operations
Rotational or rectangular shape	Operation sequence
Major dimensions	Major dimension
Minor dimensions	Production time
Material type	Tools required
Part function	Fixtures required
Length to diameter ratio (rotational parts)	Batch size
Aspect ratio (rectangular parts)	Machine tool
Surface finish	Annual production
Tolerances	Surface finish

Coding System Structure

- A Group Technology is a string of characteristics capturing information's about an item.
- A part coding scheme consists of a sequence of symbols that identify the part's Design / Manufacturing attributes

Types of Basic Code Structures

- . Hierarchical codes

(Mono codes or tree structure)

- 2. Attributes codes

  (Poly code or chain type structure)

- 3. Decision tree codes

  (hybrid code or mixed codes)

Hierarchical codes

- The interpretation of each successive symbols depends on the value of the preceding symbols
- Each symbols amplifies the information contained in the preceding digit, so that the digits in the symbols cannot be interrupt alone.
- The structure is like a tree.

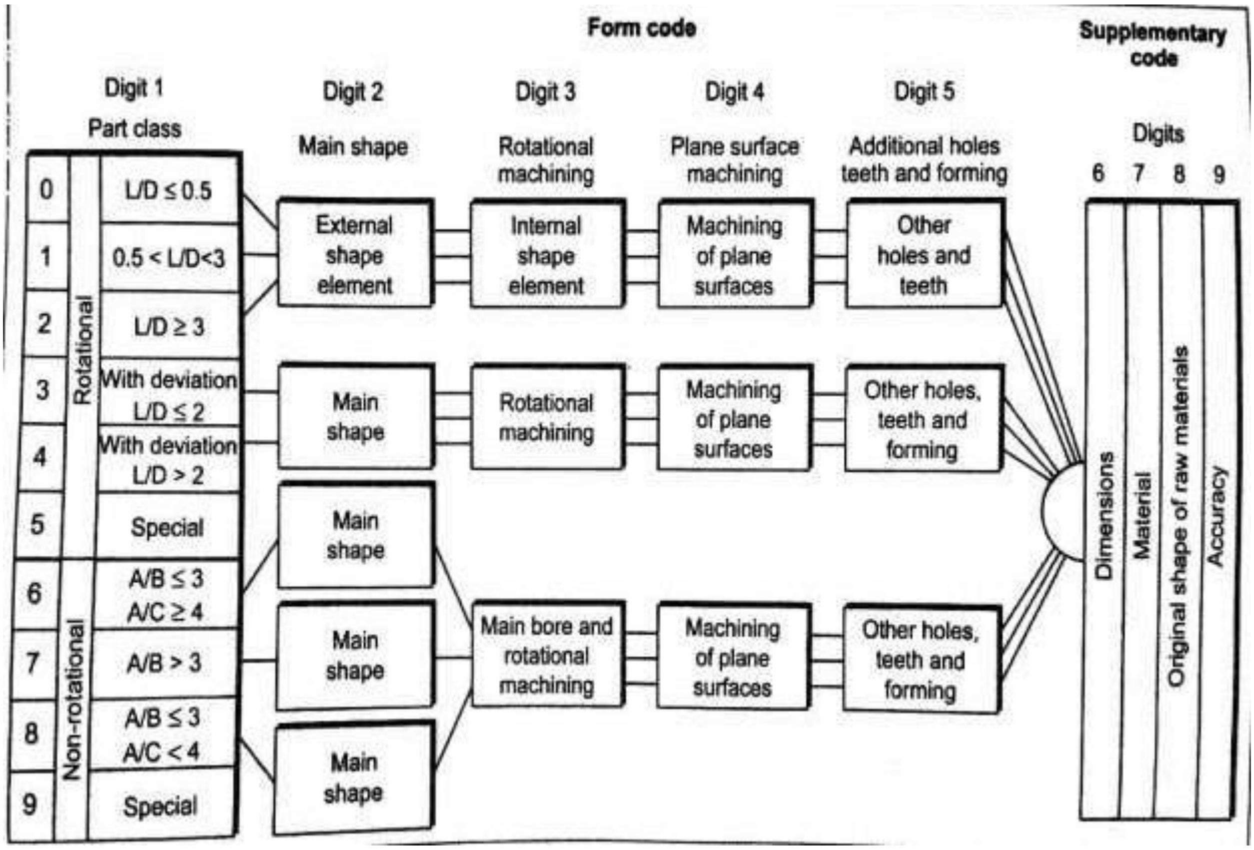
Opitz Classification Systems

- The opitz system was developed by H.Optiz of the university of Aachen in Germany.
- It was the most popular and one of the first published classification and coding scheme for mechanical parts
- This system uses alpha numeric symbols to represent the various attributes of a part.
- The following digits sequence are:

12345	6789	ABCD
FORM CODE	SUPPLEMENTARY CODE	SECONDARY CODE

- FORM CODE (12345) : This code is for design attributes
- SUPPLEMENTARY CODE (6789): This code is for Manufacturing related attributes
- SECONDARY CODE (ABCD): This code is for production operation and sequence.

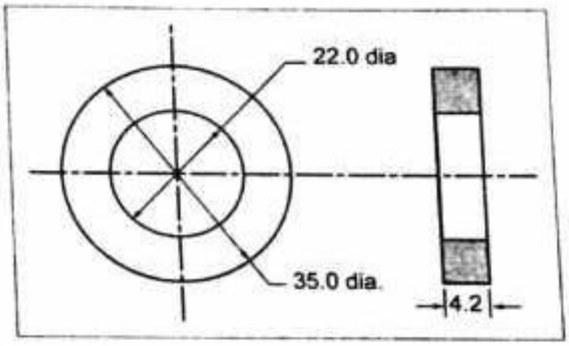
1. Opitz classification system,
2. MICLASS system,
3. DCLASS system,
4. KK-3 system,
5. CODE system,
6. CUTPLAN system,
7. RNC system,
8. Part Analog system,
9. Brisch system,
10. COFORM.



Code	Digit 1: Part class		Digit 2: External shape, external shape elements		Digit 3: Internal shape, internal shape elements		Digit 4: Plane surface machining	Digit 5: Auxiliary holes and gear teeth	
0	Rotational parts	L/D ≤ 0.5		Smooth, no shape elements		No hole, no break through	No surface machining		No auxiliary hole
1	Rotational parts	0.5 < L/D < 3	Stepped to one end or smooth	No shape elements	Smooth or stepped to one end	No shape elements	Surface plane and/or curved in one direction, external	No gear teeth	Axial, not on pitch circle diameter
2	Rotational parts	L/D ≥ 3	Stepped to one end or smooth	Thread	Smooth or stepped to one end	Thread	External plane surface related by graduation around the circle	No gear teeth	Axial on pitch circle diameter
3	Rotational parts		Stepped to one end or smooth	Functional groove	Smooth or stepped to one end	Functional groove	External groove and/or slot	No gear teeth	Radial, not on pitch circle diameter
4	Rotational parts		Stepped to both ends	No shape elements	Stepped to both ends	No shape elements	External spline (polygon)	No gear teeth	Axial and/or radial and/or other direction
5	Rotational parts		Stepped to both ends	Thread	Stepped to both ends	Thread	External plane surface and/or slot, external spline	No gear teeth	Axial and/or radial on PCD and/or other directions
6	Rotational parts		Stepped to both ends	Functional groove	Stepped to both ends	Functional groove	Internal plane surface and/or slot	With gear teeth	Spur gear teeth
7	Nonrotational parts			Functional groove		Functional groove	Internal spline (polygon)	With gear teeth	Bevel gear teeth
8	Nonrotational parts			Operating thread		Operating thread	Internal and external polygon, groove and/or slot	With gear teeth	Other gear teeth
9	Nonrotational parts			All others		All others	All others		All others

Example 3.1 *Develop the form code (five digits) in the Opitz system for the part illustrated in Fig.3.11. All dimensions are in mm.*

Solution: Refer Figs.3.9 and 3.10. For the given part, the five-digit code is developed as follows:



Step 1: Calculate $\frac{L}{D} = \frac{4.2}{35} = 0.12$. So here $\frac{L}{D} \leq 0.5$.

$\therefore$ Digit 1 = 0

Step 2: External shape: Smooth, no shape elements.

$\therefore$ Digit 2 = 0

Step 3: Internal shape: Though-hole, smooth, no shape elements.

$\therefore$ Digit 3 = 1

Step 4: Plane surface machining: None.

$\therefore$ Digit 4 = 0

Step 5: Auxiliary holes and gear teeth: None.

$\therefore$ Digit 5 = 0

Thus the form code in the Opitz system for the part is **00100** **Ans.**

Cellular Manufacturing

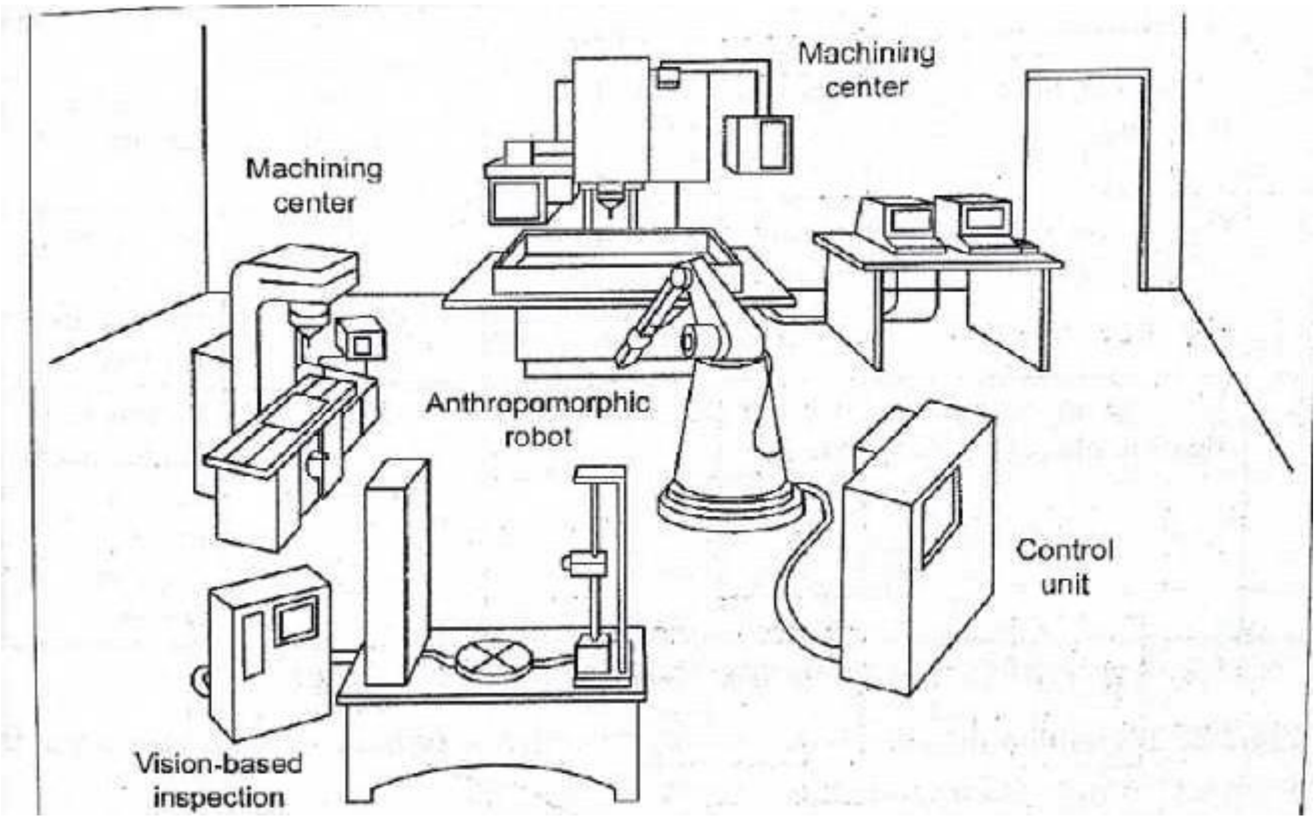
- Cellular Manufacturing (CM) is an application of group technology in which dissimilar machines have been aggregated into cells, each of which is dedicated to the production of a part family.

Composite Part Concept

- A composite part is the hypothetical part which includes all of the design and manufacturing attributes of a family.
- The composite is a single hypothetical part that can be completely processed in a manufacturing cell.
- If a new part is loaded in a machine group and if the degree of dis-similarity of the part from the hypothetical composite part is minimum, then the new part can be processed in the same manufacturing cell.

Flexible manufacturing cell or flexible manufacturing system

- FMS employs a fully integrated handling system with automated processing stations.
- Out of all four types of machine cells, the FMS is the highly automated GT machine cell.



FLEXIBLE MANUFACTURING SYSTEM (FMS) AND AUTOMATED GUIDED VEHICLE SYSTEM (AGVS)

- FMS may be defined as "a highly automated GT machine cell, consisting of a group of processing workstations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by a distributed computer system."
- FMS employs a fully integrated handling system with automated processing stations.

Flexibility and its Types

- **Flexibility is an attribute that allows a manufacturing system to cope up with a certain level of variations in part or product type, without having any interruption in production due to changeovers between models.**
- **Flexibility measures the ability to adopt "to a wide range of possible environment"**

Tests of Flexibility

- **Part variety test**
- **Schedule change test**
- **Error recovery test**
- **New part test**

Types of Flexibility

- **Machine flexibility**
- **Production flexibility**
- **Mix (or Process) flexibility**
- **Product flexibility**
- **Routing flexibility**
- **Volume (or capacity) flexibility**
- **Expansion flexibility**

Machine flexibility

- ***Definition:*** **Machine flexibility is the capability to adapt a given machine in the system to a wide range of production operations and part types.**
- ***Influencing factors:***
  - **Setup or change over time**

- Ease with which part-programs can be downloaded to machines
- Tool storage capacity of machine
- Skill and versatility of workers in the systems

Production flexibility

- ***Definition:*** **Production flexibility is the range of part types that can be produced by a manufacturing system.**
- ***Influencing factors:***
    - **Machine flexibility of individual stations**
    - **Range of machine flexibilities of all stations in the system**

Mix (or Process) flexibility

- ***Definition:*** **Mix flexibility, also known as process flexibility, is the ability to change the product mix while maintaining the same production quantity. i.e., producing the same parts only in different proportions**
- ***Influencing factors:***
    - **Similarity of parts in the mix**
    - **Machine flexibility**
    - **Relative work content times of parts produced**

Product flexibility

- ***Definition:*** **Product flexibility is the ability to change over to a new set of products economically and quickly in response to the changing market requirements.**
- ***Influencing factors:***
    - **Relatedness of new part design with the existing part family**
    - **Off-line part program preparation**
    - **Machine flexibility**

Routing flexibility

- ***Definition:*** **Routing flexibility is the capacity to produce parts on alternative workstation in case of equipment breakdowns, tool failure, and other interruptions at any particular station.**
- ***Influencing factors:***

 Similarity of parts in the mix

Similarity of workstations

Common testing

Volume (or capacity) flexibility

- *Definition:* Volume flexibility, also known as capacity flexibility, is the ability of the system to vary the production volumes of different products to accommodate changes in demand while remaining profitable.
- *Influencing factors:*
  - Level of manual labour performing production
  - Amount invested in capital equipment

Expansion flexibility

- *Definition:* Expansion flexibility is the ease with which the system can be expanded to foster total production volume.
- *Influencing factors:*
  - Cost incurred in adding new workstations and trained workers

    Easiness in expansion of layout
  - Type of part handling system

Types of FMS

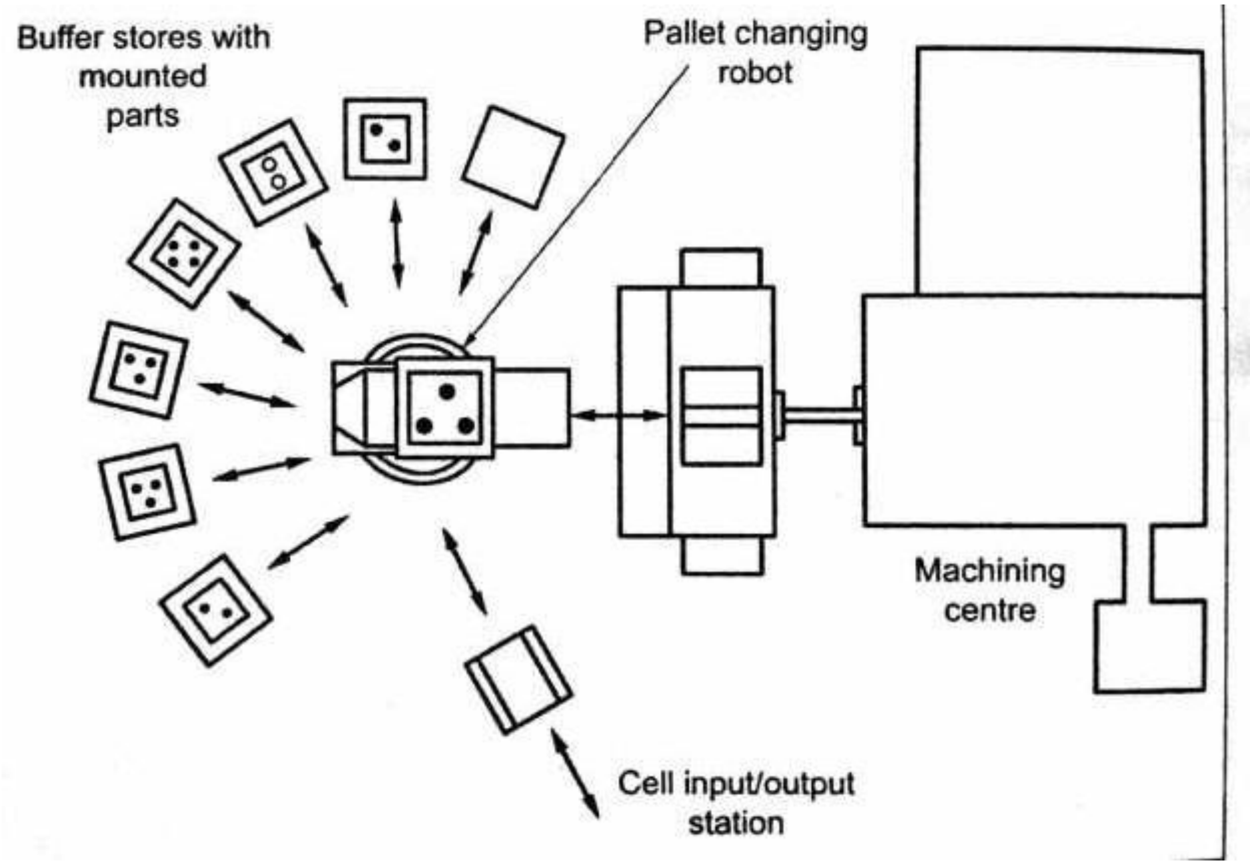
- Classification based on the kinds of operations they perform
  - Processing operation
  - Assembly operation
- Classification based on the number of machines in the system
  - Single machine cell (SMC)
  - Flexible machine cell (FMC)
  - Flexible manufacturing system (FMS)
- Classification based on the level of flexibility associated with the system

- Dedicated FMS
- Random order FMS

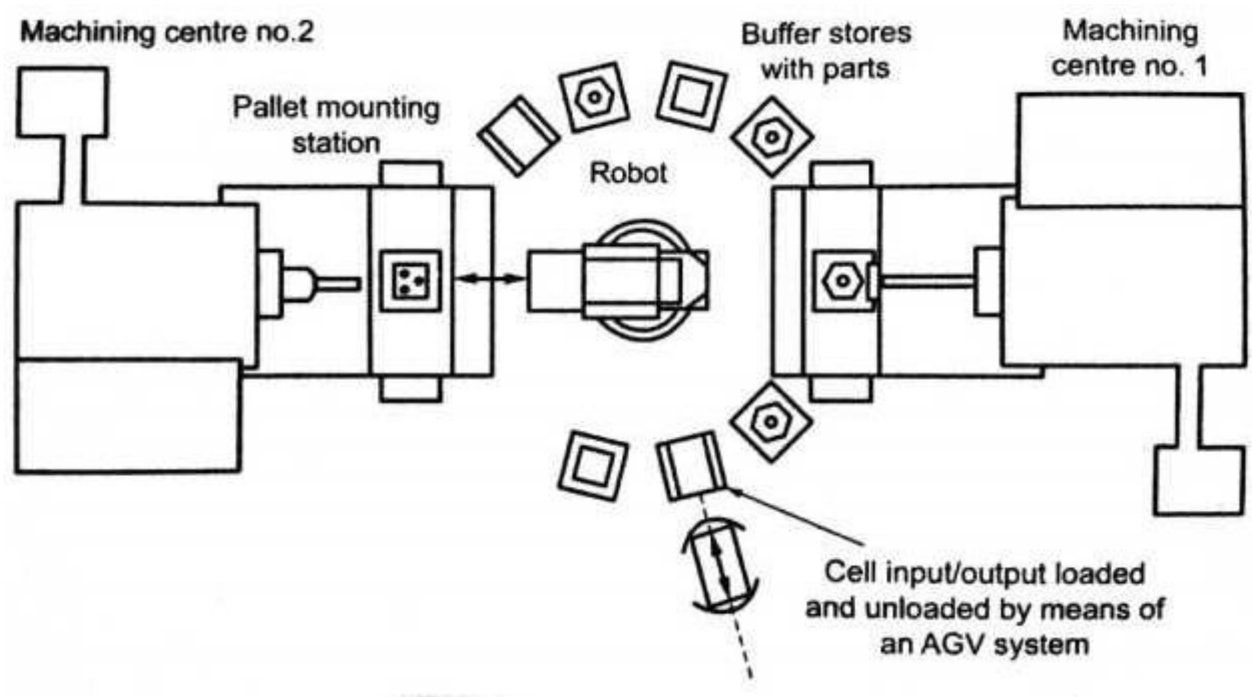
Classification based on the kinds of operations they perform

- **Processing operation**
  - **Processing operation transforms a work material from one state to another moving towards the final desired part or product.**
  - **It adds value by changing the geometry, properties or appearance of the starting materials.**
- **Assembly operation**
  - **Assembly operation involves joining of two or more components to create a new entity which is called an assembly.**
  - **Permanent joining processes include welding, brazing, soldering, adhesive banding, rivets, press fitting and expansion fits.**

Classification based on the number of machines in the system



Flexible machine cell (FMC)



FMS Workstations

- **The workstations/processing stations used in FMS depends upon the type of product manufactured by the system.**
- **The types of workstations that are usually found in a FMS are:**
  - **Load/unload stations**
  - **Machining stations**
  - **Assembly workstations**
  Inspection station
  - **Other processing stations**

Types of FMS layout Configurations

- **In-line layout**
- **Loop layout**
- **Ladder layout**
- **Open-field layout**
- **Robot-centered cell**

Functions of a FMS computer control system

Workstation/processing station control

Distribution of control instructions to workstations

Production control

Material handling system control

Workpiece monitoring

Tool control

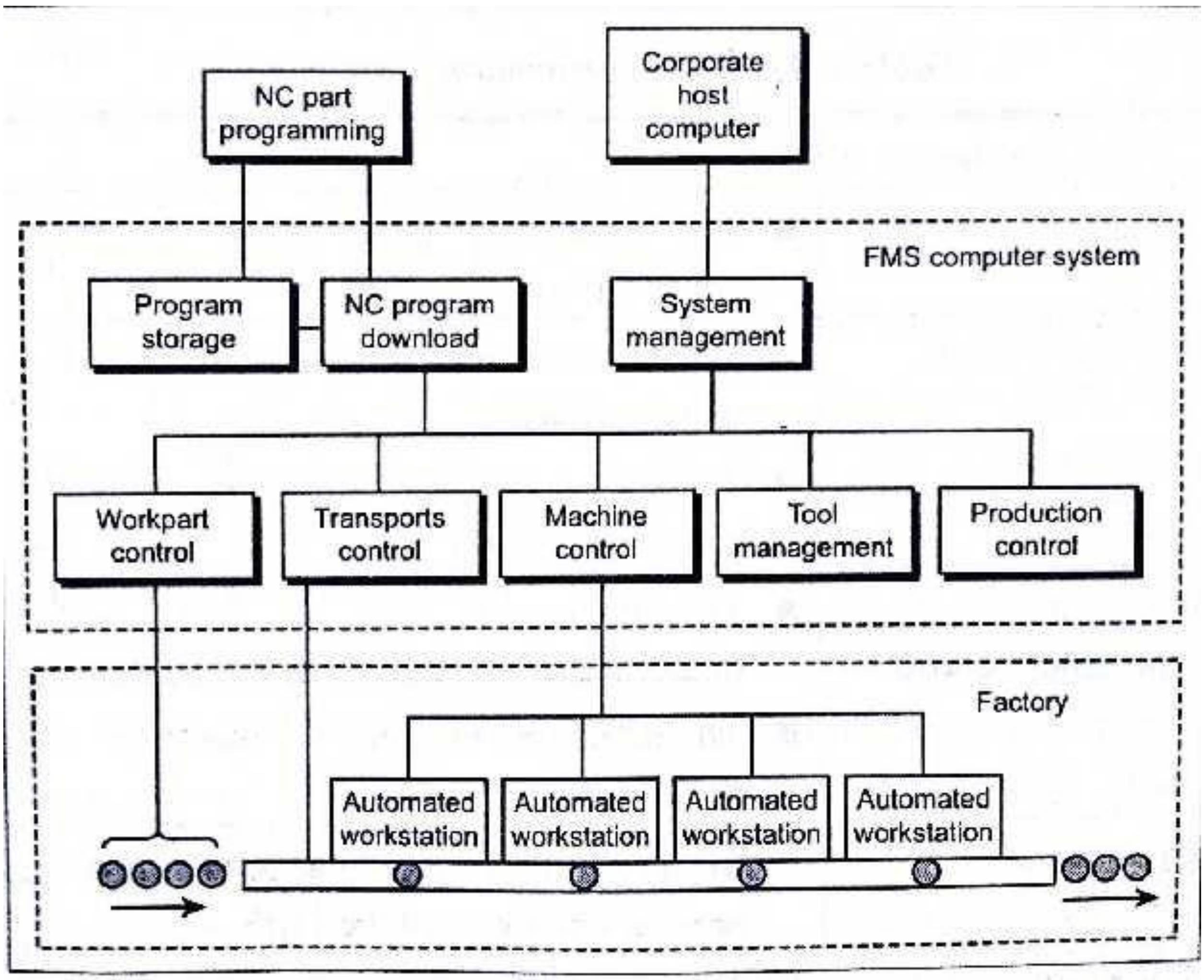
Quality control

Failure diagnosis

Safety monitoring

Performance monitoring and reporting

Structure of FMS Application software systems



Types of FMS Data Files

- **Part program file**
- **Routing file**
- **Part production file**
- **Pallet reference file**
- **Station tool file**
- **Tool life file**

FMS Applications

- **Machining**
- **Assembly**
- **Sheet-metal press working**

 Forging

 Plastic injection moulding

Welding

 Textile machinery manufacture

 Semiconductor component manufacture

Economics of FMS

 5-20% reduction in personnel

 15-30% reduction in engineering design cost

30-60% reduction in overall lead time

 30-60% reduction in work-in-process

 40-70% gain in overall production

 200-300% gain in capital equipment operating time

200-500% gain in product quality

 300-500% gain in engineering productivity

Advantages of FMS
(Benefits of FMS)

 Increased machine utilization

Reduced inventory

 Reduced manufacturing lead time

 Greater flexibility in production scheduling

Reduced direct labour cost

 Increased labour productivity

Shorter response time

 Consistent quality

 Reduced factory floor space

 Reduced number of tools and machines required

- Improved product quality

Disadvantages of FMS

- Very high capital investment is required to implement a FMS
- Acquiring, training and maintaining the knowledgeable labour pool requires heavy investment
- Fixtures can sometimes cost much more with FMS, and software development costs could be as much as 12-20% of the total expense
- Tool performance and condition monitoring can also be expensive since tool variety could undermine efficiency
- Complex design estimating methodology requires optimizing the degree of flexibility and finding a trade off between flexibility and specialization

FMS Planning and Control
(FMS Planning and Implementation issues)

- FMS planning and design issues
- FMS control (or operational) issues

FMS Planning issues

- Part family considerations
- Processing requirements
- Physical characteristics of the work parts

Production volume

FMS design issues

- Type of work stations
- Variations in process routings and FMS layout

Material handling system

- Work-in-process and storage capacity

Tooling

- Pallet fixtures

Quantitative analysis of Flexible Manufacturing System

- Flexible manufacturing system can be analysed using different models. The four different categories of FMS analysis models are:
    - Deterministic models
    - Queuing models
    - Discrete event simulation

    Other techniques

Automated Guided Vehicle System (AGVS)

- An Automated Guided Vehicle System (AGVS) is a computer controlled, driverless vehicle used for transporting materials from point to point in a manufacturing setting.
- An AGVS uses independently operated, self-propelled vehicles that are guided along pre-defined paths, and are powered by means of on-board batteries.
- The AGVs are highly flexible, intelligent, and versatile material handling systems used to transport materials from various loading locations to various unloading locations throughout the manufacturing facility.