

- N.B.:* (1) Question No. 1 is compulsory.
(2) Attempt **four** questions from remaining **six** questions.
(3) Clearly mention the **assumptions** made, if any.

Q. 1(a) Explain type of data structure generally employed in solid modelling.

6

Ans: Database structure in solid modelling-

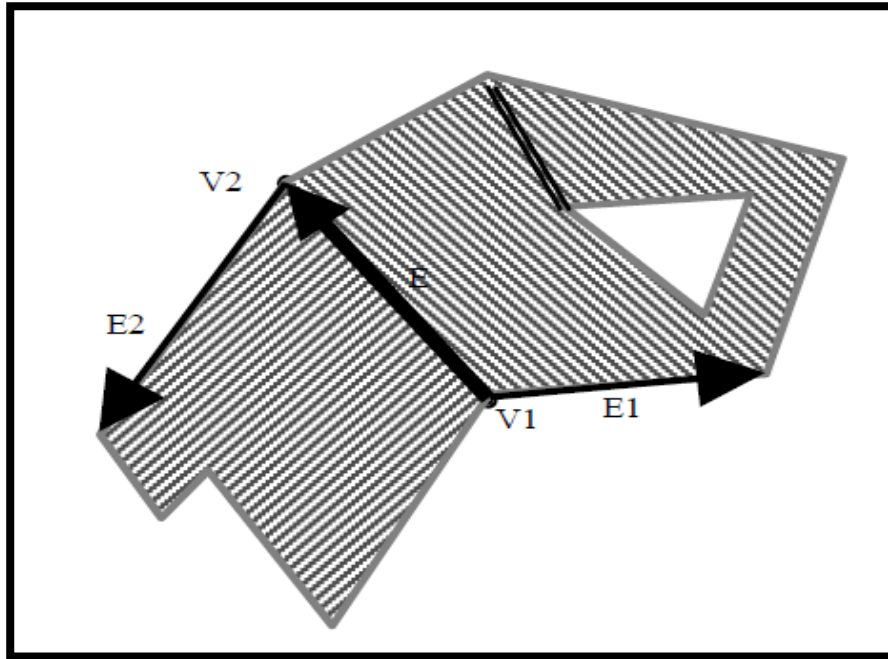
Although a simple enumeration of a solid's faces suffices to unambiguously define the solid, most boundary representation schemes store additional information to accelerate the traversal and processing of the boundary and combine the description of adjacent faces in order to eliminate the redundant descriptions of their common vertices. These data structures often capture the incidence relations between a face and its bounding edges and vertices, and between an edge and its bounding vertices.

Many data structures have been studied to achieve desired compromises between (1) the domain (or coverage) of the modeler, (2) the simplicity, regularity, and compactness of the data structure, and (3) the complexity and efficiency of the algorithms that process the representation. As an example, we describe with the help of Figure 3 a simple data structure for manifold polyhedral objects. It is a simplified version of the winged-edge representation introduced in [Baumgart72].

The vertices of the object are stored in a table with the associated coordinates. Edges are represented by references to vertices and to adjacent edges. Note that this data structure defines the geometry of the edges and of the loops which bound the faces, but does not explicitly capture the relations between the different loops of the same face. For example, the face on the right of Figure 3 has an outer loop that encloses a smaller, triangular, inner loop of edges. Some boundary representations have separate nodes for faces, and store explicitly the face and loop relationships.

Alternatively, faces with holes may be converted into simply-connected faces by introducing artificial "bridge" edges that each merge two loops of a face.

Example-



(c) *“The handling system establishes the FMS layout”. Explain above statement w.r.t handling system used in FMS.*

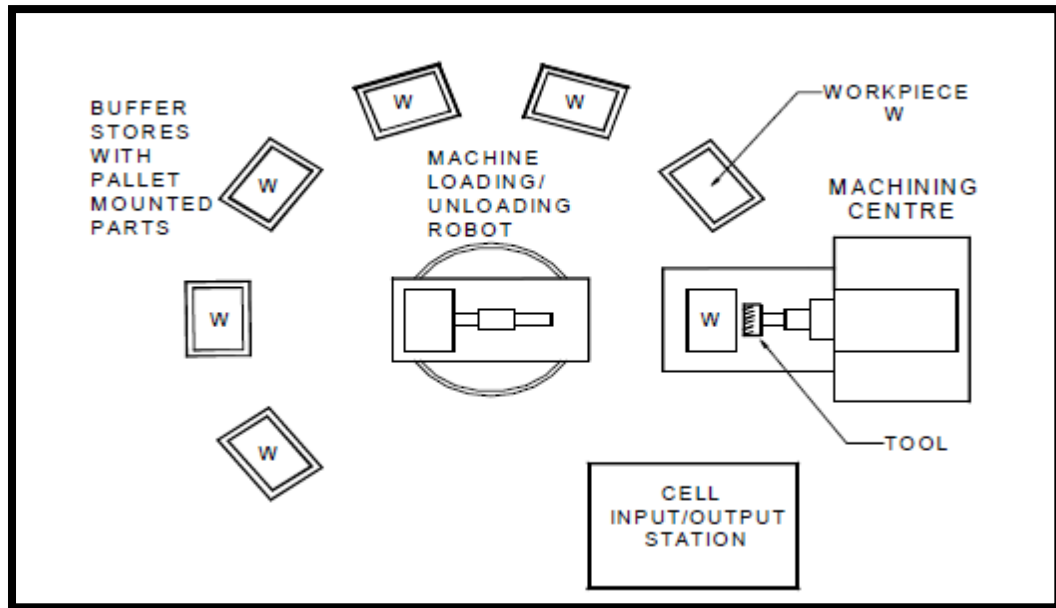
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Ans: Handling system used in FMS-

- A FMS typically needs several materials handling systems to service the machines.
- A transport system to move workpieces into and out of the FMS (e.g. overhead conveyors, gantry systems, AGV's, RGV's)
- A buffer storage system for queues of workpieces at the machines (e.g., pallets)
- A transfer system to load and unload the machines (e.g. robots, transfer fixtures)

For these systems to work effectively, they must be synchronized with the machine operations. The location and movement of workpieces must be tracked automatically. This is done by using sensors on the materials handling system and workstations. They may be either contact devices (e.g. switches) or non-contact devices (e.g. optical, RFID tags or proximity devices).

In an FMS, parts move from one work cell to another where the various processing tasks are performed. Because of the almost random production facilities of FMS, the destination cell might not always be ready to accept the incoming part and the part has to wait in a buffer store. These and other bottlenecks in the materials handling problems can be successfully detected by simulation. Buffer stores for parts will always be desirable. Figure shows a typical FMC cell layout where buffer stores are used as an integral part of the cell as well as the overall materials handling system.



In the case of turning centres, the machining time may be of the order of a few minutes. A gantry robot is used for loading and unloading the component. It is better to present the raw workpieces in a pallet to the gantry. Finished workpieces can be deposited in another pallet. The empty raw material pallet and the filled finished part pallet will be transported by the AGV. Buffer store is also recommended for sheet metal items. Machining centres with multiple pallets (2, 4, 8 or more) incorporate adequate buffer capacity to last several hours.

Hence total handling system forms typical FMS layout of the parts.

(d) What is similarity coefficient matrix? Why it is used?

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Ans: Symmetry Matrix - The global stiffness matrix is always symmetric. Because of symmetry only half the global matrix coefficients have to be stored, thereby saving storage space.

Banded matrix: It can be seen that the global stiffness matrix has a large number of coefficients that are zeros.

Use of symmetry matrix in Global matrix equation-

In the stiffness assembly procedure, the element matrices were expanded to the size of the entire system equation by adding rows and columns of zeros for the system degrees of freedom that did not exist in the given element. For small problems this could be the feasible assembly procedure. Two matrix arrays of the size of the total number of degrees of freedom of the system would be required. One would be used and reused for each element computation. The other would store

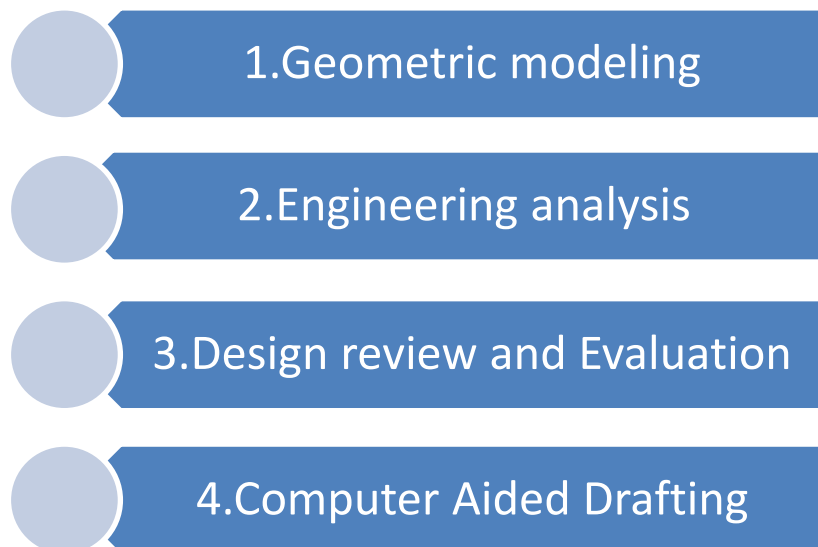
assembled matrices. Storage memory requirement for this type of procedure would be enormous for structures with large degrees of freedom.

The portion of the total stiffness matrix stored for this method is initially a sparse matrix. However, the solution procedure (Gauss elimination) does tend to expand the non-zero terms to most of all off-diagonal elements. Therefore the storage procedure cannot make use of the reduction in storage required if only the initial non-zero terms are saved. The storage required for the assembled matrix

Q.2 (a) Explain phases of CAD process. What is importance of concurrent engg. in product development cycle?

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Ans: Phases of CAD process-



Geometric modeling- Corresponds to synthesis phase of traditional design process.

Geometric models can be of three types;

- a) Wire frame model
- b) Surface model
- c) Solid model

Engineering analysis- It requires some type of mathematical analysis.

Analysis includes important mass and geometric properties such as:

- a) Mass
- b) Volume
- c) Centroid
- d) Moments of Inertia
- e) Radii of gyration
- f) Principal moments

Design review and evaluation- Routines are made for simultaneous dimensioning and tolerance, thereby reducing design errors.

Computer aided drafting- Drafting software give a variety of features such as semiautomatic dimensioning, hatching, enlargement of details, sectional views, rotated views sectioning, scaling etc.

Importance of concurrent engineering in PDC-

The cycle of engineering design and manufacturing planning involves interrelated activities in different engineering disciplines simultaneously, than sequentially as shown in Fig.

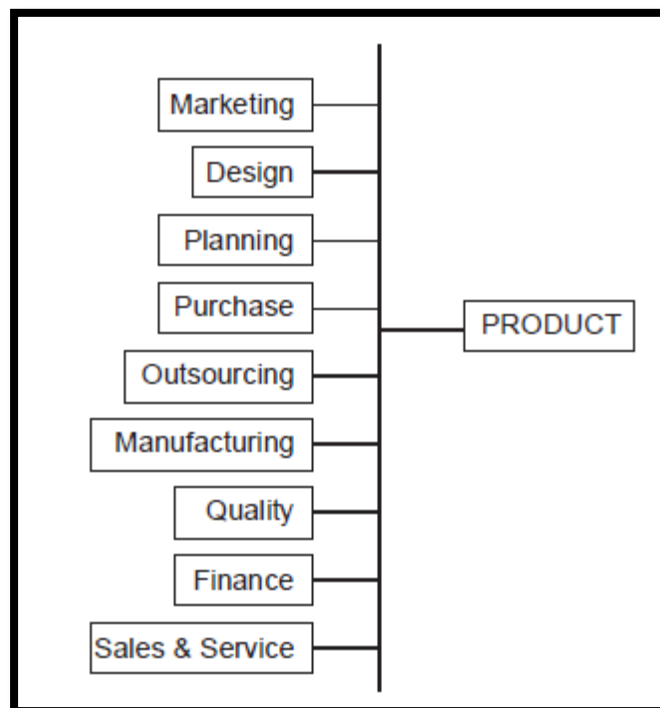


Figure : Process of concurrent engg.

It is observed that only about 15% of the budget is spent at the time of design completion, whereas the remaining 85% is already committed. The decisions taken during the design stage have an important bearing on the cost of the development of the product. Therefore the development cost and product cost can be reduced by proper and careful design. CE facilitates this advantages over sequential engg.

Following are the important benefits of implementing concurrent engg-

1. REDUCTION IN THE NUMBER OF DESIGN CHANGES
2. COST OF CHANGES IN DESIGN
3. HOLISTIC APPROACH TO PRODUCT DEVELOPMENT
4. ROBUST PRODUCTS
5. REDUCTION IN LEAD TIME FOR PRODUCT DEVELOPMENT

(c) Explain Co-ordinating Measuring Machine (CMM).

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Ans: Co-ordinating Measuring Machine (CMM)-

A coordinate measuring machine is a dimensional measuring device, designed to move the measuring probe to determine the coordinates along the surface of the work piece. Apart from dimensional measurement, these machines are also used for profile measurement, angularity, digitizing.

A CMM consists of four main components: the machine, measuring probe, control system and the measuring software. The control system in a CMM performs the function of a live interaction between various machine drives, displacement transducers, probing systems and the peripheral devices. Control systems can be classified according to the following;

1. Manually driven CMMs
2. Motorized CMMs with automatic probing systems
3. Direct computer controlled (DCC) CMMs
4. CMMs linked with CAD, CAM and FMS etc.

The first two methods are very common and self-explanatory. In the case of DCC CMMs, the computer control is responsible for the movement of the slides, readout from displacement transducers and data communication. CMM are of different configurations-fixed bridge, moving bridge, cantilever arm figure 4.(a), horizontal arm and gantry type CMM as shown in figure 4.(b).

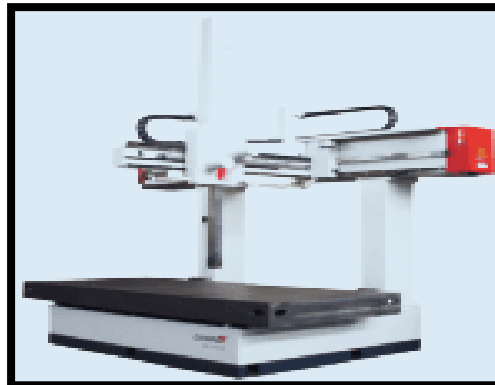


Figure : Cantilever type CMM

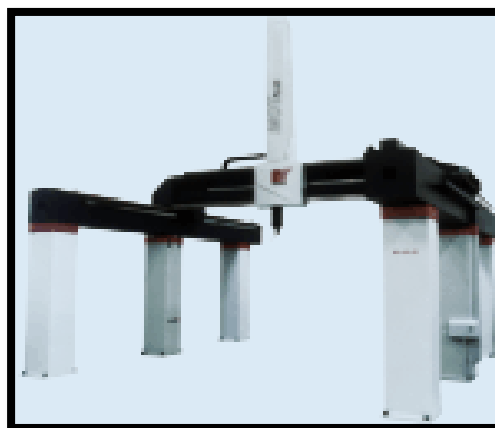
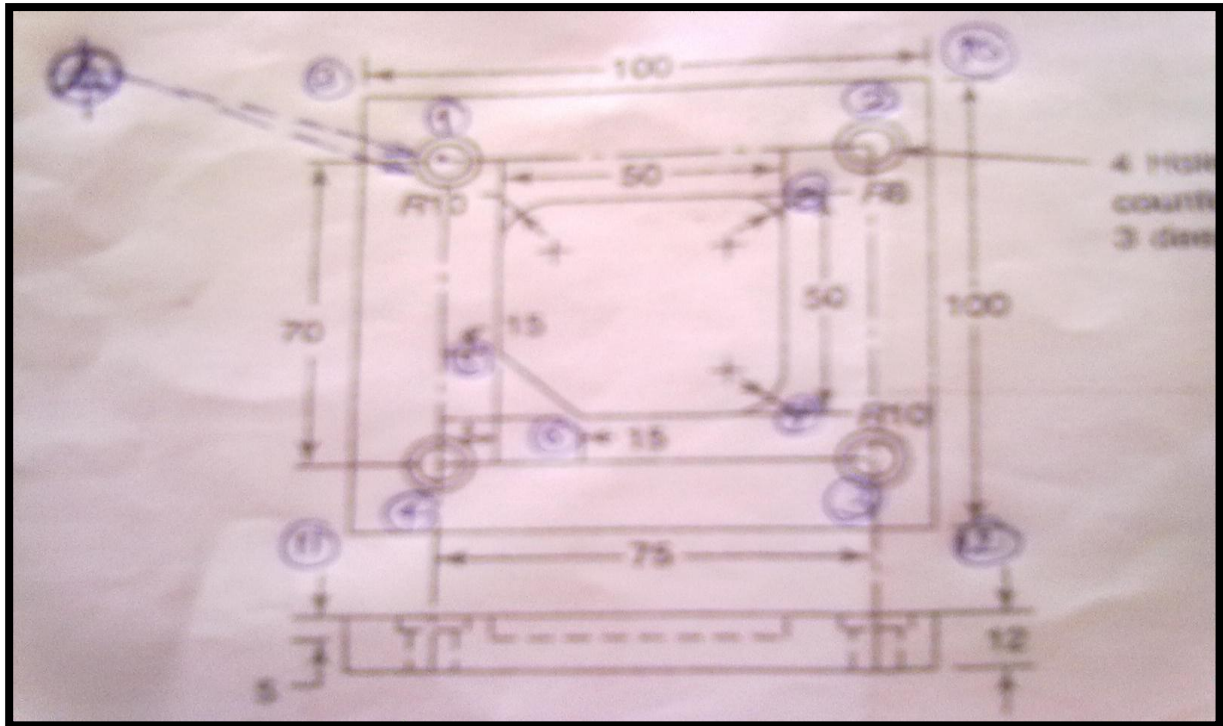


Figure: Gantry type CMM

CAD/CAM/CIM

Cutter diameter = 10 mm
Cutting speed = 90 m/min

: 100; (program start)
(DRILLING – DRILL DIA. 10)
(X0/Y0 CENTRELINE OF PART, Z0 2 MM ABOVE PART SURFACE)
N10 G80 G90 G71; (Cancel Canned cycle, absolute, metric mode)
N20 G28 G91 X0. Y0. Z0. ; (Reference point)
N30 G92 X200. Y200. Z150. ; (Preset)
(TOOL 1 – DIA 08 DRILL)
N40 G00 G90 G98 G71; (Rapid, absolute, return to initial, metric mode)
N50 M06 T01; (Tool change, use tool 1)
N60 G00 X-37.5. Y35. S3600 M03; (Rapid, go to point 1, spindle 3600 rpm, clockwise ON)
N70 G44 Z0. H01 M08; (Tool length offset, coolant ON)
N80 G81 G99 X-37.5. Y35. Z-15. R0. F500; (Canned drill cycle, feed 500 mm/min)
N90 X37.5; (Canned drilling cycle at point 2)
N100 Y-35; (Canned drilling cycle at point 3)
N110 X-37.5; (Canned drilling cycle at point 4)
N120 Y15.; (Canned drilling cycle at point 5)
N130 X15.; (Canned drilling cycle at point 6)
N140 X50.; (Canned drilling cycle at point 7)
N150 Y50.; (Canned drilling cycle at point 8)
(TOOL 2-DIA 10 MILL CUTTER)
(FINISHING OF POCKET EDGES)
N160 M06 T02; (Tool change, use tool 2)
N170 X-55. Y50. ; (Rapid to point 9)
N180 X50. ; (Finish machine till point 10)
N190 Y-50.; (Finish machine till point 12)
N200 X-50.; (Finish machine till point 11)
N210 Y50.; (Finish machine till point 9)
N220 G80 G00 Z0. M09; (Canned cycle cancel, rapid to Z(0), coolant OFF)
N230 G28 X0. Y0. ; (Return to reference position at X and Y)
N240 M30; (Signals end of program)
% (Tape stop mode)



Q.4. (a) Compare wire frame and solid modelling.

4

WIRE FRAME MODELING-

In wire frame modeling the object is represented by its edges. In the initial stages of CAD, wire frame models were in 2-D. Subsequently 3-D wire frame modeling software was introduced. The wire frame model of a box is shown in Fig.. The object appears as if it is made out of thin wires. Fig.(a), (b), (c) and (d) show three objects which can have the same wire frame model of the box. Thus in the case of complex parts wire frame models can be confusing. Some clarity can be obtained through hidden line elimination. Though this type of modeling may not provide unambiguous understanding of the object, this has been the method traditionally used in the 2-D representation of the object, where orthographic views like plan, elevation, end view etc. are used to describe the object graphically.

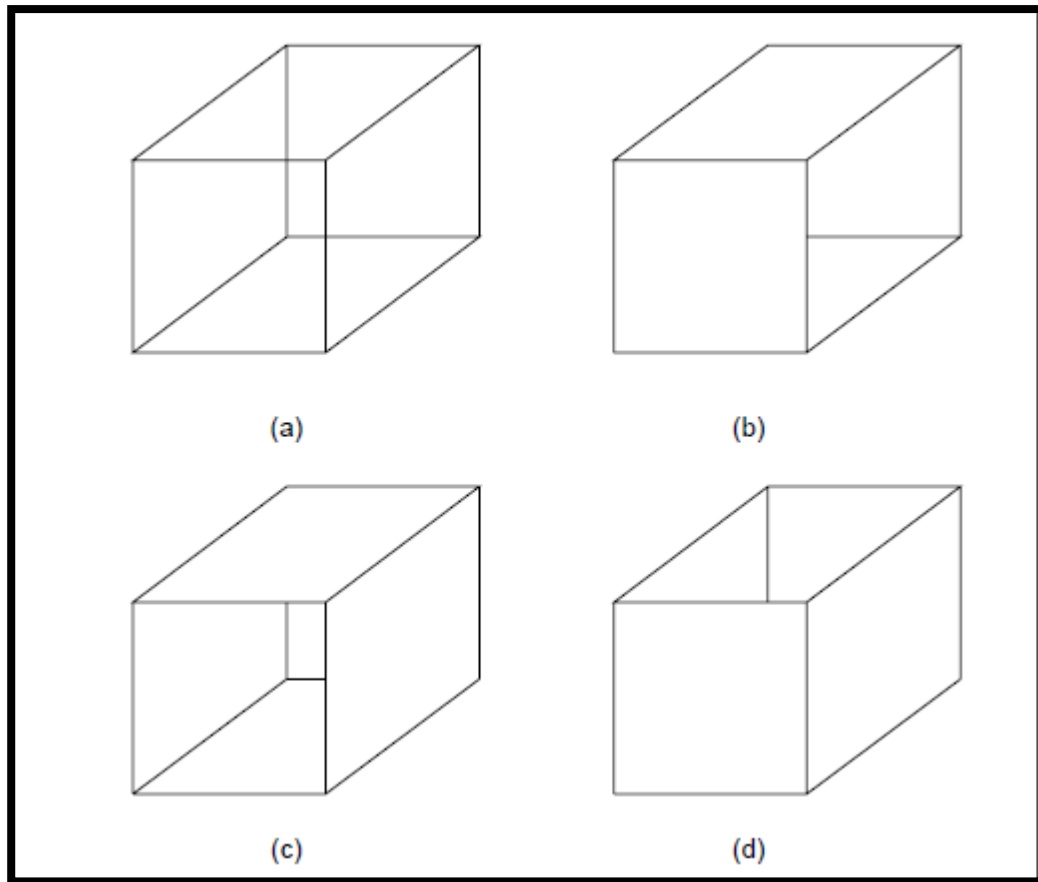


Figure : Ambiguities in wire frame modelling

SOLID MODELING-

The representation of solid models uses the fundamental idea that a physical object divides the 3-D Euclidean space into two regions, one exterior and one interior, separated by the boundary of the solid. Solid models are:

- bounded
- homogeneously three dimensional
- finite

There are six common representations in solid modeling.

i. Spatial Enumeration: In this simplest form of 3D volumetric raster model, a section of 3D space is described by a matrix of evenly spaced cubic volume elements called voxels.

ii. Cell Decomposition: This is a hierarchical adaptation of spatial enumeration. 3D space is subdivided into cells. Cells could be of different sizes. These simple cells are glued together to describe a solid object.

iii. Boundary Representation: The solid is represented by its boundary which consists of a set of faces, a set of edges and a set of vertices as well as their topological relations.

iv. Sweep Methods: In this technique a planar shape is moved along a curve. Translational sweep can be used to create prismatic objects and rotational sweep could be used for axisymmetric components.

v. Primitive Instancing: This modeling scheme provides a set of possible object shapes which are described by a set of parameters. Instances of object shape can be created by varying these parameters.

vi. Constructive Solid Geometry (CSG): Primitive instances are combined using Boolean set operations to create complex objects. In most of the modeling packages, the approach used for modeling uses any one of the following three techniques:

- i. Constructive solid geometry (CSG or C-Rep)
- ii. Boundary representation (B-Rep)
- iii. Hybrid method which is a combination of B-Rep and CSG.

(b) Justify how reflection is a special case of scaling transformation.

7

Shading is an important element in 3-D computer graphics, as it gives the necessary realism to the representation of the object. Fig.2 shows what happens when light is incident on a surface. Light gets partly reflected, partly scattered, partly absorbed and partly transmitted. The relative magnitudes of these are influenced by many factors like the opaqueness of the solid, surface texture etc.

The intensity and wave length of light reflected from a surface depends on the incident angle, the surface roughness, incident wave length and the electrical properties of the surface. In computer graphics designer can model reflected light and transmitted light

Reflected light could be categorized into two types:

- i. Diffuse Reflection
- ii. Specular Reflection

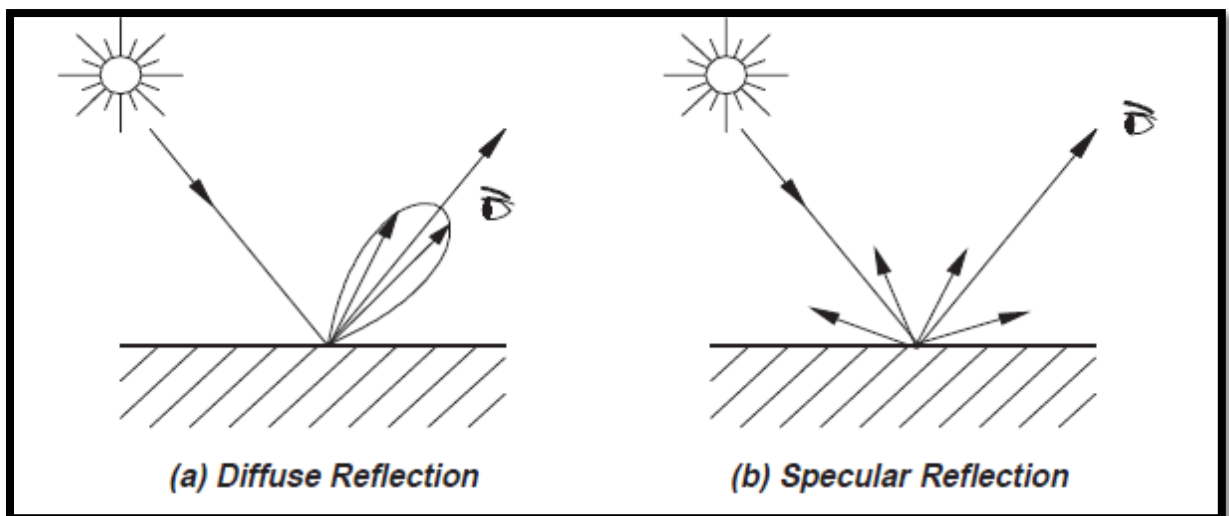


Figure : Diffuse reflection and specular reflection

Here, scaling as reflection assumes following points as;

- Light sources are point sources.
- All geometry except the surface normal is ignored.
- Diffuse and specular components are modeled as local components
- The model to simulate the specular term is empirical.
- The color of specular reflection is that of the light source
- The ambient lighting is constant.

Hence to scale the process as reflection, it has to scale into two different formats.

(c) Explain part classification and coding in group technology in detail.

(9)

Part classification and coding is concerned with identifying the similarities and using these similarities to evolve a classification code. Similarities are of two types: design attributes (such as geometric shape and size), and manufacturing attributes (the sequence of processing steps required to make the part).

Part classification-

Parts classification and coding systems can be grouped into three general types:

- i. Systems based on design attributes
- ii. Systems based on part manufacturing attributes
- iii. Systems based on both design and manufacturing attributes

Systems in the first category are useful for design retrieval and to promote design standardization. Systems in the second category are used for computer-aided process planning, tool design, and other production related functions. The third category represents an attempt to combine the functions and advantages of the other two systems into a single classification scheme. The types of design and manufacturing attributes typically included in classification schemes are listed below:

Part Design Attributes

Basic (External/Internal) shape
Axisymmetric/Prismatic/sheet metal
Length/diameter ratio
Material
Major dimensions
Minor dimensions
Tolerances
Surface finish

Part Manufacturing Attributes

Major process of manufacture
Surface treatments/coatings
Machine tool/processing equipment

Cutting tools

Operation sequence

Production time

Batch quantity

Production rate

If we take a look at a machine tool manufacturing industry, large part families can be grouped as:

- i. Heavy parts - beds, columns etc.
- ii. Shafts, characterized by large L/D ratios
- iii. Spindles (long shafts, screw rods included)
- iv. Non-rounds (small prismatic parts)
- v. Gears, disc type parts (whose L/D ratios are small)

From the manufacturing point of view, group technology can bring in considerable economy in tooling, set up time, part changeover times, machine specifications etc. The classification of components in groups can lead to formation of cells where similar components are machined. However, these considerations are extraneous to the process planning function.

Coding System-

A part coding scheme consists of symbols that identify the part's design and/or manufacturing attributes. The symbols in the code can be all numeric, all alphabetic, or a combination of both types. There are three basic code structures used in group technology applications:

- i. Hierarchical structure
- ii. Chain type structure
- iii. Hybrid structure which is a combination of the above two

With the hierarchical structure, the interpretation of each succeeding symbol depends on the value of the preceding symbols. In the chain type structure, the interpretation of each symbol in the sequence is fixed and does not depend on the value of preceding digits. Most of the commercial parts coding systems are used in industry are a combination of the two pure structures. When selecting a coding system for a component's representation, there are several factors to be considered. They include:

- i. The geometry of components (i.e., rotational, prismatic, deep drawn, sheet metal etc.)
- ii. The code structure
- iii. The digital representation (i.e., binary, octal, hexadecimal etc.)
- iv. Material of manufacture - ferrous, non ferrous, plastics, composites etc.

When using a code to represent an engineering design, it is important to represent the basic features of the design. For process planning, it is desirable to have codes that can distinguish unique production families. Some of the coding systems that have been successfully implemented in process planning are given below:

- i. OPITZ system
- ii. The CODE system
- iii. The KK-3 system
- iv. The MICLASS system

- v. DCLASS system
- vi. COFORM (coding for machining)

When implementing a parts classification and coding system, most companies can purchase a commercially available package or develop a system for their own specific use.

Q.5 (a) Explain the basic components of AS/RS system. Enlist the types of AS/RS. (Explain one in detail). What is the criteria to measure the performance of AS/RS system? 12

Automated Storage and Retrieval System (AS/RS)-

- This is material handling system in storage with sophisticated material handling m/c, high density storage techniques and computer control.
- They take the form of automated warehouses.
They are having following Characteristics:
- 1. High density storage
- 2. Automated handling system(elevators and conveyors)
- 3. Material tracking system(optical or magnetic sensors)

It is divided into following Categories-

- Unit load AS/RS-This carries the unit quantity of load for material as well as parts handling.
- Mini load AS/RS
- Man-on-board AS/RS
- Automated item retrieval system
- Deep lane SA/RS

Basic components of AS/RS are as follows-

- Storage structure
- Storage and retrieval system
- Storage modules
- Pick-up and deposit stations

AS/RS find special features like –

- Full or empty detectors
- Sizing stations
- Load identification stations
- Automated transfer cars

(b) With neat sketch of CIM wheel, explain the salient features of CIM system.

08

Sketch of CIM wheel-

Nine major elements of a CIM system are in figure as;

- Marketing
- Product Design
- Planning
- Purchase
- Manufacturing Engineering
- Factory Automation Hardware
- Warehousing
- Logistics and Supply Chain Management
- Finance
- Information Management

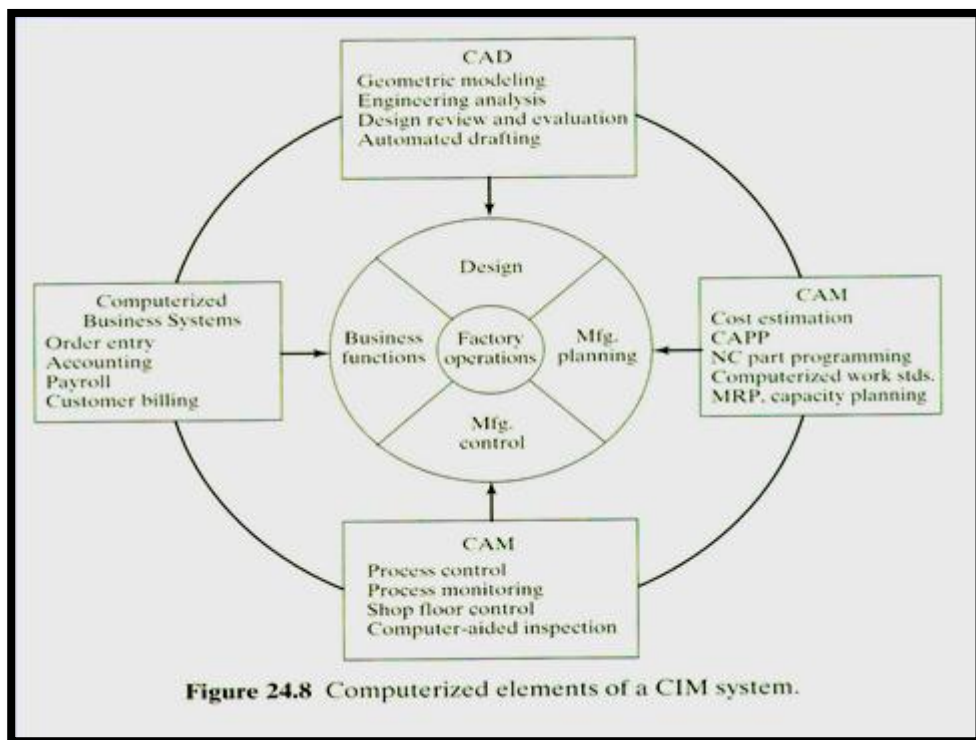


Figure : CIM wheel

Following are various salient features of CIM;

i. Marketing: The need for a product is identified by the marketing division. The specifications of the product, the projection of manufacturing quantities and the strategy for marketing the product are also decided by the marketing department. Marketing also works out the manufacturing costs to assess the economic viability of the product.

ii. Product Design: The design department of the company establishes the initial database for production of a proposed product. In a CIM system this is accomplished through activities such as geometric modeling and computer aided design while considering the product requirements and concepts generated by the creativity of the design engineer. Configuration management is an important activity in many designs. Complex designs are usually carried out by several teams working simultaneously, located often in different parts of the world. The design process is constrained by the costs that will be incurred in actual production and by the capabilities of the available production equipment and processes. The design process creates the database required to manufacture the part.

iii. Planning: The planning department takes the database established by the design department and enriches it with production data and information to produce a plan for the production of the product. Planning involves several subsystems dealing with materials, facility, process, tools, manpower, capacity, scheduling, outsourcing, assembly, inspection, logistics etc. In a CIM system, this planning process should be constrained by the production costs and by the production equipment and process capability, in order to generate an optimized plan.

iv. Purchase: The purchase departments is responsible for placing the purchase orders and follow up, ensure quality in the production process of the vendor, receive the items, arrange for inspection and supply the items to the stores or arrange timely delivery depending on the production schedule for eventual supply to manufacture and assembly.

v. Manufacturing Engineering: Manufacturing Engineering is the activity of carrying out the production of the product, involving further enrichment of the database with performance data and information about the production equipment and processes. In CIM, this requires activities like CNC programming, simulation and computer aided scheduling of the production activity. This should include online dynamic scheduling and control based on the real time performance of the equipment and processes to assure continuous production activity. Often, the need to meet fluctuating market demand requires the manufacturing system flexible and agile.

vi. Factory Automation Hardware: Factory automation equipment further enriches the database with equipment and process data, resident either in the operator or the equipment to carry out the production process. In CIM system this consists of computer controlled process machinery such as CNC machine tools, flexible manufacturing systems (FMS), Computer controlled robots, material

handling systems, computer controlled assembly systems, flexibly automated inspection systems and so on.

vii. Warehousing: Warehousing is the function involving storage and retrieval of raw materials, components, finished goods as well as shipment of items. In today's complex outsourcing scenario and the need for just-in-time supply of components and subsystems, logistics and supply chain management assume great importance.

viii. Finance: Finance deals with the resources pertaining to money. Planning of investment, working capital, and cash flow control, realization of receipts, accounting and allocation of funds are the major tasks of the finance departments.

Q.6 (a) Explain following terms:

6

i. Tool Length Compensation/ Tool offset-

The NC program is written assuming that the tool traces the path (tool path) required to produce the part. The length of traverse of the slide should take into account the length of the tool. The longer the length of the tool is, the shorter will be the travel of the slide and vice versa. The CNC system therefore should calculate the displacement of the slides considering the tool length. The length of tool is measured beforehand and input into the appropriate registers of the system. This is called tool length offset.

These are manually input into the memory locations corresponding to each tool position. Whenever a tool is changed, it is necessary to measure the new tool length and input it into the memory of the NC machine. Tool length offset is usually measured using a tool pre-setter which can be mechanical, optical or electronic. Probes are also fitted on the machine to determine and input the tool offset automatically. In the case of machining centres the path of the slide has to be altered to take also the radius of the tool into account. This is called cutter radius compensation.

Typical tool offset functions in a machining centre are:

G 45 - extension of axis travel by the amount stored in the offset data memory

G 46 - Reduction by the amount stored in the offset data memory

G 47 - Double extension

G 48 - Double reduction

(b) Write a complete APT program to machine the geometry as shown in figure. Assume suitable data.

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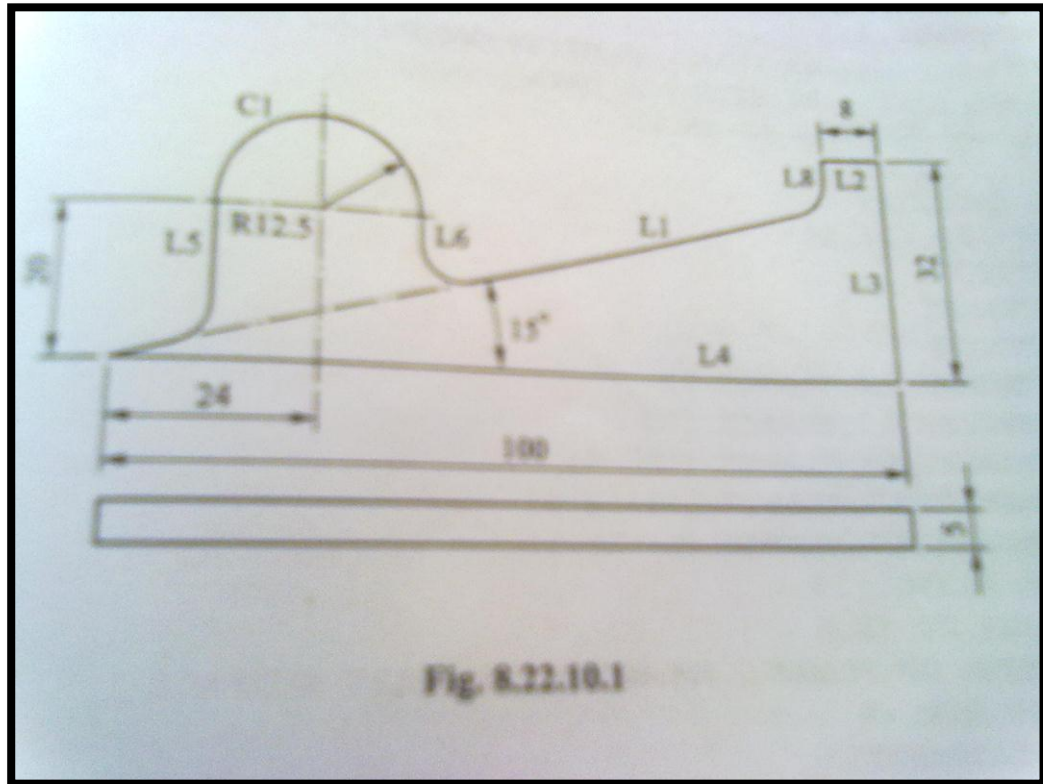
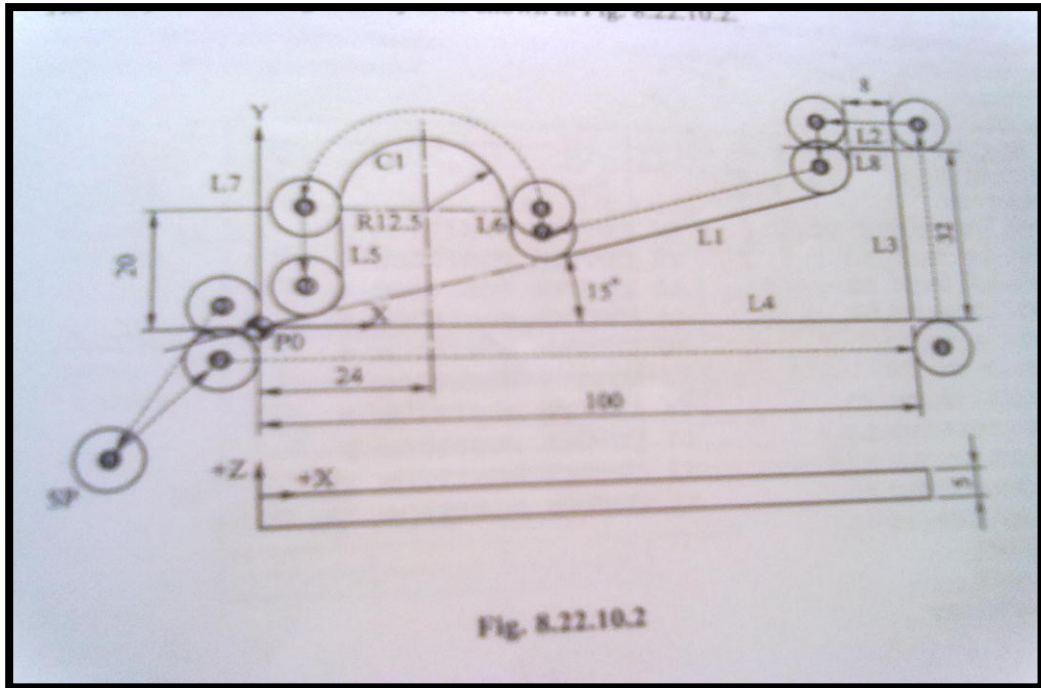


Fig. 8.22.10.1

Figure:
Tool path are as shown in figure.



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PARTNO/EXAMPLE 100
MACHIN/MMPOST, 3
PRINT/ON
CLPRNT/ON
$$ X0 Y0 ZO ASSUMED AS SHOWN
$$
$$ PART GEOMETRY
SP=POINT/-20, -20, 50
PO=POINT/0, 0
L4=LINE/XAXIS
L7=LINE/YAXIS
L2=LINE/PARALEL, L4, YLARGE, 32
L3=LINE/PARALEL, L7, XLARGE, 100
L8=LINE/PARALEL, L7, XLARGE, (100-8)
L6=LINE/PARALEL, L7, XLARGE, (24+12.5)
L5=LINE/PARALEL, L7, XLARGE, (24-12.5)
L1=LINE/P0, ATANGL, 15
C1=CIRCLE/24, 20, 12.5
$$ DEFINATION OF PLANE 7 MM BELOW THE PART SURFACE
PL1= PLANE/ 0, 0, 1, -7
$$ SETUP STATEMENTS
CUTTER/10
SPINDL/700, CLW
FEDRAT/MMPM, 90
INTOL/0.005
OUTTOL/0.005
SPINDL/ON
    
```

CAD/CAM/CIM

\$\$ MOTION STATEMENTS

RAPID, GOTO /SP

COOLNT/ON

GO/TO, L4, TO, PL1, TO, L7

\$\$ CUTTER POSITION 2

GOFWD/L4, PAST, L3

\$\$ CUTTER POSITION 3

GOLFT/L3, PAST, L2

\$\$ CUTTER POSITION 4

GOLFT/L2, PAST, L8

\$\$ CUTTER POSITION 5

GOLFT/L8, TO, L1

\$\$ CUTTER POSITION 6

GORGT/L1, TO, L6

\$\$ CUTTER POSITION 7

GORGT/L6, TANTO, C1

\$\$ CUTTER POSITION 8

GOFWD/C1, TANTO, L5

\$\$ CUTTER POSITION 9

GOFWD/L5, TO, L1

\$\$ CUTTER POSITION 10

GORGT/L1, PAST, L7

\$\$ CUTTER POSITION 11

RAPID, GODLTA/50

COOLNT/OFF

SPINDL/OFF

RAPID, GOTO/SP

FINI

Q.7. Write short notes on-

20

(a) Generative type process planning

05

Generative process planning is a system that synthesizes process information in order to create a process plan for a new component automatically. In a generative planning system, process plans are created from information available in manufacturing data base without human intervention. Upon receiving the design model, the system can generate the required operations and operation sequences for the component. Knowledge of manufacturing must be captured and encoded into efficient software. By applying decision logic, a process planner's decision making can be imitated.

Other planning

functions, such as machine selection, tool selection, process optimization, and so on, can also be automated using generative planning techniques. The generative planning has the following advantages:

- i. It can generate consistent process plans rapidly.
- ii. New process plans can be created as easily as retrieving the plans of existing components.
- iii. It can be interfaced with an automated manufacturing facility to provide detailed and up-to-date control information.

Fig. shows the modular structure of a generative CAPP system.

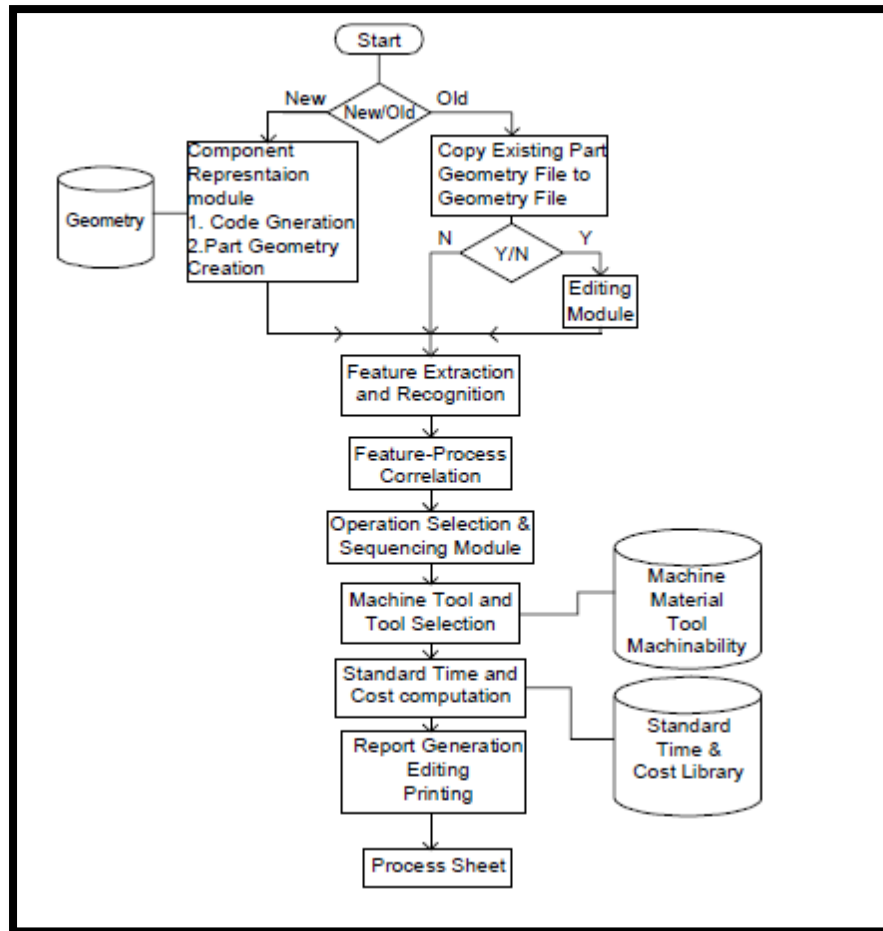


Figure: Modular Structure of a Generative CAPP System

The generative part consists of:

- Component representation module
- Feature extraction module
- Feature process correlation module
- Operation selection and sequencing module
- Machine tool selection module
- Standard time / cost computation module
- Report generation module

In order to generate a more universal process planning system, variables such as process limitations, and capabilities, process costs and so on, must be defined at the planning stage. Several of methods have been proposed for creating generative process plans. A few methods that have been implemented successfully are:

- i. Forward and backward planning
- ii. Input Format
- iii. CAPP based on CAD models
- iv. CAPP based on decision logic either using decision trees or decision tables
- v. CAPP based on artificial intelligence

(c) Reverse engineering and data capture technique-

05

Reverse Engineering-

The process of duplicating an existing component, subassembly, or product, without the aid of drawings, documentation, or computer model is known as reverse engineering.

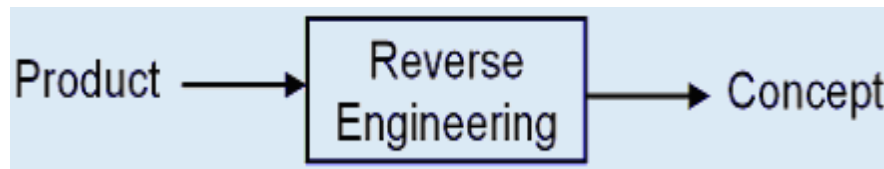


Figure : Reverse Engineering

Reverse engineering can be mainly viewed as the process of analyse a system to identify its components and their interrelationships, to create representations of it in another form or a higher level of abstraction. An important reason for application of reverse engineering is reduction of product development times. In the intensely competitive global market, manufacturers are constantly seeking new ways to shorten lead-times to market a new product. For example, injection-molding companies must drastically reduce the tool and die development times. By using reverse engineering, a three-dimensional product or model can be quickly captured in digital form, re-modeled, and exported for rapid prototyping/tooling or rapid manufacturing.

Some of the important reasons for the for reverse engineering of a product or part are;

- The original manufacturer of a product no longer produces a product
- There is inadequate documentation of the original design
- The original manufacturer no longer exists, but a customer needs the product
- The original design documentation has been lost or never existed
- Some bad features of a product need to be designed out. For example, excessive wear might indicate where a product should be improved
- To strengthen the good features of a product based on long-term usage of the product
- To analyse the good and bad features of competitors' product
- To explore new avenues to improve product performance and features
- To gain competitive benchmarking methods to understand competitor's products and develop better products
- The original CAD model is not sufficient to support modifications or current manufacturing methods
- To update obsolete materials or antiquated manufacturing processes with more current, less-expensive technologies

It can be said that reverse engineering begins with the product and works through the design process in the opposite direction to arrive at a product definition statement. In doing so, it uncovers as much information as possible about the design ideas that were used to produce a particular product.

Reverse engineering methodology

The reverse engineering process can be divided into the following broad steps:

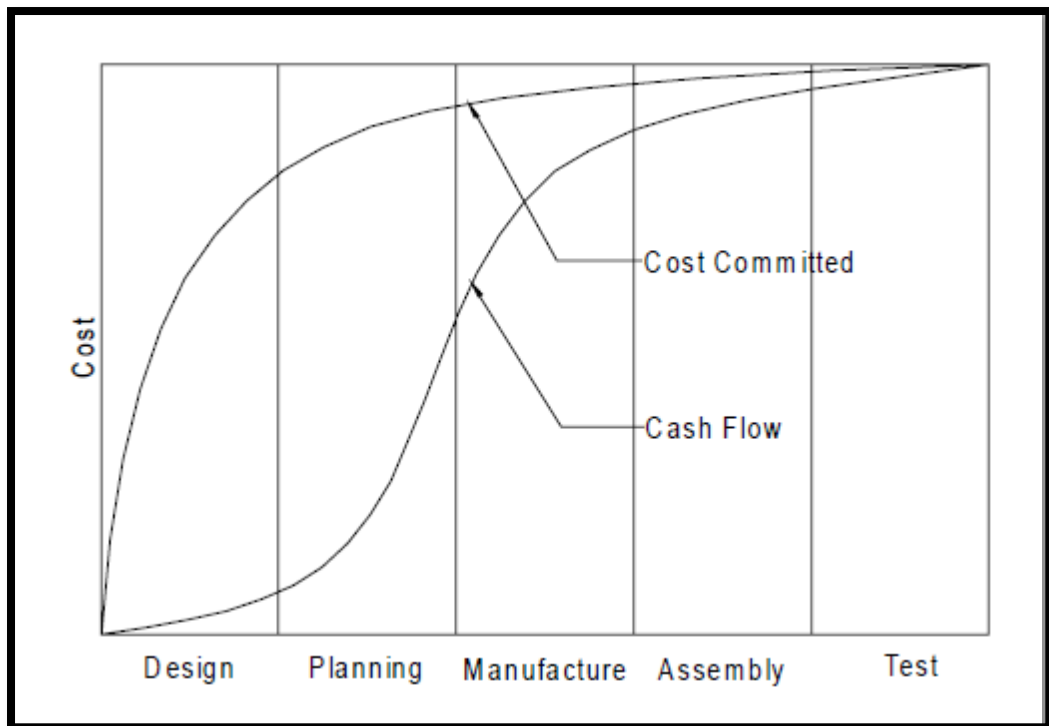
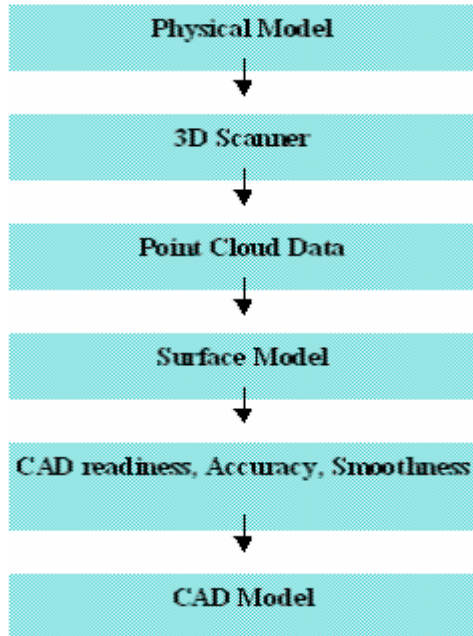


Figure: Distribution of product development cost

(e) 3-D rotation transformation

Rotation: Rotation in 3-D can be about X - , Y - or Z axis.

Rotation about Z axis:

$$R_z = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation about X axis:

$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi & 0 \\ 0 & \sin\phi & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation about Y axis:

$$R_y = \begin{bmatrix} \cos\phi & 0 & \sin\phi & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\phi & 0 & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
