STUDY MATERIAL

ON

TH-3

COMPUTER INTEGRATED MANUFACTURING

4TH SEMESTER

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CHAPTER 1

Concept of Computer Integrated Manufacturing (CIM)

- ❖ Computer Integrated Manufacturing (CIM) is a manufacturing approach in which **all production processes are integrated and controlled using automation and computers**. It links **design, planning, production, quality control and business functions** into a single automated system.
- ❖ Computer Integrated Manufacturing (CIM) is a holistic approach that uses computers and automation to integrate all aspects of a manufacturing i.e from design (CAD), planning (CAPP) to production (CAM) and business functions into a single system, enabling seamless data flow, real-time control, increased flexibility, and improved efficiency throughout the entire production life cycle.
- ❖ It connects different automated segments, like robotics, material handling, and inspection, to a central system for better coordination, reducing errors and human intervention.
- ❖ (CIM) holds the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages. The data required for various functions (design, planning, production, inspection) are passed from one application software to another (CAD, CAPP, CAM, etc) in a seamless manner.
- ❖ For example, the product data is created during design (CAD). This data has to be transferred from the modeling software to manufacturing software (CAM) without any loss of data.
- ❖ CIM uses a common database wherever feasible and communication technologies to integrate design, manufacturing and associated business functions in a manufacturing facility.

Core concepts:-

- **Integration:** Links all departments (design, planning, production, finance, sales) and processes through shared data, often using a common database.
- **Automation:** Uses machines, robots, and automated systems to perform tasks with minimal human input.

- **Flexibility:** Allows quick adaptation to product changes, varied production volumes, and market demands.
- **Real-time Control:** Gathers real-time data from sensors for immediate monitoring and adjustments.

Objectives of CIM

- Reduce production time
- Improve product quality
- Minimize human error
- Increase productivity and flexibility
- Reduce manufacturing cost
- Integrate all departments digitally

Basic components of CIM

Nine major elements of a CIM system are:-

1. ***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.

2. ***Product Design:*** The design department of the company establishes the **initial database for production** of a proposed product. In a CIM system this is done through activities such as CAD.

This stage involves:

- **Computer-Aided Design (CAD)**: Engineers use CAD software to create detailed 2D or 3D models of products. CAD allows for precise design specifications, easy modifications, and simulations to test how products will perform in real-world conditions.
- **Simulation and Prototyping**: Before actual production, designs are often simulated using computer software to predict performance under various conditions. Prototyping, either virtual or physical, is used to validate designs and make necessary adjustments.
- **Design for Manufacturing ability (DFM)**: Engineers ensure that products are designed in a way that makes them easy and cost-effective to manufacture, considering factors like material selection, tolerances, and assembly processes.

3. ***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.

Manufacturing Planning involves preparing and organizing the manufacturing process to ensure that production runs smoothly and efficiently. This stage includes:

- **Computer-Aided Process Planning (CAPP)**: CAPP systems help in planning the ***sequence of operations, selecting tools, and defining machine setting***s.
- **Material Requirements Planning (MRP)**: MRP systems calculate the materials and components needed for production, ensuring that they are available when required. This system helps in managing inventory, reducing waste, and minimizing delays.
- **Production Scheduling**: This involves allocating tasks, resources, and time frames to ensure that production meets deadlines. Effective scheduling optimizes resource use, reduces bottlenecks, and improves overall efficiency.
- **Capacity Planning**: This ensures that the manufacturing facility has the necessary resources—such as machinery, labor, and materials—to meet production demands. It involves assessing current capacity and planning for future needs

4. ***Purchase:*** The purchase departments is responsible for **placing the purchase orders and follow up, receive the items, arrange for inspection and supply the items to the stores** or arrange timely delivery depending on the production schedule.

5. ***Manufacturing and control:*** Manufacturing is the activity of carrying out the production of the product, with the help of data, production equipment and processes.

In CIM, this requires activities like **CNC programming, simulation and computer aided scheduling** of the production activity**.**

Manufacturing Control is the process of managing and monitoring the production process to ensure that it runs according to plan and meets quality standards. This stage involves:

- **Real-Time Monitoring**: Using sensors, software, and data analytics, real-time monitoring systems track the status of machines, processes, and products on the shop floor. This allows for immediate detection of issues and quick corrective actions.

- ❖ **Quality Control**: Systems like Statistical Process Control (SPC) and automated inspection tools are used to monitor product quality during manufacturing. This ensures that any defects are caught early, reducing waste and rework.
- ❖ **Shop Floor Control (SFC)**: SFC systems manage and track the production process on the shop floor, including work-in-progress, machine utilization, and labor productivity. These systems ensure that operations are running smoothly and that production goals are met.
- ❖ **Feedback and Adjustment**: Continuous feedback loops are established to monitor
- ❖ production outcomes and adjust processes as needed. This ensures that production stays on track and meets performance and quality targets.

6. ***Factory Automation Hardware:*** 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, automated inspection systems** and so on. Factory Automation involves the use of advanced technologies to automate manufacturing processes, reducing human intervention and increasing efficiency. This component includes:

- **Robotics and Automated Systems**: Robots and other automated systems perform repetitive tasks with precision, consistency, and speed. They are used for tasks like assembly, welding, painting, and material handling.
- **Programmable Logic Controllers (PLCs)**: PLCs are specialized computers that control machinery and processes on the factory floor. They are programmed to perform specific tasks, such as controlling conveyor belts, managing robotic arms, or regulating temperatures.
- **Flexible Manufacturing Systems (FMS)**: These systems allow for quick reconfiguration of manufacturing processes to produce different products. FMS increases flexibility and responsiveness to changing market demands.
- **Computer-Aided Manufacturing (CAM)**: CAM software controls machine tools and related machinery, automating the manufacturing process from design to production. CAM systems convert CAD models into machine instructions, enabling precise and efficient manufacturing.

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

8. ***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.

9. ***Information/DATA Management:*** This involves master production scheduling, database management, communication, manufacturing systems integration and management information systems.

Elements	**System Used**
Design	CAD – Computer Aided Design
Process Planning	CAPP – Computer Aided Process Planning
Manufacturing	CAM – Computer Aided Manufacturing
Production Control	PPC – Production Planning & Control
Material Handling	AGV, Robots, Automated Storage

Elements	System Used
Quality Control/inspection	CAQ – Computer Aided Quality
Business Functions	Enterprise Resource Planning **(ERP)**: Manages business resources, Manufacturing Execution System **(MES)**: Manages shop floor operations. Accounting, Sales.
Data Management	Central Database / Networking, production scheduling, communication.

Distributed database system

- ✧ A **Distributed Database System** is a database in which data is stored at **multiple physical locations** connected through a communication network, but appears to users as a **single unified database**.
- ✧ A **Distributed Database System** is a collection of logically related data distributed over different sites of a computer network and managed by a **Distributed Database Management System (DDBMS).**
- ✧ In CIM, distributed databases are used to store and share:

- ✓ Design Data
- ✓ Process Planning Data
- ✓ Production Schedules
- ✓ Inventory & Quality Control Data
- ✓ Machine Status Information

Each department has its own local database but all are connected through DDBS.

- ✧ It is **crucial for sharing real-time data** (like production, inventory, quality) across machines, departments and locations, enhancing performance and efficiency for complex manufacturing processes.
- ✧ It enables **seamless data access for various CIM components**, from CAD/CAM to planning and control, ensuring consistency and availability of real time data.
- ✧ A **Distributed Database System is the backbone of CIM**, enabling smooth flow of information between all departments, improving productivity, reducing errors, and ensuring real-time integration of manufacturing activities.

Example 1

When a designer updates a drawing in **CAD**,

- CAPP automatically accesses the updated design for process planning.
- CAM generates tool paths.
- PPC schedules production.

All this happens using the **same distributed database**.

Example 2

A manufacturing company has plants in **Delhi, Pune, and Chennai**.
Each plant stores its production data locally, but the head office can access all data as if it were in one central database.

Distributed Communication System

In CIM, manufacturing activities like design, planning, production, inspection and material handling are carried out by different subsystems. A **distributed communication system** connects these subsystems so that data flows smoothly across the factory.
It allows different computers, machines, controllers and databases in a factory to **exchange information in real time**.

Key Components

1. **Manufacturing Messaging Specification (MMS):** To support messaging between programmable devices like PLCs (Programmable Logic Controller) and robots.

2. **Middleware:** Software technology (e.g., Apache Kafka or RabbitMQ) enable interoperability across various operating systems.

3. **Networks (LAN/WAN):** Physically links devices using Ethernet, fiber optics, or broadband for high-speed data transmission between sites.

4. **Nodes:** Computers, PLCs, CNC controllers, robots, sensors, servers

5. **Database Servers:** Store design, production, quality, inventory data

6. **Protocols:** A **protocol** is a set of rules that defines how data is transmitted between computers, machines and controllers in a CIM environment.

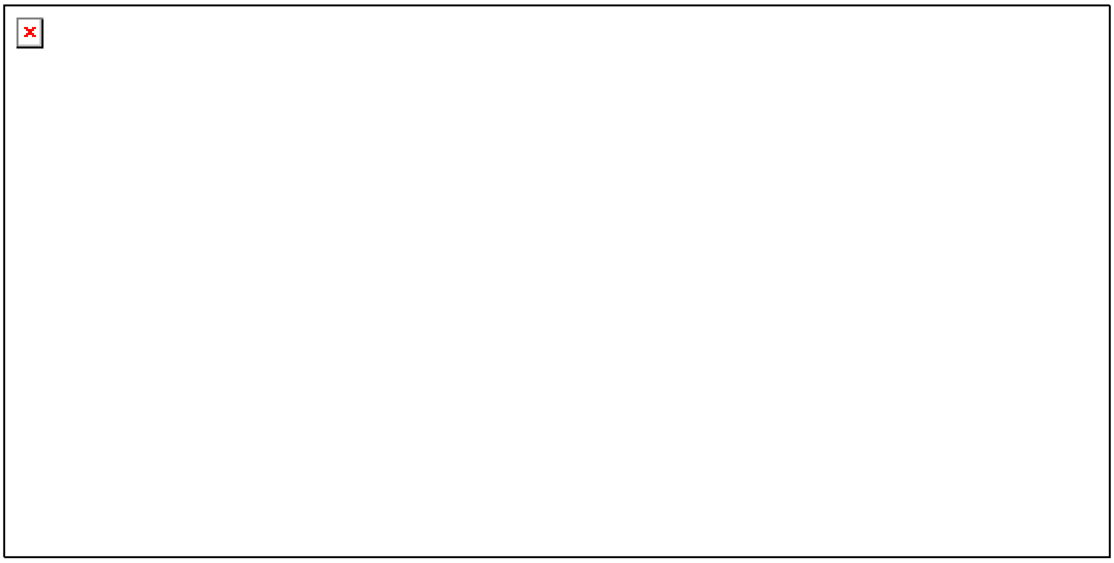
a. TCP / IP (Transmission Control Protocol / Internet Protocol) [CAD, CAM, ERP, database communication]

b. OPC / OPC-UA (Open Platform Communications) [PLC to SCADA, CNC to MES]

c. Modbus (PLCs, sensors, actuators)

d. PROFIBUS / PROFINET (PLC, robots, CNC machines)

e. DNC Protocol (Sending programs from CAM to CNC)



<u>Types of Information Exchanged</u>

- **Machine-to-Machine:** Direct communication between equipment for synchronization (e.g., a robot signaling a CNC machine that it has finished loading a part).
- **Computer-to-Machine:** Sending G-codes or production schedules from a central control computer to specific shop floor machines.
- **Enterprise-to-Shop Floor:** Connecting business functions (orders, inventory) with actual manufacturing planning and control

Benefits

- ✓ **Scalability:** New machines or departments can be added horizontally without reconfiguring the entire system.
- ✓ **Fault Tolerance:** If one node (machine or server) fails, the rest of the system continues to operate, preventing total production shutdowns.
- ✓ **Geographical Distribution:** Allows for integrated control of factories located in different countries or regions through broadband networks.
- ✓ Better process control and Supports automation and flexible manufacturing

Computer Networks for Manufacturing

- ❖ Computer Networks for Manufacturing form the communication infrastructure of **Computer Integrated Manufacturing (CIM)**. They enable the interconnection of computers, machines, controllers, and information systems to achieve integrated, automated, and flexible manufacturing.
- ❖ In CIM, computer networks link **CAD/CAM systems, CNC machines, robots, PLCs, material handling systems, and management information systems**. This integration allows real-time data exchange, monitoring, and control of manufacturing operations.
- ❖ Computer networks in CIM are organized in **hierarchical levels**. At the **device level**, sensors, actuators, robots, and CNC machines are connected using **fieldbus networks** such as PROFIBUS, CAN, and Modbus. The **cell or machine level** connects multiple machines within a manufacturing cell for coordinated control and supervision. The **plant level** integrates different cells and departments to support production planning, scheduling, and quality control. The **enterprise level** connects the factory with corporate offices, suppliers, and customers using WAN and internet technologies.
- ❖ Different **types of networks** are used in CIM. **Local Area Networks (LANs)** are widely used within factories for high-speed communication. **Wide Area Networks (WANs)** connect geographically separated plants. **Fieldbus networks** provide reliable and deterministic communication for industrial control, while **Industrial Ethernet** technologies such as PROFINET and EtherCAT support real-time manufacturing applications.

- A significant development in manufacturing networks is the **Manufacturing Automation Protocol (MAP)**, developed by General Motors, which follows the OSI model and ensures standard communication among devices from different vendors.
- The use of computer networks in CIM offers several **advantages** such as improved productivity, reduced lead time, better coordination, real-time monitoring, flexibility, and efficient resource utilization. However, challenges include high initial cost, system complexity, security issues, and the need for skilled manpower.
- Thus, computer networks act as the **backbone of CIM**, enabling seamless integration of design, manufacturing, and management for efficient and automated production systems.
- In **CIM**, computer networks interconnect:

- CAD/CAM systems
- CNC machines
- Robots and PLCs
- Automated material handling systems
- Production planning and control systems

This integration allows **real-time monitoring, control, coordination, and decision-making** across the manufacturing enterprise.

Objectives of Computer Networks in CIM

- Enable **real-time data communication**
- Integrate **design, manufacturing, and management**
- Improve **productivity and flexibility**
- Reduce **lead time and errors**
- Support **automation and smart manufacturing**

Levels of Manufacturing Networks

Level	Name	Main Purpose
4	Enterprise Level	Business planning & management
3	Factory / Plant Level	Production planning & monitoring
2	Cell / Area Level	Supervisory control & data acquisition
1	Machine Level	Machine automation
0	Field Level	Sensors & actuators

Manufacturing computer networks are arranged in **hierarchical levels** so that information flows smoothly from shop-floor machines to top management.

Level 0 – Field Level (Process / Device Level)

- ❖ Connects sensors, actuators, CNC machines, robots
- ❖ Uses **Fieldbus networks**
- ❖ Examples: PROFIBUS, CAN, Modbus, DeviceNet

Main elements:

Sensors (temperature, pressure, proximity, flow) and Actuators (valves, motors, relays)

Functions:

- ✓ Collect real-time physical data from machines
- ✓ Execute basic control actions

Level 1 – Machine Level

- ❖ Links machines within a manufacturing cell
- ❖ Used for **machine control and monitoring**
- ❖ Examples: Industrial Ethernet, MAP

Main elements:

CNC machines, Robots, PLCs, Drives

Functions:

- ✓ Machine control and automation
- ✓ Executes control programs
- ✓ Interfaces with sensors and actuators

Level 2 – Cell / Area Level

Main elements:

Cell controllers, HMIs (Human Machine Interface), SCADA systems

Functions:

- ✓ Monitoring and controlling a group of machines
- ✓ Data acquisition from PLCs
- ✓ Alarm handling and visualization

Level 3 – Factory / Plant Level

- ❖ Connects different cells and departments
- ❖ Supports **production planning, scheduling, quality control**
- ❖ Examples: Ethernet, TCP/IP

Main elements:

Manufacturing Execution System (MES), Production planning and scheduling software, Quality management systems

Functions:

- ✓ Production scheduling
- ✓ Work order management
- ✓ Quality data analysis
- ✓ Performance reporting

Level 4 – Enterprise Level

- ❖ Links factory with corporate offices, suppliers, customers
- ❖ Supports **ERP, SCM, MIS**
- ❖ Uses WAN, Internet, Cloud networks

Main elements:

ERP systems, MIS (Management Information System), Accounting, HR, Sales databases

Functions:

- ✓ Business planning
- ✓ Inventory control
- ✓ Costing and finance
- ✓ Decision support

Computer Networks for Manufacturing are essential for integrating various components of CIM. Here’s how they contribute:

1. **Data Communication:** Networks enable seamless communication between different systems, such as CAD, CAM, and Enterprise Resource Planning (ERP) systems. This ensures that data flows smoothly across the entire manufacturing process.
2. **Real-Time Monitoring:** Networks connect sensors, machines, and control systems, allowing for real-time monitoring and control of the production process. This helps in quickly identifying and addressing any issues.
3. **Remote Access and Control:** With networked systems, engineers and managers can access and control manufacturing processes remotely, improving flexibility and responsiveness.
4. **Integration of Supply Chain:** Networks facilitate the integration of supply chain management, linking suppliers, manufacturers, and distributors to optimize the flow of materials and products.
5. **Security and Data Integrity**: Robust network security measures ensure that sensitive manufacturing data is protected from unauthorized access and cyber threats.

Future Automated Factory (Smart Factory / Industry 4.0)

The future automated factory represents a significant shift in how manufacturing operations are conducted, driven by advancements in technology such as robotics, artificial intelligence (AI), the Internet of Things (IoT), and big data. Computer Integrated Manufacturing (CIM) plays a central role in this transformation, providing the framework for integrating these technologies into a cohesive, efficient, and flexible manufacturing system.

A **future automated factory** is a highly intelligent, flexible and self-optimizing manufacturing system where machines, computers, products and people are fully connected through digital technologies.

Key features:-

1. ***Advanced Robotics and Automation***

- **Robots and Cobots**: The factory will be equipped with advanced robots and collaborative robots (cobots) that can work alongside human workers. These machines will handle a wide range of tasks, from assembly to packaging, with high precision and speed.
- **Autonomous Systems**: Autonomous vehicles and robots will navigate the factory floor, transporting materials and components without human intervention.

2. ***Artificial Intelligence and Machine Learning***

- **Predictive Maintenance**: AI will be used to predict equipment failures before they happen, allowing for proactive maintenance and reducing downtime.
- **Smart Manufacturing**: AI-driven systems will optimize production processes in real-time, adjusting to changing conditions and demand.

3. ***Internet of Things (IoT)***

- **Connected Devices**: IoT will connect machines, sensors, and devices, enabling real-time data collection and analysis across the entire manufacturing process.
- **Smart Sensors**: Sensors will monitor every aspect of the production environment, including temperature, humidity, and machine performance, ensuring optimal conditions for manufacturing.

4. Big Data and Analytics

- **Data-Driven Decisions**: The future factory will generate vast amounts of data, which will be analyzed to improve decision-making, optimize production, and enhance product quality.
- **Supply Chain Integration**: Big data analytics will be used to optimize the supply chain, ensuring that materials and products are delivered just-in-time.

5. ***Additive Manufacturing (3D Printing)***

- **Rapid Prototyping**: 3D printing will enable the quick production of prototypes, accelerating the product development cycle.
- **On-Demand Production**: Factories will be able to produce customized products on demand, reducing the need for large inventories.

6. ***Sustainability and Energy Efficiency***

- **Green Manufacturing**: The future factory will focus on sustainability, using energy-efficient processes and renewable energy sources. Waste reduction and recycling will be integral parts of the manufacturing process.

SOCIAL AND ECONOMIC FACTORS

1. Social Factors Affecting CIM

1.1 Employment Pattern

CIM reduces the need for unskilled and semi-skilled labour.

Increases demand for **highly skilled manpower** such as:

- CNC programmers
- Automation engineers
- System analysts

Causes **job displacement**, creating the need for retraining programs.

1.2 Skill Development and Training

Workers must learn:

- Computer programming
- CAD/CAM software
- Robotics operation

Organizations must invest heavily in **training and re-skilling**.

1.3 Working Conditions

- Manual, repetitive, and hazardous jobs are minimized.
- Work becomes more **safe, clean and comfortable**.
- Operators mainly perform monitoring and control functions.

1.4 Social Acceptance

- Workers may resist CIM due to: Fear of job loss & Lack of computer knowledge
- Management must create awareness and involve employees in the transition process.

1.5 Organizational Structure

- Traditional hierarchical structures change to **team-based, flexible organizations**.
- Better coordination between design, planning and production departments.

2. Economic Factors Affecting CIM

2.1 Initial Investment Cost

- Very high cost for: CNC machines, Robots, Computers, servers and networks, CAD/CAM software
- Small industries often find CIM **financially difficult to adopt**.

2.2 Operating Cost

- Reduction in: Labour cost, Rework and scrap cost
- Increase in: Maintenance cost, Software upgrades, Skilled manpower salary

2.3 Productivity Improvement

- CIM increases: Production rate, Machine utilization
- Reduces: Setup time, Lead time, Idle time

2.4 Quality Improvement

- Automated inspection and control reduce defects.
- Better product quality reduces warranty and rejection costs.

2.5 Market Competitiveness

CIM enables:

- Faster product development
- Quick response to customer demands

- Mass customization

Firms using CIM gain **global competitiveness**.

2.6 Return on Investment (ROI)

Though initial cost is high, long-term benefits are: Higher profits, Reduced production cost, Better market share

CHAPTER 2

Computer Aided Design (CAD)

Computer Aided Design (CAD) is the use of computer systems to assist in the **creation, modification, analysis, and optimization** of designs. It is widely used in engineering, architecture, manufacturing, and product design.

It is a technology that enables designers and engineers to create **precise drawings and 3-D models of physical objects** using specialized software.

This software is used to increase the productivity of the designer, improve the quality of design, improve **communications through documentatio**n, and to create a **database for manufacturing**.

Objectives of CAD

- Increase design accuracy and quality
- Reduce design time and cost
- Improve productivity of designers
- Facilitate easy modification and optimization
- Provide better visualization of products

Output: 2D drawings and 3D models that can be used for visualization, simulation, and production.

Functions of CAD

- **Drafting:** Creation of detailed 2D engineering drawings.
- **Modeling:** 3D solid, surface, and wire frame modeling of components.
- **Simulation & Analysis:** Checking for stresses, motion, and interference.
- **Documentation:** Automatic generation of dimensions, bills of materials (BOM), and annotations.
- **Design Optimization:** Enables easy modification and testing of design variations.

Software that is of interest to CAD/CAM/CIM Engineers falls under different categories. They are:

i. Operating Systems

ii. Application Software for

a. Geometric modeling

b. Design and analysis of components and systems

c. Finite elements analysis

d. Mechanism analysis

e. Other design applications

f. CNC programming

g. Process planning

h. Tool Design

i. Inspection

j. ERP

CAD Software

CAD (Computer-Aided Design) software refers to computer programs used to create, modify, analyze, and document engineering designs and drawings in both two-dimensional (2D) and three-dimensional (3D) forms. It is widely used in mechanical, civil, electrical, architectural, and manufacturing industries.

Types of CAD Software

2D CAD Software

2D CAD software is mainly used for drafting and detailing work. It helps in preparing accurate drawings such as layouts, plans, and schematics.

Examples: *AutoCAD, DraftSight, LibreCAD.*

3D CAD Software

3D CAD software is used for solid modeling, surface modeling, and assembly design. It allows designers to visualize products before manufacturing.

Examples: *SolidWorks, CATIA, Creo (Pro E), Siemens NX, Fusion 360.*

Specialized CAD Software

These are developed for specific engineering applications.

Examples: *Revit (Architecture and BIM design), Civil 3D (Civil Engineering), AutoCAD Electrical and EPLAN (Electrical control system design), Altium Designer (PCB design).*

Integrated CAD Software

Some CAD systems are integrated with CAE and CAM software to perform analysis and manufacturing operations.

Examples: *NX*, *CATIA*, *Creo*.

Features of CAD Software

- ✓ High accuracy and precision
- ✓ Easy modification and editing of drawings
- ✓ 2D drafting and 3D modeling capability
- ✓ Layer management
- ✓ Libraries of standard parts
- ✓ Rendering and visualization
- ✓ Easy storage and data sharing

Advantages of CAD Software

- ✓ Reduces design time
- ✓ Improves design quality and productivity
- ✓ Better visualization of designs
- ✓ Easy documentation and revision
- ✓ Minimizes human errors

Common CAD Softwares

Common CAD software are widely used computer programs that help engineers and designers in creating accurate 2D drawings and 3D models for various engineering applications.

1. AutoCAD

AutoCAD is one of the most widely used CAD software developed by Autodesk. It is mainly used for **2D drafting** and basic **3D modeling**.

- ❖ Used in mechanical, civil, electrical, and architectural fields
- ❖ Provides precise drawing and editing tools

- Supports layers, blocks, dimensioning, and annotations
- Commonly used for engineering drawings and layouts

2. SolidWorks

SolidWorks is a **parametric 3D CAD software** mainly used for mechanical design.

- Used for solid modeling and assemblies
- Supports part modeling, assembly modeling, and drafting
- Allows simulation and motion analysis
- Widely used in manufacturing and product design industries

3. CATIA

CATIA (Computer Aided Three-Dimensional Interactive Application) is a powerful CAD software developed by Dassault Systèmes.

- Used for complex surface and solid modeling
- Widely used in aerospace, automobile, and shipbuilding industries
- Supports large assembly design
- Integrated with CAM and CAE modules

4. Creo (Pro/ENGINEER)

Creo is a parametric 3D modeling software developed by PTC.

- Used for product design and development
- Supports solid, surface, and sheet-metal modeling
- Feature-based and parametric design
- Commonly used in mechanical engineering industries

5. Siemens NX (Unigraphics)

NX is an advanced integrated CAD/CAM/CAE software.

- Used for high-end mechanical design
- Supports solid, surface, and free-form modeling

- Suitable for complex assemblies
- Widely used in automotive and aerospace industries

6. Fusion 360

Fusion 360 is a cloud-based CAD software developed by Autodesk.

- Supports 3D modeling, simulation, and CAM
- Useful for small industries and startups
- Enables collaboration and cloud data storage
- Easy to learn compared to other advanced CAD tools

7. Revit

Revit is mainly used for **Building Information Modeling (BIM)**.

- Used in architecture, structural, and MEP design
- Allows 3D building modeling with detailed information
- Automatically updates drawings when changes are made
- Widely used in construction and infrastructure projects

CAD Hardware

CAD (Computer-Aided Design) hardware refers to the physical components of a computer system required to run CAD software efficiently for creating, modifying, and displaying engineering drawings and models.

1. Input Devices

Input devices are used to enter data and commands into the CAD system.

- **Keyboard** – used to enter commands, dimensions, and text
- **Mouse** – used for selection, drawing, editing, and navigation
- **Digitizer / Graphics Tablet** – provides high accuracy for tracing drawings
- **Scanner** – converts paper drawings and images into digital form

Light Pen (obsolete) – used in early CAD systems for screen interaction

2. Central Processing Unit (CPU)

The CPU is the brain of the CAD system.

- Performs calculations and logical operations
- Multi-core, high-speed processors improve CAD performance
- Essential for handling complex 3D models and rendering

High-speed CPU: Intel i7/ i9 or AMD Ryzen 7/9

3. Main Memory (RAM)

RAM stores programs and data currently in use.

- Large RAM capacity improves speed and multitasking
- Helps in handling large assemblies and detailed drawings
- Typical CAD systems require 8–32 GB RAM

4. Graphics Processing Unit (GPU)

GPU handles graphical display and rendering.

- Dedicated graphics cards improve 2D and 3D performance
- Essential for visualization, shading, and animation
- Reduces load on CPU

GPU: **NVIDIA Quadro / RTX, AMD Radeon Pro**

5. Output Devices

Output devices display or produce CAD drawings.

- **Monitor** – high-resolution display (Full HD / 4K) for accurate visualization
- **Printer** – prints small-size drawings and reports
- **Plotter** – used for large-size engineering drawings (A0, A1)
- **3D Printer** – used to create physical prototypes

6. Storage Devices

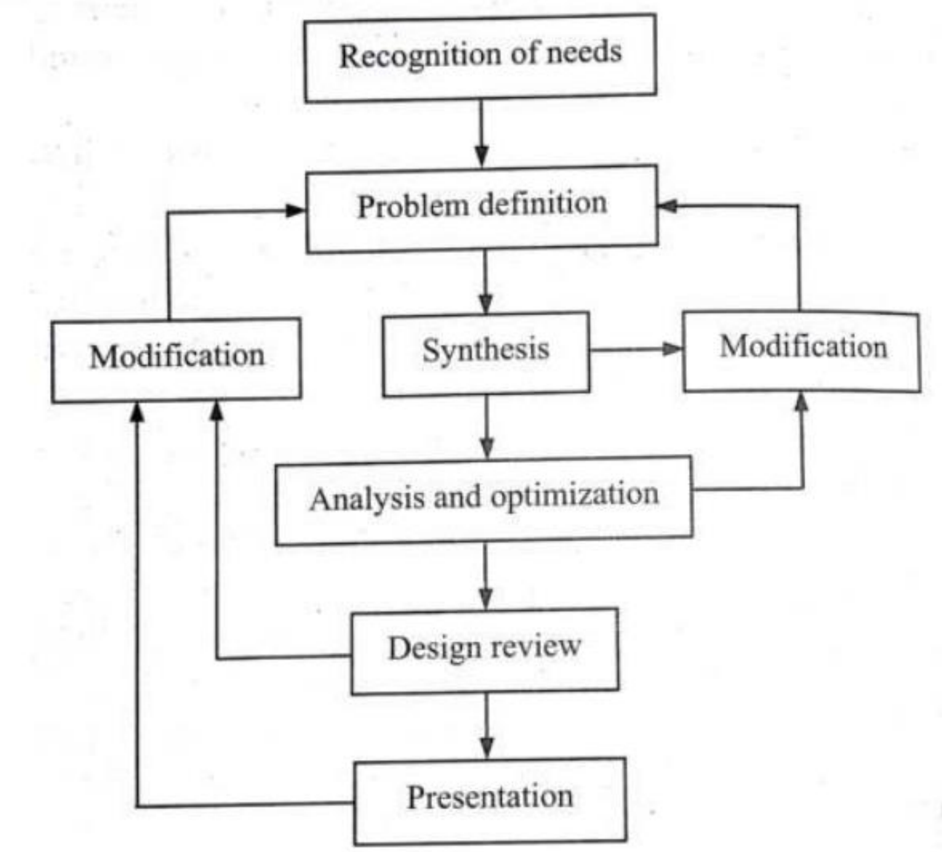
Used for storing CAD data and files.

Hard Disk / SSD – stores software and design files

External storage / Cloud – used for backup and data sharing

CAD hardware plays a vital role in achieving accurate, fast, and efficient design work. A powerful CPU, sufficient RAM, dedicated graphics card, and appropriate input-output devices are essential for effective CAD operations in modern engineering industries.

Conventional design process



Recognition of need

• Adoption of existing design

• Modification of existing design

• Completely new design

Problem definition (i.e., specification)

• The designer collects different information, about the existing products of similar type, about the market potential, about the manufacturing constraints, about the legal requirements and standards, and so on.

Synthesis (i.e., conceptualization)

The end goal of synthesis is a **conceptual design** of the product. Synthesis sub process generates the information regarding design of the product. In this phase, **sketches of different components and assembly are drawn**.

Analysis and Optimization

Analysis determines whether the performance complies with the requirements or not. The analysis sub process selects suitable **material** and its associative mechanical properties. Calculations are performed to **determine the size or parameters** using the physical laws (i.e., laws of momentum, motion, energy conservation, etc.).

• The different types of engineering analyses are stress-strain analysis, kinematic analysis, dynamic analysis, vibration analysis, thermal analysis, fluid-flow analysis, etc.

• Optimization means the best possible solution for the given objectives. All possible solutions are analyzed and optimum is selected. After every phase of design process, the designer may go to the previous steps and modify them.

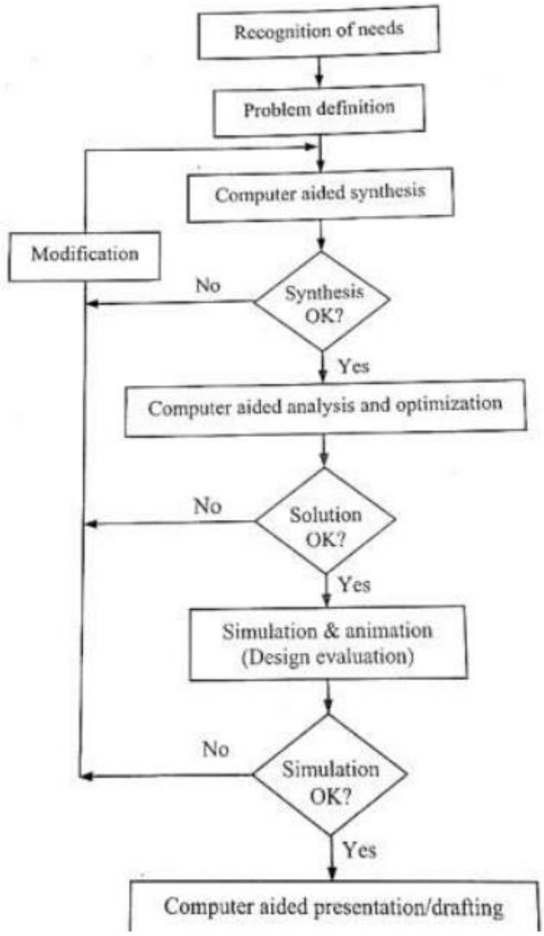
Design review (i.e., evaluation):

• Evaluation means measuring the design against the specifications set in the problem definition.

Presentation (i.e., drafting)

• The final stage in the design process is the presentation and documentation of the design on the paper. This forms an interface between design and the manufacturing.

Computer aided design



PRODUCT MODELLING

Computer representation of the geometry of a component using software is called a geometric model. Geometric modeling is done in three principal ways. They are:

i. Wire frame modeling

ii. Surface modeling

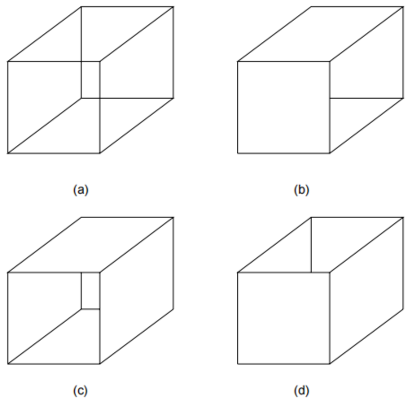
iii. Solid modeling

These modeling methods have distinct features and applications.

WIRE FRAME MODELING

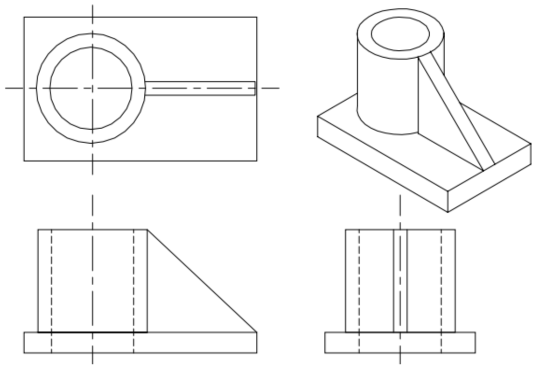
In wire frame modeling the object is represented by its edges. In the initial stages of CAD, wire frame models were in 2-D. Subsequently 3-D wire frame modeling software was introduced.

The wire frame model of a box is shown in Fig. (a). The object appears as if it is made out of thin wires. Fig. (b), (c) and (d) show three objects which can have the same wire frame model of the box.



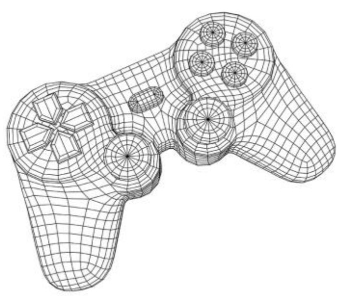
Thus in the case of complex parts wire frame models can be confusing. Some clarity can be obtained through hidden line elimination.

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.



four views (plan, elevation, end view and isometric)

Wireframe modelling represents an object using **only lines, curves, and edges**.



Key features

- Consists of points, lines, arcs, splines
- No surfaces or volume
- Transparent — you can see through the model

Advantages

- Simple and fast to create
- Low computational requirement
- Useful for conceptual layouts

Limitations

- No information about surfaces or mass
- Ambiguous geometry (inside/outside not defined)
- Cannot be used directly for manufacturing or analysis

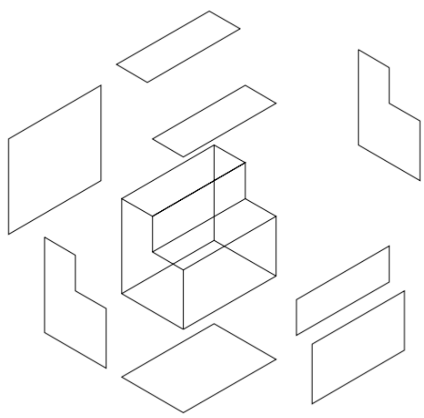
Applications

- Early concept design
- Tool path definition
- Reference geometry for surface modelling

SURFACE MODELING

In this approach, a component is represented by its surfaces which in turn are represented by their vertices and edges.

For example, eight surfaces are put together to create a box, as shown in Fig.



Surface representation

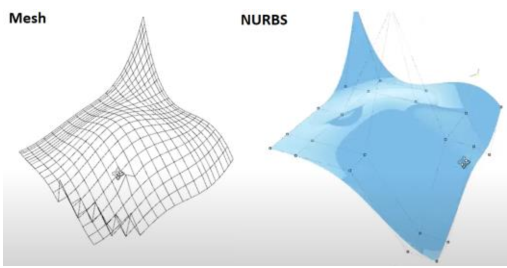
Surface modelling is a computer-aided design technique in which a product is represented by **mathematical surfaces having zero thickness**, used mainly to define the **external shape and geometry** of a component.

A surface model is defined in terms of points, lines and faces. This type of modeling is superior to wire frame modeling discussed earlier in this chapter. A major advantage of surface modeling is its ability to differentiate flat and curved surfaces. In graphics, this helps to create shaded image of the product. In manufacture, surface model helps to generate the NC tool path for complex shaped components that are encountered in aerospace structures, dies and moulds and automobile body panels.

In surface modelling, the object is created using **surface elements** such as planes, cylinders, lofted surfaces, swept surfaces, and free-form surfaces like **B-splines and NURBS**. These surfaces describe the outer boundary of the product without defining its internal volume.

A **B-spline surface** is generated by blending a set of control points using basis functions. The surface does not necessarily pass through all control points; instead, the points act as a **control polygon** that influences the shape. B-splines provide **local control**, meaning modification of one control point affects only a limited area of the surface, resulting in stable and smooth geometry.

(A **NURBS surface** is an extension of B-splines that includes **weights** for control points and a **non-uniform knot vector**. This allows NURBS to accurately represent both **free-form shapes** and **exact analytical geometry** such as circles, ellipses, cylinders, and spheres. Because of this versatility, NURBS are widely used in advanced CAD systems.



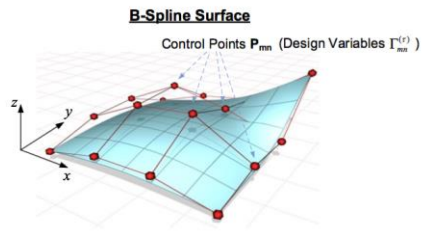


Figure 3: An illustration of B-spline surface constructing by uniformly spaced control points.

Free-form surfaces using B-splines and NURBS offer excellent **smoothness, continuity, and curvature control**, making them ideal for high-quality surface design. However, they require higher computational power and skilled modelling techniques.)

Surface modelling provides high control over **curvature, smoothness, and aesthetics**, making it suitable for complex and organic shapes. Continuity between adjacent surfaces is maintained using **G0 (position), G1 (tangency), and G2 (curvature) continuity**, ensuring smooth visual transitions.

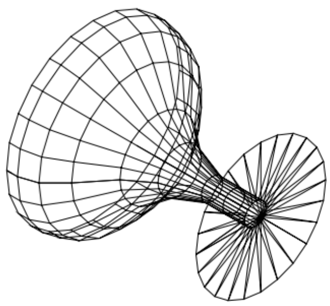
Although surface models accurately represent shape, they **do not provide mass, volume, or structural properties**. Therefore, surface models are usually converted into **solid models** before manufacturing or engineering analysis.

Surface modeling has been very popular in aerospace product design and automotive design. Surface modeling has been particularly useful in the development of manufacturing codes for automobile panels and the complex doubly curved shapes of aerospace structures and dies and moulds.

A surface can be created in several ways:

i. Creating a plane surface by the linear **sweep** of a line or series of lines.

ii. **Revolving** a straight line about an axis. Cylindrical, conical surfaces etc. can be generated by this technique.



iii. Revolving a curve about an axis.

iv. Combination of plane surfaces.

v. **Analytic surfaces:** Planes, cylinders, cones, ellipsoid, parabolic hyperboloid etc can be defined by mathematical equations in terms of X, Y and Z co-ordinates.

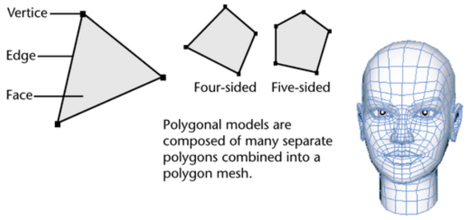
vi. **Sculptured surfaces:** These are also called **free form surfaces**. These are created by spline curves in one or both directions in a 3-D space. These surfaces are used in the manufacture of car body panels, aircraft structures, mixed flow impellers, telephone instruments, plastic containers and several consumer and engineering products.

<u>SURFACE MODELING COMMANDS</u>

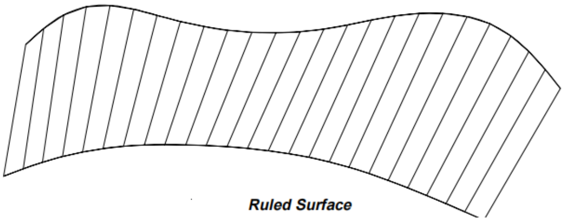
There are a number of commands to create a surface model

i. 3-D face: The different faces of an object can be modeled using this command. The X,Y,Z co-ordinates of each vertex are input one after another to model a face and each of the faces is defined one after another in this manner.

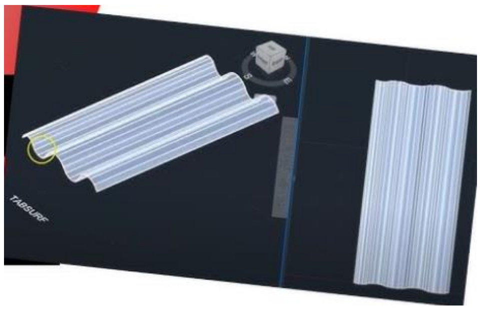
ii. P face: The P-face command produces a general polygon mesh. Using this command, it is possible to avoid defining a single vertex several times as is done in 3-D face command.



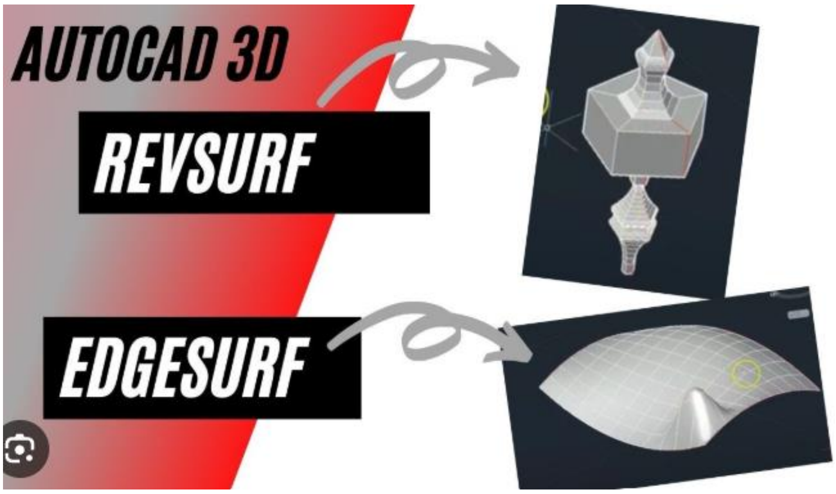
iii. Rulesurf: This command creates a polygon representing the ruled surface between two curves. Figure shows an example of ruled surfaces.



iv. Tabsurf: A polygon mesh representing general tabulated mesh defined by a path curve and a direction vector is created by this command. Fig. shows a typical surface created by this command.



v. Revsurf: A surface of revolution is created by rotating a path curve or profile about an axis. The rotation can be through 360 degrees or part of it.



Advantages of surface modelling

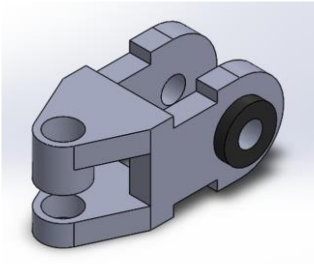
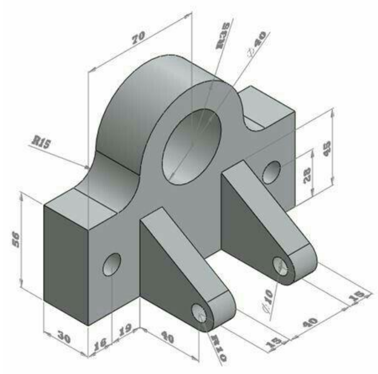
- ✓ Excellent for **complex and organic shapes**
- ✓ Precise control over **curvature and smoothness**
- ✓ Essential for **styling and aerodynamic design**
- ✓ More flexible than solid modelling for form development

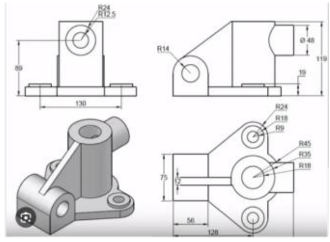
Limitations

- ✓ No mass, volume, or center-of-gravity data
- ✓ Not directly suitable for structural analysis
- ✓ Must be converted to a **solid model** for manufacturing

SOLID MODELLING

Solid modelling is a computer-aided design technique in which a product is represented as a **complete three-dimensional solid with well-defined interior and exterior boundaries**. Unlike wireframe and surface modelling, solid modelling fully defines the **volume** of the object.



In solid modelling, objects are created using feature-based operations such as **extrusion, revolution, sweep, loft**, and Boolean operations (union, subtraction, and intersection). These operations ensure that the model remains **topologically valid** at all times.

Solid models allow direct computation of **mass properties** such as volume, weight, center of gravity, and moments of inertia. They also support **engineering analysis** like finite element analysis (FEA), motion studies, and interference checking.

Due to their accuracy and reliability, solid models are directly used for **manufacturing processes** such as in CNC machining, injection moulding, casting, and additive manufacturing.

Applications include mechanical components, machine assemblies, tooling, fixtures, and mass-produced industrial products.

Advantages

- ✓ Complete and unambiguous geometry
- ✓ Accurate mass and physical properties
- ✓ Suitable for analysis and manufacturing
- ✓ Easy modification through parameters

Limitations

- ✓ Requires more computational resources
- ✓ Less flexible for highly free-form styling without surface tools

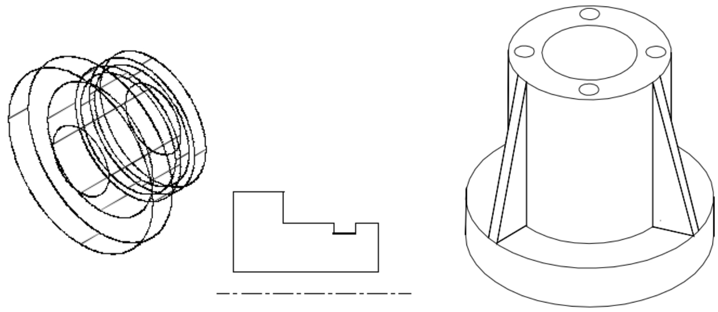
SALIENT FEATURES OF SOLID MODELING

- A solid model is a 3-D representation of an object. It is an accurate geometric description which includes not only the external surfaces of part, but also the part’s internal structure.
- A solid model allows the designer to determine information like the object’s mass properties, interferences, and internal cross sections.
- Solid models differ from wire frame and surface models in the kind of geometric information they provide. Wire frame models only show the edge geometry of an object. They say nothing about what is inside an object. Surface models provide surface information, but they too lack information about an object’s internal structure. Solid models provide complete geometric descriptions of objects.
- Solid models can be used for quick and reliable design analysis. Solid models apart from geometric information provide important data such as volume, mass, mass properties and centre of gravity. The designer can also export models created to other applications for finite element analysis (FEA), rapid prototyping and other special engineering applications.
- Finally designers can generate detailed production drawings directly from the solid model. This capability increases design productivity considerably
- In more advanced design and manufacturing environments, solid models are used for rapid prototyping and automated manufacturing applications.
- In typical 2-D CAD applications, a designer draws a part by adding basic geometric elements such as lines, arcs, circles and splines. Then dimensions are added. In solid modeling a 3-D design is created by starting a base feature and then adding other features, one at a time, until the accurate and complete representation of the part’s geometry is achieved.

A feature is a basic building block that describes the design, like a keyway on a shaft. Each feature indicates how to add material (like a rib) or remove a portion of material (like a cut or a hole). Features adjust automatically to changes in the design thereby allowing the capture of design intent. This also saves time when design changes are made.

- In typical solid modeling software the designer can create a feature in two basic ways. One is to sketch a section of the shape to be added and then extrude, revolve, or sweep it to create the shape. These are called sketched features.

Another type of feature is the pick-and-place feature. Here the designer simply performs an engineering operation such as placing a hole, chamfering or rounding a set of edges.



❖ An important component of every feature is its dimensions. Dimensions are the variables that one changes in order to make the design update automatically. When a dimension is changed the solid modeling software recalculates the geometry.

Features/available in typical solid modeling software are:

Extrude	Revolve	Thin
Blend	Slot	Cut
Protrusion	Shaft	Round
Hole	Flange	Rib
Chamfer	Push	Dome
Draft	Ear	Shell
Offset	Lip	
Pipe	Sweep	

<u>SOLID MODELING TOOLS</u>

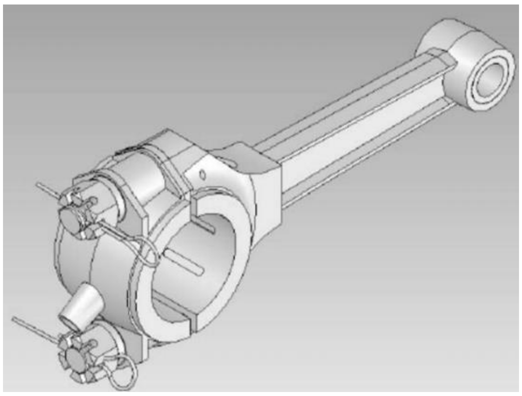
Sketching

The first step in creating many 3-D features is sketching a 2-D section. Then by using appropriate instructions the design conveys the information regarding how far to extend this section in a space. The third dimension is created this way. For instance, a 30 mm circle extruded 50 mm through space produces a cylinder 30 mm diameter and 50 mm high.

Creating Parts

As mentioned earlier solid modeler uses features such as cuts, protrusions, holes, chamfers, and other basic shapes to build part geometry. The designer gets the information about the geometry of a feature (like the size and shape of cuts and protrusions), from a sketcher window.

As the features are added the geometry of the part is enhanced. By adding to geometry one feature at a time, parts with very complex geometry can be created as shown in Fig.



Building Assemblies

Designs usually consist of several parts. Solid modelers can put two or more parts together in an assembly. All the tools a designer needs to build, modify, and verify assemblies are available in solid modeling softwares.

Documenting Designs

The final step of designing a part or assembly is communicating it in a medium other than the computer monitor's display.

<u>FEATURES OF A DRAFTING PACKAGE</u>

Typical features that one expects in a drafting package are listed below:

i. **<u>Drawing utilities:</u>** This includes selection of units, screen limits, scale, snap, grid, layers etc.

ii. <u>Entity drawing:</u> Several standard entities like line, circle, arc, polyline, polygon, ellipse etc are available to create the model required.

iii. <u>Edit commands:</u> A number of commands are available to modify or copy or replicate the entities or groups of entities in a model.

iv. <u>Standard parts:</u> Facilities are available to create symbols, shapes, and other standard parts. Frequently used parts can be stored as blocks which can be inserted into a drawing as and when required.

v. <u>Display</u>: The model can be enlarged, reduced in size, or moved across the screen, using display commands.

vi. <u>Cross hatching:</u> Sectional plans can be indicated through cross hatching.

vii. <u>Dimensioning:</u> Parts can be dimensioned using a number of standard dimensioning systems.

viii. <u>Plotting:</u> Facilities to get hard copies of drawings using a pen or electrostatic plotter and printer will be available.

ix. <u>Configuration:</u> A software has to be configured to a given hardware environment.

x. <u>Customization:</u> Drafting productivity can be enhanced through customizing software package.

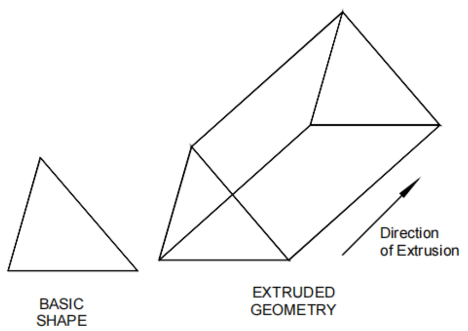
xi. <u>Drawing interchange:</u> It may be necessary to import or export drawing files created in one software package to another.

<u>3-D DRAWING COMMANDS</u>

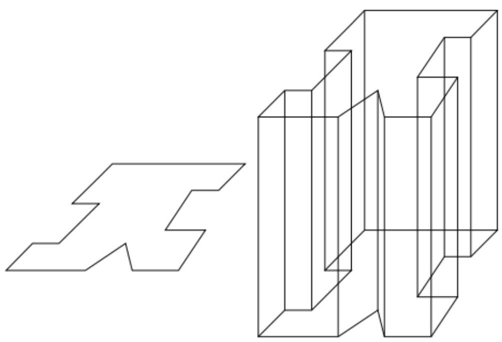
Though 2-D drafting can meet a substantial drafting requirements, 3-D modeling enables creation of objects in 3-D. 3-D drawings are prepared in several ways.

EXTRUSION (LINEAR SWEEP)

Simple 3-D objects can be created by extruding 2-D images in the third dimension. The extrusion thickness can be specified by an appropriate command. The objects extruded will have uniform thickness in the Z direction. Fig (a) shows a triangle extruded in the third dimension and Fig. (b) shows the extrusion of a complex plane.



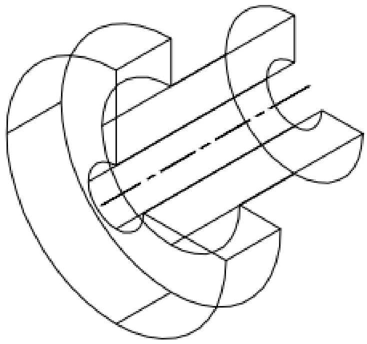
a



b

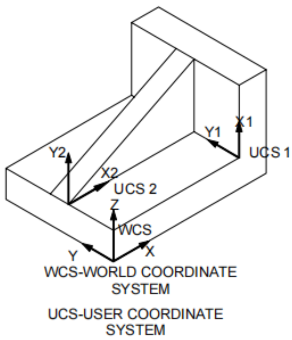
REVOLUTION

Wire frame images can be created by revolving an entity about an axis. In Fig. a set of entities are revolved about an axis through 270° to create a wire frame object. Rotation through 360°will produce complete objects.



USING USER CO-ORDINATE SYSTEMS (UCS)

CAD packages have a facility to define several user co-ordinate systems. Plane figures can be drawn in these user co-ordinate systems to create a 3-D wire frame model. For example, consider the object shown in Fig. Different sides of the object can be created in the respective planes as indicated.



A plane figure drawn in a User Co-ordinate System can be assigned a thickness to create a 3-D wire frame model. Complex 3-D models can be created using a combination of several user co-ordinate systems and thicknesses.

AUTOMATIC DRAFTING

Automatic drafting in Computer-Aided Design (CAD) is the process of using software algorithms, rules, and AI to generate technical drawings, such as 2D engineering sheets from 3D models, with minimal human intervention.

It transforms the "manual drafting cycle" into a streamlined workflow, significantly reducing time spent on repetitive tasks like dimensioning and annotation.

Automatic drafting in CAD refers to the process of **automatically generating 2D engineering drawings** from a 3D CAD model using computer-aided design software. The system extracts geometric and dimensional information directly from the model, reducing manual drafting work.

In automatic drafting, standard views such as **orthographic, sectional, auxiliary, and isometric views** are created automatically. Dimensions, tolerances, center marks, and annotations can be generated based on predefined **drafting standards** like ISO, ANSI, or BIS.

- ✧ **(Orthographic views** (top, front, side) show precise, 2D, multi-view projections. **Sectional views** expose internal details via a cutting plane. **Auxiliary views** show the true shape of inclined surfaces, while **isometric views** offer a 3D, representation.)

Key Components of Automatic Drafting

- **Automated 2D Generation:** Tools like **iDrafter** or **DraftAid** automatically create 2D views (front, top, side, isometric) directly from a 3D model's geometry.
- **Intelligent Dimensioning:** Algorithms calculate the best placement for linear, angular, and radial dimensions while avoiding overlaps and ensuring compliance with standards.
- **Annotation Automation:** Systems can automatically populate title blocks, add centerlines and insert standard symbols based on the model's data.
- **Parametric Design:** Models are built with defined parameters so that any change in dimensions automatically updates all related 2D drawing sheets.

Automatic drafting also supports **automatic Bill of Materials (BOM)** generation, title blocks, revision tables, and standard symbols. It is widely used in modern CAD systems such as SolidWorks, AutoCAD, Creo, CATIA, and NX.

Advantages

- ❖ Saves time and drafting effort
- ❖ High accuracy and consistency
- ❖ Easy updating of drawings after design changes

- Conforms to international drafting standards

Applications

- Manufacturing drawings
- Assembly drawings
- Production documentation
- Inspection and quality control drawings

ENGINEERING ANALYSIS

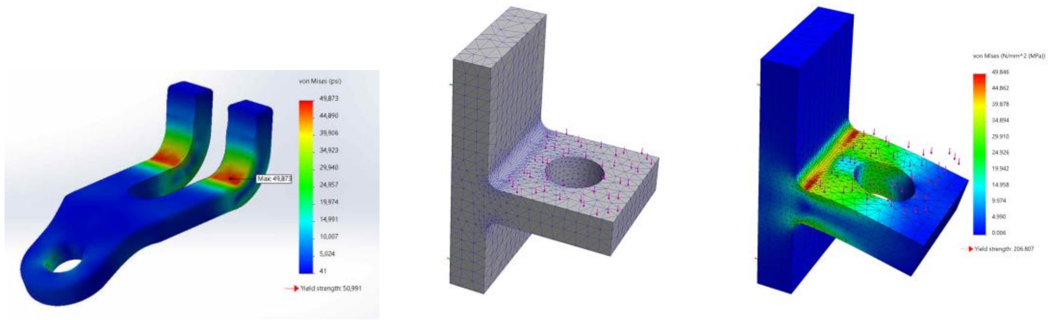
- Engineering analysis in CAD refers to the use of digital models to **simulate, predict, and optimize** how a design will behave under real-world conditions.
- The analysis may take the form of stress-strain calculations, heat transfer analysis, or dynamic simulation.
- The computation are often complex and time consuming, and before the advent of the digital computer, these analyses were usually greatly simplified or even omitted in the design procedure.
- The availability of software for engineering analysis on a CAD system greatly increases the designer's ability and willingness to perform a more thorough analysis of a proposed design. The term *computer-aided engineering* (CAE) is often used for engineering analyses performed by computer.

Key Types of Analysis in CAD

1. **Finite Element Analysis (FEA):** It is the most common method used to evaluate structural integrity by breaking a model into small "elements" to calculate stress, strain, heat transfer, fluid flow, deformation under various loads and other engineering computations.

It is a numerical analysis technique for determining approximate solutions to physical problems described by differential equations that are very difficult or impossible to solve.

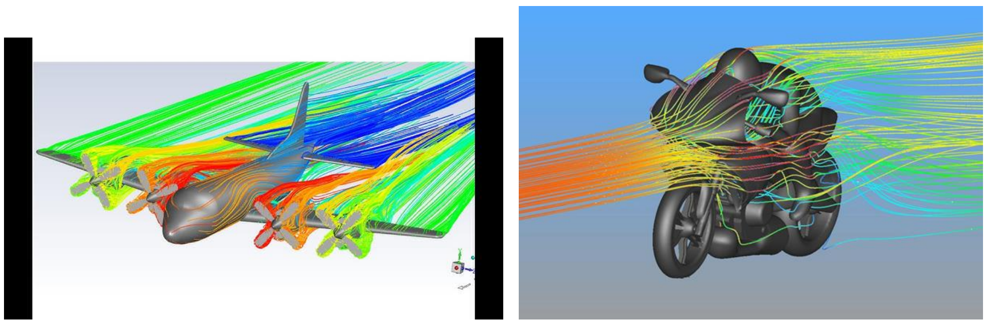
In FEA the physical object is modeled by an assemblage of discrete interconnected nodes (finite elements), and the variable of interest (e.g., stress, strain, temperature) in each node can be described by relatively simple mathematical equations, By solving the equations for each node. the distribution of values of the variable throughout the physical object is determined.



Result of a finite element analysis which is carried out on simple mechanical elements.

- ✧ Different colors which indicate various stress levels and deflection level .
- ✧ This gives enough feedback to designers as to what are the critical portions where the strengthening is required or what are the portions where the stresses are not very high or the deflections are not very high where one can go back and reduce the sections or may be remove material in some form in order to optimize the design.

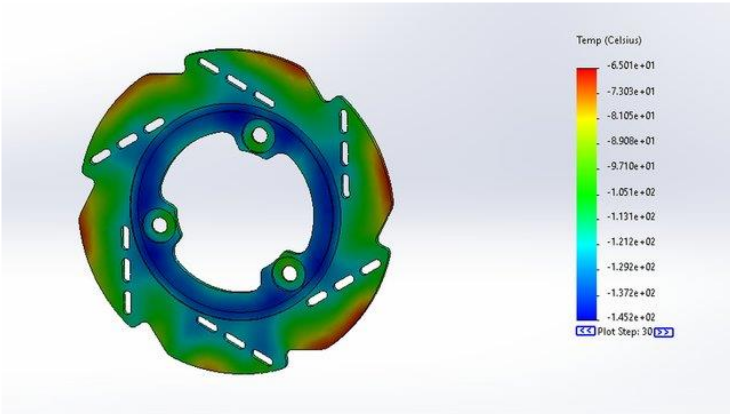
2. **<u>Computational Fluid Dynamics</u> (CFD):** Used to simulate fluid flow (liquids or gases) and heat transfer in and around a design, essential for aerodynamics and thermal management.



3. **<u>Dynamic and Kinematic Analysis</u>:** Kinematic analysis involves the study of the operation of mechanical linkages to analyze their motions. A typical kinematic analysis consists of specifying the motion of one or more driving members of the subject linkage, and the resulting motions of the other links are determined by the analysis package.

Dynamic analysis extends kinematic analysts by including the effects of the mass of each linkage member and the resulting acceleration forces as well as any externally applied forces.

4. **Thermal Analysis:** Predicts how heat is distributed through a part and how it expands or contracts when subjected to temperature changes.



5. **Tolerance analysis:** Software for analyzing the specified tolerances of a product components is used for the following functions: (1) to assess how the tolerances may affect the product's function and performance, (2) to determine how tolerances may influence the ease or difficulty of assembling the product and (3) to assess how variations in component dimensions may affect the overall size of the assembly.

6. Interference checking: This CAD software examines 2D geometric models consisting of multiple components to identify interference between the components. It is useful in analyzing mechanical assemblies, chemical plants, and similar multi component designs.

Benefits for Designers

i. **Early Issue Detection:** Find potential failure points before manufacturing, significantly reducing the risk of product failure.

ii. **Cost & Time Savings:** Virtually testing multiple design iterations reduces the need for costly physical prototypes and accelerates the time-to-market.

iii. **Design Optimization:** Tools like SolidWorks Simulation allow engineers to minimize material use while maintaining strength, leading to more efficient products.

iv. **Data-Driven Decisions:** Provides visual 3D gradients (e.g., color maps for stress).

Popular Software Tools

Many modern CAD platforms include integrated modules for engineering analysis, or "CAE" (Computer-Aided Engineering):

- **Autodesk Fusion:** A cloud-based platform that combines design, FEA, and CFD in one workflow.
- **ANSYS:** A specialized simulation suite often used for high-end structural, thermal, and fluid dynamics analysis.
- **Siemens NX / Solid Edge:** Offers advanced parametric modeling and high simulation capabilities.

Finite element modeling (FEM) and finite element analysis (FEA)

Traditional approach to design analysis has the following limitations:

i. Stresses and strains are obtained only at macro level. This may result in inappropriate deployment of materials. Micro level information is necessary to optimally allocate material to heavily stressed parts.

ii. Adequate information will not be available on critically stressed parts of the components.

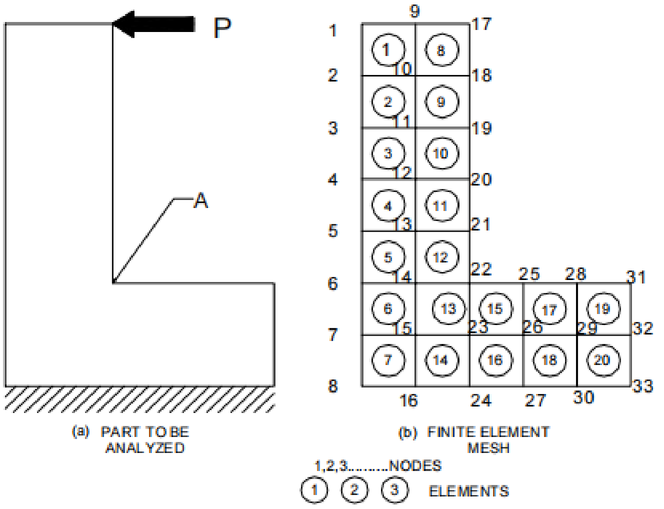
iii. It may be necessary to make several assumptions to design complex components and systems, if design analysis is carried out in the conventional manner.

iv. Manual design is time consuming and prone to errors.

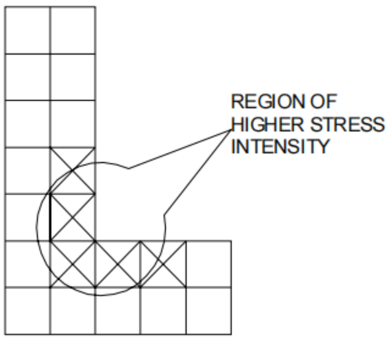
v. Design optimization is tedious and time consuming.

- FEA is a convenient tool to analyze simple as well as complex structures. In manufacturing, FEA is used in simulation and optimization of manufacturing processes like casting, machining, plastic molding, forging, metal forming, heat treatment, welding etc. Structural, dynamic, thermal, magnetic potential and fluid flow problems can be handled with ease and accuracy using FEA.
- The finite element method is a numerical procedure. This method involves modeling the structure using a finite number of small interconnected elements.

- Consider the plate shown in Fig. (a) Suppose that it is acted upon by a force P as shown and our interest is to determine the stresses in the plate. The plate is discretized into 20 of elements and 33 nodes as shown in Fig. (b).



- Nodes in this case are the corner points of each element which have a square shape. The nodes are numbered 1 to 33. Each element is formed by four nodes. For example, nodes 1,9,10,2 form element 1. The elements are numbered 1 to 20.
- **A displacement function** is associated with each element. Every interconnected element is linked to other neighboring elements through common interfaces (nodes, edges and surfaces). Using the stress- strain relationship of the material of the part under analysis, the designer can determine the behavior of a given node.
- The set of equations describing the behavior of all nodes results in a set of algebraic equations. These equations are expressed in matrix form and are solved by FEA.
- The solution obtained by finite element analysis is approximate. The accuracy of solution may depend on the type of element used and the number of elements.
- It may be necessary to refine the mesh to improve the accuracy of the solution in specific parts of the component being analyzed. For example, referring to above figure, we can state by intuition that the intensity of stress around point A will be more. It is therefore advisable to refine the mesh around point A.



Mesh refinement

- An example of refined mesh is shown in Fig. Five more nodes have been added and the number of elements is now 35. This may yield a better solution to the stress intensity.

The steps involved in a finite element modeling and analysis procedure are summarized as below:

1. **SELECT THE ELEMENT TYPE AND DISCRETIZE THE COMPONENT**

The first step is to select an element which closely represents the physical behaviour of the structure. The size of the elements to start with is a matter of judgment of the designer.

2. **SELECT A DISPLACEMENT FUNCTION**

A displacement function within the element using the nodal values of the element is then defined. These may be linear, quadratic or cubic polynomials. The same displacement function is used for all the elements.

3. **DEFINE STRESS STRAIN RELATIONSHIP**

Definition of stress strain relationship for each element is the next step. For example in the case of one dimensional deformation, if u is the displacement in the direction X, the strain is related to the displacement by the relation

$$\varepsilon_x = du/dx$$

The stresses are related to the strains through the stress strain law or constitutive law. Using Hooke's law, the stress strain law can be written as:

$$\sigma_x = E\,\varepsilon_x$$

where σ is the stress in the X direction and E is the modulus of elasticity.

4. **DERIVE THE ELEMENT STIFFNESS MATRIX**

The equations describing the behavior of an element related to nodal forces can be written in matrix form as

$$\begin{Bmatrix} f_1 \\ f_2 \\ f_3 \\ - \\ - \\ f_n \end{Bmatrix} = \begin{bmatrix} k_{11} & k_{12} & k_{13} & - & k_{1n} \\ k_{21} & k_{22} & k_{23} & - & - \\ k_{31} & k_{32} & - & - & - \\ - & - & - & - & - \\ - & - & - & - & - \\ k_{n1} & - & - & - & k_{nn} \end{bmatrix} \begin{Bmatrix} d_1 \\ d_2 \\ d_3 \\ - \\ - \\ d_n \end{Bmatrix}$$

This may also be written in the form {f} = [k] {d} where {f} is the vector of element nodal forces, [k] is the element stiffness matrix and {d} is the displacement vector.

5. **ASSEMBLE GLOBAL STIFFNESS MATRIX**

The individual element stiffness matrices are then assembled to obtain the global stiffness matrix of the whole component being analyzed. The global stiffness matrix is written as: [F]= [K]{d}

where [F] vector of global nodal forces, [K] is the global stiffness matrix and {*d* }is the vector of unknown displacements.

6. **SOLVE TO OBTAIN NODAL DISPLACEMENTS**

Pre-multiplying both sides of above equation by the inverse of stiffness matrix we will obtain the solution for the displacements.

Strains can be computed from the displacements. Once the strain is known the stress can be calculated using Hooke's law. Principal stresses, shear stresses, von Mises stresses (equivalent stress) etc. could be computed depending on the interest of the designer.

Application areas of FEA

- Static analysis of trusses, beams, frames, plates, bridges. machine **structures.** Structural analysis of **aircraft wings**. missile and **rocket** structures.
- **Natural frequencies** and modes of structures, linkages, gears, flywheels. and cams.
- **Dynamic response** of structures subjected to a periodic loads and random loads.
- **Stress analysis** of pressure vessels, flywheels, crankshafts, cams, linkages, gears, machine members. etc.

- **Thermal analysis** in IC engines, turbine blades, steam pipes, and rocket nozzles.
- **Analyses of fluid flow** and wave propagation problems.
- Steady state analysis of synchronous and induction machines, **eddy current** and core losses in electric machines.
- Stress analysis of **bones and teeth**, load bearing capacity of implant and prosthetic systems, and **mechanics of heart values**.
- Analysis of casting, forming. welding and machining processes.

Advantages of FEA

- As previously indicated, the FEM has been applied to numerous problems, both **structural and nonstructural.**
- The ability to model **complex shaped bodies** quite easily
- **Handle several load conditions** without difficulty
- Handle different kinds of **boundary conditions**
- Model bodies composed of **several different materials**
- **Discretize the bodies with combination of different elements.**

Disadvantages of the FEA

- The FEA is applied to an approximation of the mathematical model of a system. so it obtains only "**approximate" solutions.**
- **Experience and judgment** are needed in order to construct a good finite element model.
- **Mistakes by users** while analyzing the problem in software can be fatal.
- A **powerful computer** and reliable FEA software are essential.
- **Input and output data** may be large and tedious to prepare and interpret.

DESIGN REVIEW AND EVALUATION

Design review and evaluation by Finite Element Method (FEM) (or FEA) involves validating structural integrity, identifying weaknesses, and optimizing designs by simulating real-world conditions like load, stress, and thermal factors.

It enables rapid, cost-effective, and accurate assessments of complex geometries in materials like concrete, steel, and timber, replacing physical prototypes.

Objective of the FEM Design Review

The review ensures that:

a. Structural strength meets design loads
b. Stresses are below allowable limits
c. Deflection is within functional tolerance
d. Fatigue life meets service requirements
e. Buckling safety is adequate
f. Thermal performance is acceptable (if applicable)
g. The model assumptions are valid

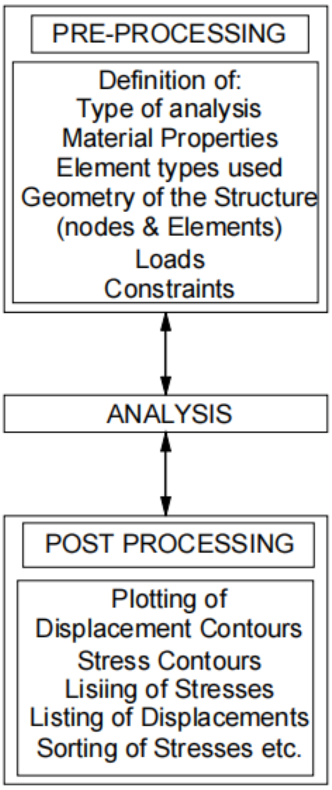
STAGES OF FEM DESIGN REVIEW

The review of a structure during its design process is accomplished by the solution of the partial differential equations which describe the given model. This involves the following three steps.

(i) The description of the geometry, the physical characteristics and the mesh (pre processing)

(ii) The application of the finite element analysis (solution). In the analysis part, computer solves the unknowns in the finite element problem, i.e., it solves the linear or non-linear system of equations.

(iii) The visualization and interpretation of the results of the solution (post processing).



Pre processing

The pre-processing module is used for entering all the information necessary to define the problem. This data relates to the discretization of the structure and the representation of its physical behavior.

The pre-processing module must accomplish the following three functions:

a. Description of the geometry of the object in terms of the chosen element types

b. Mesh generation

c. Definition of loading and boundary condition. [Fixed supports, Loads (force, pressure, torque), Contacts, Thermal loads]

- The nodes are defined by their co-ordinates while the elements are characterized by their type and a list of their nodes.
- The shape of the elements must not be too irregular (elongated) and should, as much as possible, resemble the standard elements (triangles or tetrahedra, squares or cubes, etc.).
- Material Properties such as Young's modulus, Poisson's ratio, Yield strength, Ultimate strength, Fatigue properties should be within the limit.

Analysis

- In the analysis part, computer solves the unknowns in the finite element problem, i.e., it solves the linear or non-linear system of equations based on the variational or the projective formulation.
- Input to analysis module is the finite element model, the physical characteristics and the boundary conditions (pre-processor file). Its output is the value of the unknown quantity at each of the nodes of the grid.

Post processor

The large amount of data is generated in the solution phase (several thousand of nodal values in complex problems). These are often too much to be understood without further processing. The post processor presents the output of the problem in a manner which is easily understood and interpreted by the user.

The post processor performs two tasks:

(i) **Extraction of significant information:** The information may be related to local quantities (magnetic flux density, stress distribution) or global quantities (heat flux, electromagnetic forces, etc.).

(ii) **Synthetic presentation of the numerical data via graphics facilities:** This makes the data more understandable and easier to interpret (stress plots, displacement plots, isothermal plots, temperature Vs time curves, magnetic field along a line, etc.).

Advantages of FEM for Evaluation

- ✓ **Performance Optimization:** Allows fine-tuning of designs to improve performance (e.g., strengthening weak points) before physical fabrication.
- ✓ **Material Efficiency:** Enables the use of optimized, lighter, or alternative materials to meet structural requirements.
- ✓ **Assessment:** Covers varied loading scenarios (static, moving, time-history) to ensure robustness.
- ✓ **Versatility:** Applicable to diverse industries, from structural engineering (concrete, timber) to biomedical devices (prosthetic sockets, stents).

GROUP TECHNOLOGY (GT) CENTRE

Group technology is an operations management philosophy based on the similarities occur in the design and manufacture of various parts. Similar parts can then be arranged into part families. To implement such a system, some form of classification of parts and coding is required.

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 FAMILIES

A part family is a collection of parts which are similar either because of geometry and size or because similar processing steps are required in their manufacture. The parts within a family are different, but their similarities are close enough to merit their identification as members of the part family. The major obstacle in changing over to group technology from a traditional production shop is the problem of grouping parts into families. There are three general methods for solving this problem.

i. Visual inspection

ii. Production flow analysis

iii. Parts classification and coding system

What is desirable in a computer integrated manufacturing environment is a software which will analyze the geometric model of the part and come out with a set of alphabetic/ numeric characters which can broadly embed similarities.

PARTS CLASSIFICATION AND CODING SYSTEMS

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

- Systems based on design attributes
- Systems based on part manufacturing attributes
- Systems based on both design and manufacturing attributes

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
- Fixtures needed

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.

CODING STRUCTURES

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.

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)

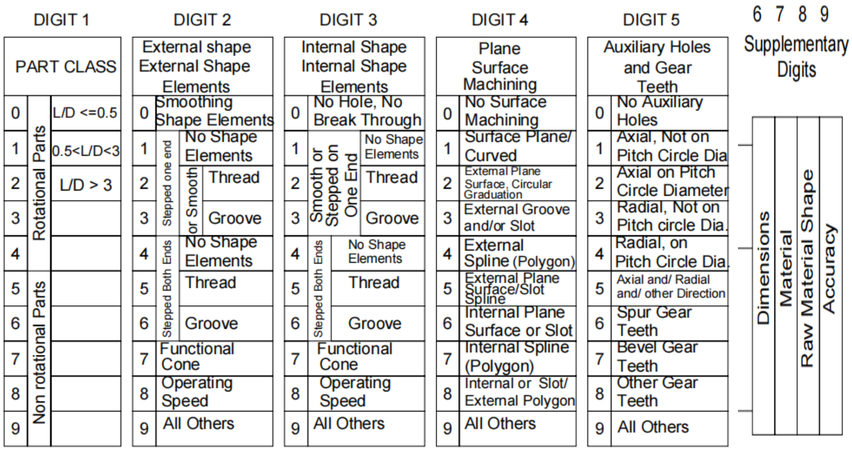
When implementing a parts classification and coding system, most companies can purchase a commercially available package or develop a system for their own specific use.

OPITZ CLASSIFICATION SYSTEM

The Opitz coding system uses the following digit sequence:

12345 6789 ABCD

The basic code consists of nine digits, which can be extended by adding four more digits. The first nine digits are intended to convey both design and manufacturing data. The general interpretation of the nine digits is indicated in Fig. The first five digits, 12345, are called the **"form code"** and describe the primary design attributes of the part. The next four digits, 6789, constitute the **"supplementary code"**. It indicates some of the attributes that would be of use to manufacturing (work material, raw work piece shape, and accuracy). The extra four digits, "ABCD", are referred to as the **"secondary code"** and are intended to identify the production operation type and sequence. The secondary code can be designed by the firm to serve its own particular needs.



Group Technology (GT) Centre is a specialized manufacturing arrangement where similar parts are grouped into families and produced together in a dedicated factory area.

This concept shifts away from traditional machine-oriented layouts, instead organizing machines into "cells" based on the design features or production requirements of specific part families.

Core Functions of a GT Centre

- ✓ **Part Families:** Identifies items with similar design, geometrical shapes, dimensions, or manufacturing processes.
- ✓ **Resource Integration:** Brings together machines, tools, inspection equipment, and skilled operators in one location to handle a particular group of parts.
- ✓ **Process Standardization:** Promotes the reuse of tooling and process knowledge, reducing setup times and material movement.

Key Aspects of GT in CAD/CAM Integration:

- ✧ **Part Families:** Components are grouped by common geometric, size, or manufacturing features.
- ✧ **Classification & Coding:** Parts are assigned codes (e.g., Opitz, MICLASS) to identify, store, and retrieve similar designs, enabling design standardization.
- ✧ **Computer-Aided Process Planning (CAPP):** GT acts as a foundation for CAPP systems, which automatically generate production routes for new parts based on existing, similar families.
- ✧ **Cellular Manufacturing:** Machines are arranged in cells to produce specific part families, reducing material handling and setup time.

Benefits of GT:

1. Increased productivity
2. Improved accuracy in estimation of costs
3. Greater standardization and variety reduction
4. Reduced set up times
5. Better product delivery (Helps to implement just-in-time (JIT) manufacturing)
6. Reduced cost of purchasing
7. Improved plant efficiency

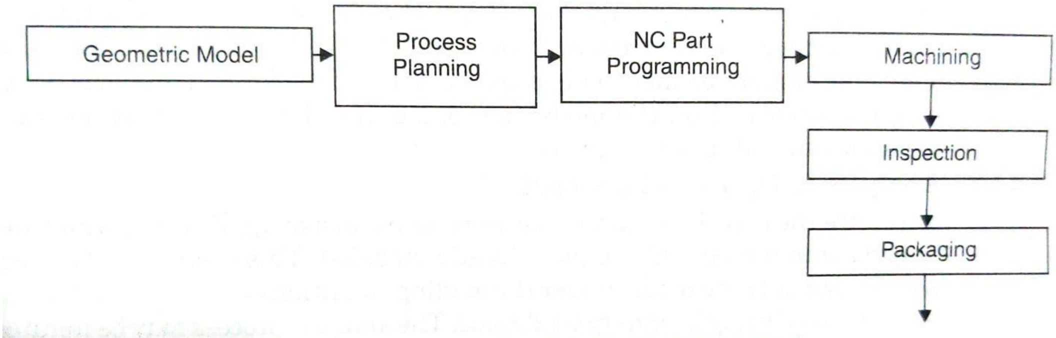
Impact of GT

Before	*After*
Discontinuous, Random Flow of Parts Through the Shop	Structured Flow of Parts
Reinvent New Parts	Retrieve Parts Already in Production
Multitude of Process Plans for Some Parts	Consistent, Single, Best Process Plans
Continuous Purchase of Components due to Lack of Total Visibility	Regulated Purchase of Components
Inflexible, Rigid, Unable to Respond to Changing Environment	Flexible

CHAPTER 3

COMPUTER AIDED MANUFACTURING (CAM)

Computer aided manufacturing includes those activities, which manufacture the product with the product drawing and technical illustration as a input from the CAD and then make the product ready for shipment after inspection and packaging. The various phases of computer aided manufacturing section are as given in figure.



Phases of CAM process

In computer aided manufacturing, the basic information required is actually geometrical information, which is supplied to the CAM processes through the CAD model already generated and analysed.

Interface algorithms in CAM extract that necessary geometrical information from the CAD model and feed it for **process planning, part programming, machining, inspection and packaging.**

Hence the CAM is defined as "A Process of use of computers in planning, manufacturing, inspecting and controlling the manufacturing operation directly or indirectly".

Computer aided Manufacturing (CAM) tool includes following three elements:

1. **CAD Tool:** The basic geometric information of the model is extracted from the geometric model created in the CAD phase of the product cycle. From the model, necessary information regarding the shape, contours and sizes is extracted so as to implement in a manufacturing tool

2. Manufacturing Tool: It describes the method in which the product can be manufactured. This includes generation of part programming and manufacturing (CAM), and computer aided Process planning (CAPP) and tool and cutter design etc.

3. **Networking Tool:** The knowledge of networking and interfaces is required for communication compatibility between various machines and computers. eg.

transferring a part program from one computer to four different machines, controlling a robot from a computer etc.

Computer aided Manufacturing employ computers for two basic purposes:

(Application areas of CAM)

(a) **Computer Monitoring and Control (Direct control):** Where computers are used to control and monitor the applications. The major applications included in this category are:-

- ***Process monitoring and control:*** It is concerned with observing and regulating the production equipment and manufacturing processes in the plant. They include transfer lines, assembly systems, NC, robotics, material handling and flexible manufacturing systems.
- ***Quality control***
- ***Shop floor control***
- ***Inventory control.***
- ***Just-in-time production systems.***

(b) **Manufacturing support applications (Indirect control):** it included those applications which are not controlled directly by computer but are used to support the primary and direct operations. Such applications include:

- ***Computer-aided process planning (CAPP).*** Process planning is concerned with the preparation of route sheets that list the sequence of operations and work centers required to produce the product and its components.
- ***Computer-assisted NC part programming.*** For complex part geometries, computer assisted part programming represents a much more efficient method of generating the control Instructions for the machine tool than manual part programming.
- ***Development of work standards.*** There are several commercially available computer packages for setting work standards. These computer programs use standard time data that have been developed for basic work elements. By summing the times for the individual element of the job, the program calculates the standard time for the job.
- ***Production and inventory planning.*** maintenance of inventory records, automatic reordering of stock items when inventory is depicted. production

scheduling, maintaining correct priorities for the different production orders, material requirements planning, and capacity planning.

Computer-aided line balancing. Finding the best allocation of work elements among stations on an assembly line is a large and difficult problem if the line is of significant size. Computer programs have been developed to assist in the solution of this problem.

COMPUTER AIDED PART PROGRAMMING

- The integration of CAD and CAM has resulted in a radical change in the methodology of NC programming. Today geometry of the component can directly be obtained from the 3-D CAD model and CAM softwares can create the NC program from the geometry data which later on pass to a CNC machine to manufacture a component.
- It is also possible to design and model the fixture set up, design the blank, process plan, select optimum process parameters, and simulate the machining operations on the CAD/CAM workstations to ensure that the program is capable of producing acceptable components.

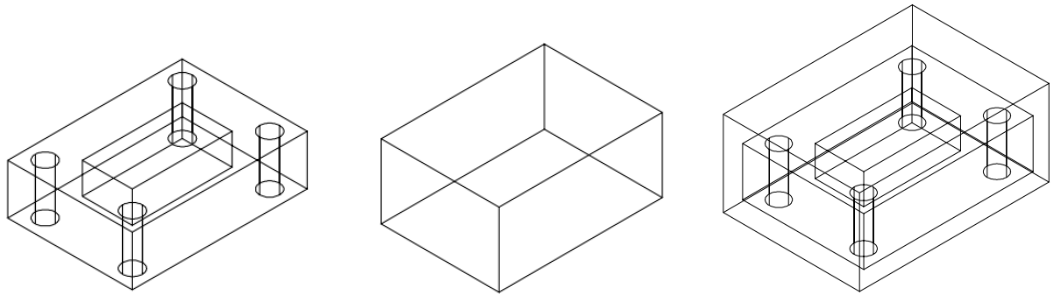
DRAWBACKS FOR MANUAL PART PROGRAMMING

- Manual programming of complex structures/parts is very difficult because of the sheer size and complexity in geometry of parts.
- Mathematical calculations involved in 5-axis contouring is time consuming and tedious.
- A programmer is liable to make mistakes and detection and elimination of mistakes is a time consuming activity.
- Moreover writing NC codes of 20 or 30 thousand lines manually is a stupendous task. These programming operations will involve complex calculations to determine the co-ordinates of points for the positioning of tools.
- Further, errors if undetected will result in enormous wastage in terms of materials and time resulting in over runs in project time and cost.

THE STEPS INVOLVED IN THE PART PROGRAM DEVELOPMENT USING CAM SOFTWARES

CAM software generates an NC program from a CAD model by translating geometric data into machine-readable instructions.

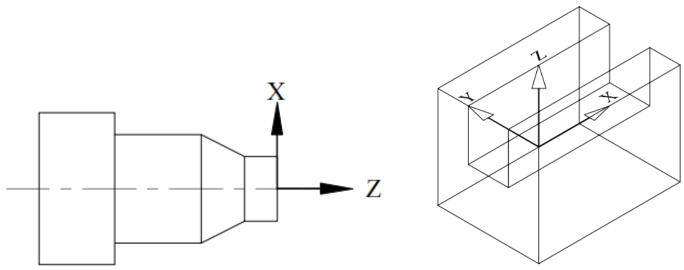
i. Create a manufacturing model from the design model and the workpiece.



Designed model workpiece manufacturing model

Selecting co-ordinate system:

Co-ordinate systems are vital components in manufacturing. They define the orientation of the workpiece on the machine and act as the origin of the CL data generation. The co ordinate system can belong to the workpiece or the design model.



When The CAD profile is imported into CAM.

The software:

- Identifies the X-Z profile
- Defines the axis of rotation
- Prepares geometry for toolpath generation

ii. **Set up the tool database.** Tools must be defined before an operation is performed. Tool libraries can be created and retrieved for a manufacturing operation.

Sample Tool Database Table (Turning)

Tool ID	**Tool material**	**Insert**	**Nose Radius**	**Vc (cutting speed m/min)**	**Feed (mm/rev)**	**ap** (Depth of cut in mm)
T01	carbide	CNMG	0.8	180	0.25	2

iii. **Select the set up for the machining operation.** A component may require more than one set up to complete the machining operation.

The programmer defines:

- ✓ Machine type (3-axis, 4-axis, 5-axis CNC)
- ✓ Work coordinate system (WCS)
- ✓ Stock material size
- ✓ Fixture setup
- ✓ Tool selection (Rough turning tool/Finish turning tool/Grooving tool etc.)

For a turning operation in lathe:

Manufacturing setup includes:

- ➢ Machine type (CNC Lathe / Turn-Mill)
- ➢ Chuck position
- ➢ Work Coordinate System (WCS)
- ➢ Stock diameter and length
- ➢ Safe clearance distances

This step determines the starting reference and work holding condition and it tells the software how the part is positioned and how it will be machined.

iv. Create a machinability database. (selection of parameters)

Cutting parameters are selected based on:Workpiece material, Tool material, Type of operation.

Important parameters:

- ➢ Cutting speed (Vc)
- ➢ Spindle speed (RPM)
- ➢ Feed per revolution (mm/rev)
- ➢ Depth of cut (ap)

Spindle speed is calculated as:

$$RPM = \frac{1000 \times Vc}{\pi \times D}$$

Where:

Vc = Cutting speed (m/min)

D = Workpiece diameter (mm)

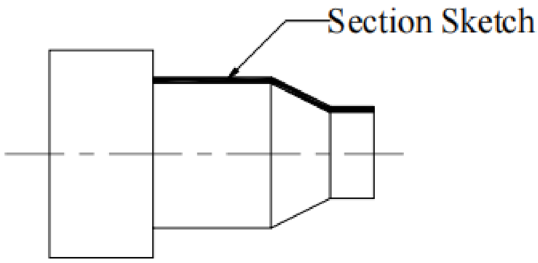
iv. **Create the manufacturing operations to generate the CL data. (cutter location path generation)**

To generate **CL (Cutter Location) data**, we must define structured **manufacturing operations** that translate CAD geometry into tool motion paths. The software calculates the path the tool will follow.

Defining turn profile

The profile (outline) of the workpiece is to be defined in the to generate the tool path. A CAM software provides several facilities to create the profile. Some of the common facilities are:

i. Sketching the profile.



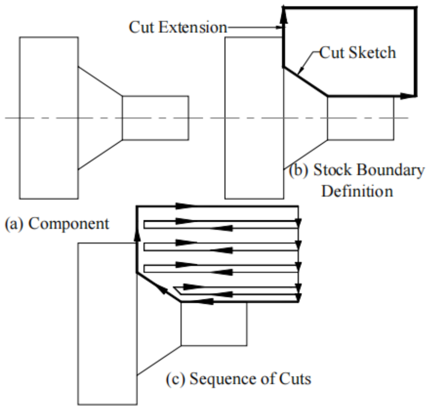
The profile of the cut can be sketched as shown in Fig.

ii. Using surfaces to define a profile

iii. Using a curve to define a turn profile

Stock boundary and area turning

It is often convenient to define the stock boundary and then create the NC sequences through the **area turning approach**. Figure (a) shows a component to be machined. The stock boundary can be defined as shown in Fig. (b). Area turning allows the programmer to define the stock material removed graphically. The tool path will be generated by scanning this area to remove the material step by step. The successive cuts for machining this area are shown in Fig (c).



1. Setup Operation

Purpose: Define machine, coordinate system, and stock.

Inputs: Workpiece diameter & length, Chuck position, Work offset (G54 equivalent), Tool turret configuration

Example CL Data:

```
PARTNO/TURN_PART1
UNITS/MM
MACHIN/TURN
FROM/100,100
```

2. Facing Operation

Purpose: Remove material from front face of workpiece.

Parameters: Tool type: CNMG / VNMG insert, Spindle speed (RPM), Feed rate (mm/rev), Depth of cut

Tool path Logic:

- Rapid to safe position
- Feed in Z direction to center
- Retract

Sample CL Data:
SPINDL/1200,CLW
FEDRAT/0.2,MMPREV
RAPID/60,5
GOTO/0,0
RAPID/60,5

Explanation:

X60 = approach diameter

Z5 = clearance

Z0 = face position

CL data in turning typically contains:

- Tool position (X, Z)
- Feed rate
- Spindle speed

- Motion type (RAPID / GOTO / CIRCLE)
- Tool orientation

3. Straight Turning (Longitudinal Turning)

Purpose: Reduce diameter along length.

Parameters: Initial diameter, Final diameter, Length of cut, Depth of cut (ap), Feed per revolution

Example CL Data:
SPINDL/1000,CLW
FEDRAT/0.25,MMPREV

RAPID/52,2
GOTO/50,0
GOTO/50,-80
RAPID/52,2

RAPID/48,2
GOTO/46,0
GOTO/46,-80
RAPID/48,2

Multiple passes reducing X diameter progressively.

4. Step Turning

Purpose: Create multiple diameters at different lengths.

Example Geometry:

Ø60 for 20 mm

Ø40 for 40 mm

Ø30 for 60 mm

Sequential axial moves with diameter changes.

Sample CL Data:

RAPID/62,2

GOTO/60,0

GOTO/60,-20

GOTO/40,-20

GOTO/40,-60

GOTO/30,-60

GOTO/30,-100

RAPID/62,5

V. Toolpath Simulation and Verification

The CL data can be used to display the tool path. This feature will help to locate errors in the program. The CL data can be edited and modified by rotation, translation, mirroring and scaling.

Before generating NC code, CAM performs simulation to:

- Detect collisions
- Check tool interference
- Verify stock removal
- Prevent tool over-travel

This improves safety and accuracy.

vi. Post-process the CL file to create the NC program.

The CL files require to be modified to generate a NC program to suit a machine tool-control system. This procedure is called post-processing and CAM softwares usually incorporate a software module called **generic post-processor** for this purpose.

Usually the **MACHIN** statement is used to select the post-processor.

A **GENER** statement will retrieve all the necessary information about the CNC controller from the database (e.g., from Fanuc or Siemens). The NC program thus created can be stored, listed or simulated on the screen for editing or modification if needed, or transferred to a CNC machine for production.

Example of Turning G-Code:

G21

G90

T0101

G97 S1000 M03

G00 X60 Z5

```
G01 X50 Z0 F0.25
G01 Z-80
M30
```

CAM PROCEDURE FOR TURNING

Create CAD Profile
(2D X–Z Section)
↓
Import into CAM
↓
Define Setup
(Lathe, WCS, Stock)
↓
Select Tools
(Rough/Finish etc.)
↓
Select Parameters
(Vc, RPM, Feed, ap)
↓
Generate Roughing
Toolpath
↓
Generate Finishing
Toolpath
↓
Simulation &
Verification
↓
Post-Processing
(Generate G-Code)
↓
CNC Machining

COMPUTER AIDED PROCESS PLANNING

PROCESS PLANNING

- Process planning is that function within a manufacturing facility that establishes which machining process, machine tools and process parameters are to be used to convert a work material (blank) from its initial form (raw material) to a final form.
- Process planning is concerned with determining the sequence of individual manufacturing operations needed to produce a given part or product. All the information determined by the process planning function is recorded on a sheet called operation sheet or route sheet.
- The operation sheet is a listing of the production operations and associated machine tools for a work part or assembly. This provides the instructions for the production of the part. It contains the operation sequence, processes, process parameters and machine tools used.

The process planning activity can be divided into the following steps:

1. Selection of processes and tools
2. Selection of machine tools/Manufacturing equipment
3. Sequencing the operations
4. Grouping of operations
5. Selection of work piece holding devices
6. Selection of inspection instruments
7. Determination of production tolerances
8. Determination of the proper cutting conditions
9. Determination of the cutting times and non-machining times (setting time, inspection time) for each operation

Fig shows a typical process planning sheet.

XYZ GLOBAL MANUFACTURING LTD. VELLORE 632014

PART NUMBER : 610 415 3426 **MATERIAL: FG 200**

PART NAME : PIN

Process Number	*Process Details*	*Machine*	*Tool Tip Tool holder*	*Cutting Speed m/min*	*Spindle Speed rpm*	*Feed/ Feed Rate*	*Set Up Time min*	*Process Time min*
01	HOC CC Drill	CNC LATHE						
02	Drill	CNC LATHE						
03	Face & Turn	CNC LATHE						

PROBLEMS IN MANUAL PROCESS PLANNING AND SOLUTION:

In conventional production system, a process plan is created by a process planner.

- It requires a significant amount of time and expertise to determine an optimal routing for each new part design.
- Individual engineers will have their own opinions about what constitutes the best routing.
- There are differences among the operation sequences developed by various planners. Efficient process planning requires the service of experienced process planners.

COMPUTER AIDED PROCESS PLANNING (CAPP)

Computer Aided Process Planning (CAPP) is a manufacturing technology that uses computer systems to **assist in creating process plans** for converting raw materials into finished products. It acts as a bridge between **product design (CAD)** and **manufacturing (CAM)**.

Computer Aided Process Planning (CAPP) is the use of computer software to help engineers determine the **best manufacturing processes, sequence of operations, machines, tools, and parameters** required to produce a part.

It reduces manual effort in process planning and improves consistency and efficiency.

Objectives of CAPP

a) Reduce **process planning time**
b) Improve **production efficiency**
c) Standardize manufacturing methods
d) Reduce **manufacturing cost**
e) Improve **documentation and accuracy**
f) Integrate **design and manufacturing**

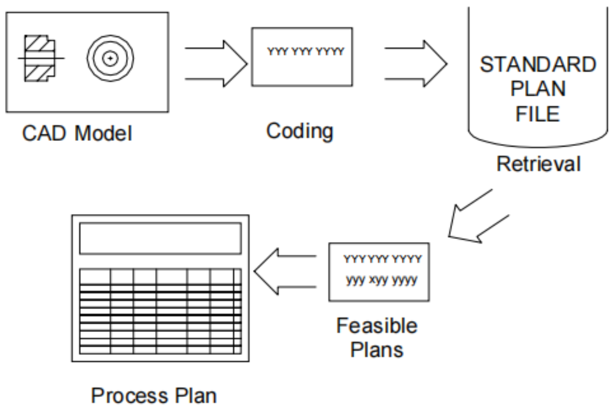
METHODS OF CAPP

i. Variant

ii. Generative

1. Variant CAPP

- ✓ This approach is based on **Group Technology (GT)**.
- ✓ Parts with **similar design and manufacturing features** are grouped into families.
- ✓ A **standard process plan** is prepared for each part family. (A process plan that can be used by a family of components is called a standard plan. A standard plan is stored permanently with a family number as its key.)
- ✓ When a new part is introduced, the system **retrieves the existing plan of a similar part** and **modifies it if necessary**.
- ✓ Relies on classification and coding systems.
- ✓ Easier to implement but **less flexible**.
- ✓ Not suitable for completely new or complex parts.



Steps:

The following are the sequences in the design of a variant process planning system:

i. Family formation

ii. Data base

iii. Search algorithm development and implementation (retrieve process plans for similar components)

iv. Plan editing

v. Process parameter selection/updating

The majority of existing process planning systems is based on variant process planning software. Some of them are: **CAM-I CAPP, MIPLAN, MITURN, MIAPP, UNIVATION, CINTURN, COMCAPPV**, etc.

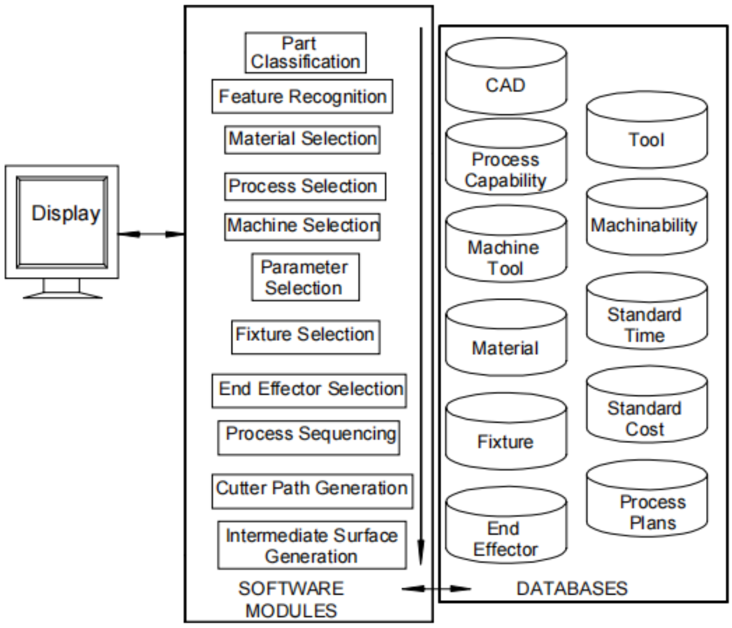
2. Generative CAPP

- ✓ In this approach, the process plan for a new component is **generated automatically by analyzing process information, decision logic, algorithms, and manufacturing databases**.
- ✓ 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.
- ✓ Other planning functions, such as machine selection, tool selection, process optimization, and so on, can also be automated using generative planning techniques.
- ✓ The system **creates a new process plan from scratch** for each part.
- ✓ Uses **knowledge-based systems and decision rules**.
- ✓ Does not rely on previously stored plans.
- ✓ More suitable for **complex and new designs**.
- ✓ Highly flexible and automated.
- ✓ Can optimize process plans.
- ✓ Complex to develop and costly.
- ✓ Requires a large database and detailed rules.

There are some generative software, such as **METCAPP, CPPP, AUTAP, and APPAS.**

<u>STRUCTURE OF A PROCESS PLANNING SOFTWARE</u>

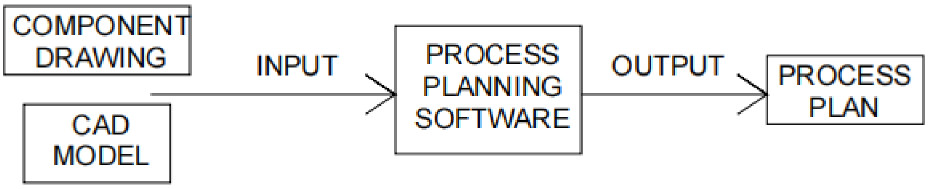
- ❖ Modules are not necessarily arranged in the proper sequence but can be based on importance or decision sequence.
- ❖ Each module may require execution several times in order to obtain the optimum process plan.
- ❖ The input to the system will most probably be a solid model from a CAD data base or a 2-D model.
- ❖ The process plan after generation and validation can then be routed directly to the production planning system and production control system.



Structure of a Computer Aided Process Planning System

❖ The geometric model of the part is the input for the process planning system. The system outputs the process plan. The other prerequisites for process planning are given below:

➢ Parts list
➢ Annual demand/batch size
➢ Accuracy and surface finish requirement (CAD Database)
➢ Equipment details
➢ Data on cutting fluids, tools, jigs & fixtures, gauges
➢ Standard stock sizes
➢ Machining data, data on handling and setup



Activities in Process Planning

BASIC FUNCTIONS OF A COMPUTER AIDED PROCESS PLANNING SOFTWARE

A typical process planning software may provide the following basic functions:

i. Process planning

ii. Initialization function

iii. Report generation

PROCESS PLANNING

- ✓ Create a new plan
- ✓ Retrieve a plan and edit
- ✓ Delete a plan
- ✓ Display plan on monitor
- ✓ List summary information

CREATING A NEW PLAN

Creation of a new plan involves several stages. Fig. shows the header of a typical process plan format. The user has to enter various data as per the above format.

PART NUMBER DRAWING NUMBER	XYZ MANUFACTURING COMPANY	
REV.NUMBER	Note:	
IGES/STEP FILE No:	Classification Code	Material:
PLAN REV. No:	Quantity:	Standard Plan ID
MACHINING TIME	Unit Cost:	

Format of Header for Process Plan

The manufacturing sequence is entered in a suitable format. A typical format is given in Table.The process plan gives each operation to be performed in sequence.

Serial Number	***Machine***	***Operation Description/ Assembly Operations***	***Set Up Time***	***Production Time***	***Tool***	***Cutting Speed m/min***	***Feed/ Feed rate***	***rpm***	***Number of cuts/ Passes***
04	CNC Lathe	Turning	-	2	P40	240	0.5mm/ rev.	1400	4
05	”	Drilling	-	0.2	BW Drill	200	0.2mm/ rev.	2200	1

Format of Manufacturing Sequence

The example given is for turning and drilling a workpiece. The machine, tool and the technology parameters are specified in the process plan.

Some process plans will also give the inspection tool details, jigs and fixtures to be used and will have a column for remarks, which may contain some instructions to the operator.

The process planning software provides some standard strings that are to be used when describing operations. Some examples are given below:

i. Hold between centres

ii. Rough turn …….. dia. stock to …….. dia.. for entire length of part

iii. Rough turn …….. dia. to ……… dia..

iv. Finish turn ……… dia. to ……… dia.

v. Finish face …….. dia. and chamfer.

RETRIEVAL OF PLANS

Retrieval of plans is an important step in **Variant CAPP systems**. In this method, an **existing standard process plan is retrieved from a database and modified** to create a new plan for a similar part.

Example

Suppose a company already has a process plan for a **cylindrical shaft**.

If a new shaft with slightly different **diameter or length** is designed:

- ✓ The system retrieves the **existing shaft process plan**.
- ✓ The planner only adjusts parameters like **cutting speed, dimensions, or operations**.

This saves a lot of time compared to creating a plan from scratch.

SUMMARY INFORMATION

Summary information in **Computer Aided Process Planning (CAPP)** refers to the **general overview or condensed information of a process plan** that gives the essential details required for manufacturing a part.

It provides a **brief description of the operations, machines, tools, and processing sequence** without going into very detailed instructions.

The summary information generally includes:

a) **Part identification:** Part name, Part number, Material type
b) **List of operations:** Major manufacturing operations required to produce the part.
c) **Machine tools required:** Types of machines used (lathe, milling machine, drilling machine, etc.).
d) **Sequence of operations:** The order in which operations must be performed.
e) **Estimated production time:** Approximate time required for each operation.
f) **Tooling information:** Major cutting tools or fixtures needed.

Automatic time standard system (calculation of machining time)

Process planning software will have several modules. One such module is the **automatic time standards system**.

Time standards are based on cutting conditions used and therefore calculation of machining time requires selection of cutting parameters.

Typical input data for such a system is:

Material : C45

Material hardness : 220 BHN

Work Centre Number : L 120

The software displays available tool materials:

i. Coated Carbide

ii. Ceramic

iii. Cubic Boron Nitride

iv. Diamond coated tools

From the CAD model and operation description, dimensions will be retrieved (like starting diameter, finish diameter, cut length and depth of cut).

It also calculates number of passes, displays recommended values of depths, spindle speeds, power required and machining time. These data can be edited manually if necessary. Similarly there may be modules for time calculation for loading and unloading.

REPORT GENERATION

Report generation is the **automatic creation of process planning documents from the CAPP system database**, which include information about plan, operations, machines, tools, materials, and production instructions.

- Converts stored process planning data into **readable documents**
- Provides **clear instructions for production**
- Helps in **production scheduling and control**
- Supports **quality control and documentation**

Types of Reports Generated in CAPP

1. **Process Plan Report:** Shows the complete sequence of manufacturing operations.
2. **Operation Sheet:** Details of each operation such as machining steps and parameters.
3. **Tool List:** List of cutting tools, fixtures, and gauges required.
4. **Machine Requirement Report:** Information about machines needed for each operation.
5. **Time Estimation Report:** Estimated machining time and production time.
6. **Cost Estimation Report:** Approximate cost involved in manufacturing the part.

COMPUTER AIDED MATERIAL REQUIREMENTS PLANNING (MRP)

Computer Aided MRP is a computerized technique used to **calculate the quantity and timing of raw materials, components, and subassemblies required for production** based on production schedules.

Material Requirements Planning (MRP) is a **computer-based system used to plan and control inventory and production processes**. It helps determine **what materials are needed, how much is needed, and when they are needed** for manufacturing.

It uses information from the bills of material, inventory, shop and purchase orders, and the master schedule to draw a detailed material requirements plan.

Objectives of MRP

The main objectives of MRP are:

- **Ensure availability of materials** for production and delivery.
- **Maintain minimum inventory levels** to reduce storage costs.
- **Plan manufacturing activities efficiently.**

❖ **Schedule purchasing and production operations.**

INPUTS TO MRP SYSTEM

The MRP system uses three main inputs:

1. Master Production Schedule (MPS)

- ✓ The master schedule is a macro level document which sets top-level priorities for what will be manufactured and when, looking at the material that will be required over the production cycle.
- ✓ Master production schedule provides great flexibility in reflecting the overall production plans of management, allowing planned production to be based on predicted demand.
- ✓ The master production schedule becomes a direct input to the material requirements planning (MRP) function, which determines the material needed at each work centre location in order to meet the master production schedule.
- ✓ Shows **what products need to be produced and when**.
- ✓ It is based on customer orders and demand forecasts.

2. Bill of Materials (BOM)

- ✓ A **detailed list of all the raw materials, components, and subassemblies** required to manufacture a product. It also includes the **quantity of each item needed and their relationship in the product structure**.
- ✓ In **Material Requirements Planning (MRP)** and **Computer Integrated Manufacturing (CIM)**, the BOM acts as a **product structure file** that helps determine the materials needed for production.
- ✓ **Bill of Materials (BOM)** is a **structured list of components, raw materials, and assemblies required to produce one unit of a finished product.**

3. Inventory Records

Information about **current stock levels**, lead times, and orders already placed.

WORKING OF COMPUTER AIDED MRP

The computer processes the input data and performs the following steps:

- ✓ **Determine total material requirements** from the production schedule.
- ✓ **Check available inventory** in stock.
- ✓ **Calculate net material requirements** after subtracting available stock.
- ✓ **Schedule purchase or production orders** considering lead time.

The system automatically generates **purchase orders and work orders**.

OUTPUTS OF MRP SYSTEM

Typical outputs include:

- ➢ **Planned order releases**
- ➢ **Purchase order schedules**
- ➢ **Work order schedules**
- ➢ **Inventory status reports**
- ➢ **Exception reports** (delays or shortages)

CHAPTER 4

Computer Aided Production Scheduling (CAPS)

Computer Aided Production Scheduling is a technique that uses computers to allocate resources, sequence jobs, and determine the timing of operations to achieve efficient production with minimum cost and in due time.

CAPS is the process of **organising, timing, and sequencing** manufacturing tasks to ensure that resources like **labor, machinery, and raw materials are used as efficiently as possible**. While **CAPP** sets high-level targets for "what" and "how much" to make, production scheduling focuses on the granular "when" and "where" of daily shop-floor operations.

It is the process of deciding **when, where and in what order jobs will be processed on available machines** to achieve optimal utilization of resources and meet delivery deadlines.

Factors to be considered:- **machine capacity, labor availability, materials, and due dates.**

Objectives of CAPS:

a) To minimize total production time
b) To ensure timely delivery of products
c) To maximize machine and labor utilization
d) To reduce idle time and work-in-progress
e) To improve overall productivity

Inputs to CAPS:

- Bill of Materials (BOM)
- Process plans (from CAPP)
- Machine availability and capacity
- Workforce details
- Order priorities and due dates
- Inventory and material status

Functions of CAPS:

- ❖ **Loading**

  Allocation of jobs to machines or work centers based on their capacity and availability.
- ❖ **Sequencing**

  Determining the order in which jobs or operations are to be processed on each machine.
- ❖ **Scheduling**

  Fixing the start and finish times for each operation to ensure timely completion of jobs.
- ❖ **Dispatching**

  Releasing production orders and instructions to the shop floor for execution.
- ❖ **Monitoring**

  Continuously tracking the progress of jobs and comparing actual performance with the planned schedule.
- ❖ **Control**

  Taking corrective actions (like rescheduling or reallocation) when deviations from the plan occur.
- ❖ **Resource Allocation**

  Efficient assignment of machines, tools, and manpower to different tasks.
- ❖ **Data Management**

  Collecting, storing, and processing production-related data for accurate scheduling.

<u>Techniques Used:</u>

1. **Heuristic Methods**

   Heuristic methods are simple, rule-based approaches used to obtain quick and practical solutions for scheduling problems. They do not guarantee the optimal solution but provide satisfactory results within a short time.

Examples:

- ➢ **FCFS (First Come First Serve)**

  Jobs are processed in the order they arrive.

  Simple but may lead to longer waiting times.
- ➢ **SPT (Shortest Processing Time)**

  Job with the shortest processing time is handled first.

  Minimizes average waiting time.

- **EDD (Earliest Due Date)**

  Job with the earliest due date is processed first.

  Helps in meeting delivery deadlines.
- **LPT (Longest Processing Time)**

  Job with the longest processing time is processed first.

  Useful in balancing machine loads.
- **CR (Critical Ratio)**

  Priority is based on ratio:

  CR=Time remaining until due date/Processing time remaining

  Helps identify urgent jobs.

2. **Mathematical Optimization Techniques**

   Use mathematical models to find the best possible schedule.

   Examples:

- Linear Programming (LP)
- Integer Programming (IP)
- Dynamic Programming

3. **Network-Based Methods**

   Techniques like:·

- PERT (Program Evaluation and Review Technique)
- CPM (Critical Path Method)

Outputs of CAPS:

- Detailed production schedules
- Machine-wise job allocation
- Operation start and completion times
- Performance and utilization reports

Advantages:

- ✓ Improves efficiency and productivity

- ✓ Reduces production delays
- ✓ Better utilization of resources
- ✓ Quick response to changes
- ✓ Accurate and reliable scheduling

Limitations:

- ✓ High initial investment
- ✓ Requires accurate and updated data
- ✓ Complex system implementation
- ✓ Dependence on computer systems

Problems In Traditional Quality Control:

- ❖ Quality control, which includes inspection, measurement and testing, is a vital part of any manufacturing activity and is applied to ensure consistently high quality in manufactured goods.
- ❖ The quality control (QC) function has traditionally been performed using manual inspection methods and statistical sampling procedures.
- ❖ Manual inspection is generally a time consuming procedure, which involves precise, yet tedious work. Parts may have to be removed from the production machines to a separate inspection area. This causes delays and often obstructs smooth flow of the components through different processes.
- ❖ The use of statistical sampling procedures have the risk that some defective parts will slip through.
- ❖ There is another aspect of statistical QC inspection process, which detracts it from its usefulness. It is often performed after the parts are already made. If the parts are defective they must be scrapped or reworked at an additional cost.

Computer integrated manufacturing attempts to solve these problems in a different way. This concept is called **total quality management.**

QC AND CIM

- ➢ A wide range of computer-based instrumentation is being used for quality control. In particular the increased use of sensors and transducers, which are part of CIM, is making it easier to carry out **pre-process, in-process, and post-process inspection.**

- The incorporation of digital techniques in manufacturing systems and the use of computers and microprocessors have resulted in the introduction of several types of inspection techniques.
- In modern manufacturing systems, inspection is no longer considered as an appraisal oriented process (ACCEPTED/ REJECTED) but as **prevention oriented process.**
- At present, inspection with the use of computers has acquired a status of its own known as **COMPUTER AIDED INSPECTION (CAI)** and is an integral part of CIM.

COMPUTER AIDED INSPECTION (CAI)

- **Computer Aided Inspection (CAI)** is the use of computer systems and software to perform inspection and quality control of manufactured components by comparing measured data with design specifications.
- For a mechanical component, this would be probably concerned with the dimensions, surface texture and tolerances specified for the part.
- CAI is able to track the production process and has the potential for providing information to implement corrective action before the process goes out of control.
- CAI can be carried out by both contact type and non-contact type inspection which can collect the data not only to qualify a component but also to correct the manufacturing process that may cause undesirable deviation.

Working of Computer Aided Inspection (CAI)

The working principle of CAI is based on **measuring the actual part and comparing it with the CAD model or design specifications** to detect deviations.

Steps Involved

1. **CAD Model Input** : The design data (geometry, dimensions, tolerances) is taken from the CAD system as a reference.
2. **Data Acquisition** : Measurement of the physical part is carried out using devices like **CMM, laser scanners, or probes**.

3. **Data Processing** : Collected measurement data is processed and converted into digital form.
4. **Alignment and Comparison** : The measured data is aligned with the CAD model. Actual dimensions are compared with nominal (design) values.
5. **Deviation Analysis** : Differences between measured and design values are calculated. Tolerances are checked to determine acceptability.
6. **Result Visualization** : Results are displayed using graphs, color maps, or deviation charts.
7. **Report Generation** : Inspection reports are generated, including errors, tolerances, and quality status.

Types of Computer Aided Inspection (CAI)

1. Contact Inspection

- Uses physical contact with the workpiece
- Performed using devices like **Coordinate Measuring Machine (CMM)**
- High accuracy but slower process
- Suitable for precision components

2. Non-Contact Inspection

- No physical contact with the part
- Uses **laser scanners, vision systems, optical sensors**
- Faster inspection and suitable for delicate or complex shapes
- Slightly less accurate than contact methods

Types of Inspection Software

1. **CMM Software (Coordinate Measuring Machine Software)**
    1. Used with CMMs for precise dimensional measurement
    2. Controls probe movement and data collection
    3. Example: *PC-DMIS, ZEISS Calypso*
2. **3D Inspection / Metrology Software**

    1. Analyzes 3D scanned data and compares it with CAD models
    2. Generates deviation maps and surface analysis
    3. Example: *Geomagic Control, PolyWorks*

3. **Vision Inspection Software**

    1. Used in camera-based and optical inspection systems
    2. Performs image processing and feature detection
    3. Suitable for small and delicate components

4. **Statistical Process Control (SPC) Software**

    1. Performs statistical analysis of inspection data
    2. Uses control charts, histograms, and trend analysis
    3. Helps in quality improvement and process control

COMPUTER AIDED INSPECTION PLANNING (CAIP)

Computer Aided Inspection Planning (CAIP) is a system that uses computers to plan, design, and optimize inspection processes in manufacturing. It ensures that products meet quality standards efficiently by automating inspection planning activities.

Computer-Aided Inspection Planning (CAIP) is the use of computer software and systems to **automate the creation of inspection plans** for manufactured parts. It serves as a vital bridge between **Computer-Aided Design (CAD)** and the physical inspection process, ensuring that products meet specified quality standards with minimal manual intervention.

It replaces manual, time-consuming inspection planning with a software-driven process that defines the most efficient sequences and paths for measuring instruments like **Coordinate Measuring Machines (CMMs)** or **On-Machine Measurement (OMM)** systems.

CAIP is the application of computer technology to generate inspection plans, select inspection methods, and determine measurement procedures based on product design and specifications.

Objectives

- Ensure product quality and accuracy

- Reduce inspection time and cost
- Minimize human error
- Improve consistency in inspection
- Integrate inspection with CAD/CAM systems

CAIP systems typically automate following main tasks to generate an actionable inspection routine:

a. **Feature Extraction:** Automatically identifies critical geometries (holes, surfaces, slots) and their associated tolerances (dimensions, flatness, etc.) from a CAD model.

b. **Inspection Sequencing:** Determines the optimal order in which features should be inspected to minimize movement and tool changes.

c. **Path Planning:** Generates collision-free paths for measurement probes, ensuring the sensor can reach all necessary points without hitting the part or fixture.

d. **Sensor & Strategy Selection:** Selects the appropriate measuring tool (e.g., touch probes or non-contact laser scanners) and the number of points to be sampled for accurate verification.

e. **Code Generation:** Outputs the final plan into standardized formats like **DMIS** (Dimensional Measuring Interface Standard) or **STEP-NC** to be executed by measuring hardware.

Components of Computer Aided Inspection Planning (CAIP) System

1. **CAD Model Input:** Provides product design data (geometry, dimensions, tolerances). Forms the base for inspection planning.
2. **Feature Recognition Module** : Extracts and identifies important geometric features (holes, slots, surfaces) from the CAD model.
3. **Database** : Stores inspection standards, tolerance data, rules, and past inspection information. Helps in decision-making.
4. **Knowledge Base / Decision Logic** : Contains rules, algorithms, or AI techniques to select inspection methods and strategies.
5. **Inspection Planning Module** : Core component that generates inspection plans, selects tools, and defines procedures.

6. **Inspection Method Selection Module** : Chooses suitable inspection equipment like CMM, gauges, or optical systems.
7. **Sequencing Module** : Determines the optimal order of inspection operations for efficiency.
8. **Program Generation Module** : Generates NC/CMM programs for automated inspection machines.
9. **User Interface** : Allows interaction between user and system for input, editing, and control.
10. **Output Interface / Reporting Module** : Produces inspection plans, reports, and documentation.

Steps in Computer Aided Inspection Planning (CAIP)

1. **Input of CAD Model** : The product design (geometry, dimensions, tolerances) is imported into the CAIP system.
2. **Feature Extraction / Recognition** : Important geometric features such as holes, slots, and surfaces are identified from the CAD model.
3. **Identification of Inspection Requirements** : Critical dimensions, tolerances, and quality requirements are determined.
4. **Selection of Inspection Methods** : Suitable inspection techniques (CMM, gauges, vision systems) are chosen based on accuracy and feature type.
5. **Selection of Inspection Equipment** : Appropriate instruments and tools are selected for measurement.
6. **Determination of Inspection Parameters** : Measurement points, probe paths, speed, and accuracy levels are defined.
7. **Inspection Sequencing** : The optimal order of inspection operations is decided to improve efficiency.
8. **Generation of Inspection Plan** : A detailed inspection plan is created including procedures, tools, and standards.
9. **Program Generation (CMM/NC)** : Automated programs are generated for inspection machines.
10. **Output and Documentation** : Inspection reports, instructions, and quality records are produced.

CAIP systems are generally categorized by :

1. **By Equipment Type**:

   Coordinate Measuring Machines (CMMs): The coordinate measuring machine (CMM) is the most prominent example of the equipment used for contact inspection of parts. When used for CIM these machines are controlled by CNC.

   On-Machine Inspection (OMI): Using the same CNC machine that cut the part to perform the inspection, which eliminates the need to re-clamp the workpiece.

2. **By Planning Logic**:

   Tolerance-Driven: Focuses strictly on features with specific **Geometric Dimensioning and Tolerancing (GD&T)** requirements.

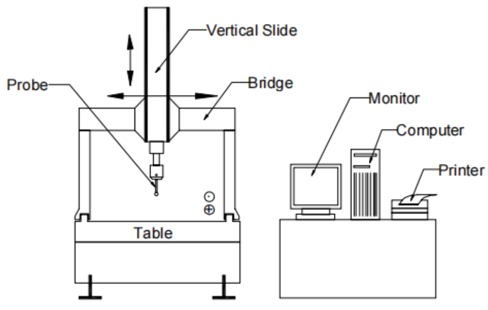
   Geometry-Based: Compares the entire physical geometry of the part against the original CAD model, often used with **3D laser scanners**.

Coordinate Measuring Machine (CMM)

A **Coordinate Measuring Machine (CMM)** is a precision measuring device used to determine the **geometrical characteristics of an object** by measuring coordinates (X, Y, Z) of points on its surface.

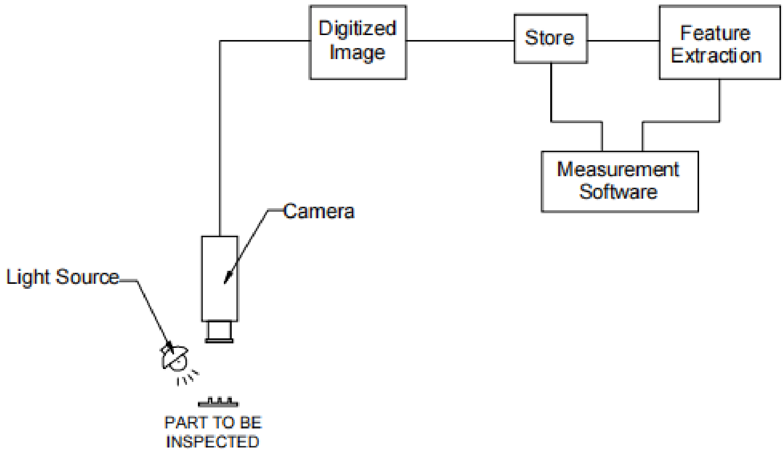
Working Principle

- The probe of the CMM touches or scans the surface of the workpiece.
- The machine records the **exact coordinates (X, Y, Z)** of each point.
- These measured points are compared with the **CAD model or design specifications**.
- Deviations and tolerances are calculated to check accuracy.



Main Components of CMM

1. **Machine Structure** : Frame (bridge, cantilever, gantry type) providing support
2. **Probe System** : Touch trigger probe or scanning probe used for measurement
3. **Drive System** : Moves the probe along X, Y, Z axes
4. **Measuring System (Scales)** : Measures displacement with high precision
5. **Control System** : Controls machine movements (manual or CNC)
6. **Computer & Software** : Processes data and generates inspection reports



Non-contact Vision inspection method

Industry-Leading CAIP & Metrology Softwares:

For **Computer-Aided Inspection Planning (CAIP)**, several high-performance software tools are available that integrate with **CAD**, **CMM** (Coordinate Measuring Machines), and **OMM** (On-Machine Measurement). These tools automate the creation of measurement routines directly from digital models.

Examples: **Hexagon PC-DMIS, Zeiss CALYPSO, Verisurf 2026, Renishaw MODUS, SOLIDWORKS Inspection Professional 2026, Autodesk Fusion, Metrology Mentor, Siemens NX**

Economic Order Quantity

Economic Order Quantity (EOQ) is an inventory management technique used to determine the optimal order quantity that minimizes the total cost of ordering and holding inventory.
It is the ideal order size a company should purchase to minimize total inventory costs, including holding and ordering costs.

EOQ helps in deciding how much quantity should be ordered each time so that the sum of: (Ordering Cost + Holding Cost) is minimum.

EOQ Formula:

$$\text{EOQ} = \sqrt{\frac{2DS}{H}}$$

D - Annual Demand: The number of units expected to be sold or used in a year.

S - Order Cost: The fixed cost per order, including shipping, handling, and processing.

H - Holding Cost: The cost of storing inventory per unit per year, including warehousing, insurance, and damages.

Example: If a company has an annual demand of 10,000 units, an order cost of 100/- per order, and a holding cost of 2/- per unit per year

$$\text{EOQ} = \sqrt{\frac{2 \times 10,000 \times 100}{2}} = \sqrt{\frac{2,000,000}{2}} = \sqrt{1,000,000} = 1,000 \text{ units}$$

ABC Analysis

ABC analysis is an inventory categorization technique that prioritizes stock items based on their **value and importance** to a business. It is rooted in the **Pareto Principle** (the 80/20 rule), which suggests that roughly 20% of items generate 80% of total revenue.

It classifies inventory items into three categories (A, B, and C) according to their importance, usually based on annual consumption value.

Classification of Items

1. **Category A (High Value Items)**

- ✓ About 10–20% of total items
- ✓ Contribute around 70–80% of total inventory value
- ✓ Require strict control, precise forecasting and continuous monitoring

2. **Category B (Moderate Value Items)**

- ✓ About 20–30% of items
- ✓ Contribute around 15–25% of value
- ✓ They require moderate monitoring and regular reviews.

3. **Category C (Low Value Items)**

- ✓ About 50–70% of items
- ✓ Contribute only 5–10% of value
- ✓ Require simple control

Steps in ABC Analysis

1. Calculate annual consumption value (AV = Unit cost × Annual units sold)
2. Arrange items in descending order of value
3. Calculate the percentage of total value each item represents and its cumulative total across the entire inventory.
4. Group the top performers into Class A, the next tier into B, and the remainder into C.

Supply chain management:

Most prominent companies have an efficient Supply Chain Management (SCM): from finding reliable sources of supply to distributing their end products. Activities are mainly the procurement of materials, the transformation of these materials into intermediate and finished products, and the distribution of finished products to end-users.
Supply Chain Management (SCM) is concerned with the integrated management of the flow of goods and information through the supply chain so as to ensure that the right goods are delivered in the right place and quantity at the right time.

Flow in Supply Chain

Material Flow: Supplier → Manufacturer → Distributor → Retailer → Customer

Information Flow: Customer demand → Backward through chain

Financial Flow: Customer → Retailer → Distributor → Manufacturer → Supplier

Just In Time (JIT)

Just-In-Time (JIT) is a production and inventory management technique where materials are purchased and goods are produced **only when needed**, in the exact quantity required, and at the right time.

JIT is a system that aims to **minimize inventory levels** by receiving goods only as they are needed in the production process.

Working of JIT

- Customer places an order
- Production starts only after order is received
- Raw materials are ordered just in time
- Goods are produced and delivered immediately

Reorder Point (ROP)

The **Reorder Point (ROP)** is the specific inventory level that signals it is time to place a new order for the product. In a computer-aided system, hitting this number triggers an automated purchase alert to prevent a **stockout.**

$$ROP = (Average\ \ Demand \times Lead\ \ Time) + Safety\ \ Stock$$

Average Demand (D) – Daily or weekly consumption
Lead Time (L) – Time between placing and receiving order
Safety Stock (SS) – Extra stock to handle uncertainty

Average daily demand = 50 units

Lead time = 4 days

Safety stock = 20 units

ROP = $(50 \times 4)+20 = 220$ units

When inventory reaches **220 units**, a new order should be placed.

COMPUTER AIDED INVENTORY PLANNING

Computer-aided inventory planning (CAIP) uses specialized software and digital technologies to automate the process of determining optimal stock levels, forecasting demand, and scheduling restocking.
It is the use of software and digital technologies such as ERP systems, AI, and barcode scanners ***to automate, track, and optimize inventory levels.***

It replaces manual processes, like spreadsheets, with **a centralized system** that offers:

- ❖ Real-time visibility of inventory,
- ❖ Automated reordering,
- ❖ Data-driven demand forecasting,
- ❖ Helping businesses reduce holding costs,
- ❖ Avoid stockouts,
- ❖ Improve efficiency.

Functions of Computer-Aided Inventory Planning

a) ***Real-Time Tracking & Visibility:*** Systems provide instant updates on stock levels across multiple locations using **barcode scanning or Radio Frequency Identification**, ensuring accuracy in stock counts.

b) ***Automated Demand Forecasting:*** Software algorithms analyze historical data and market trends to predict future demand, allowing for proactive stocking.

c) ***Automated Reordering & Replenishment:*** Determines **when to order** and **how much to order** using techniques like EOQ and Reorder Point. When stock falls below pre-set levels (**reorder points**), the software automatically generates purchase orders/requisition.

d) ***Inventory Optimization:*** Advanced AI tools calculate optimal stock levels for stock keeping units, considering variability in supply and demand to reduce inventory investments (often by 25–35%).

e) ***ABC Analysis:*** Computer tools automatically classify inventory based on value (A, B, C) to prioritize management attention on high-value items.

f) ***Data Storage and Management***

Maintains a centralized database of inventory records, transactions, and supplier details.

g) ***Cost Analysis and Optimization***

Evaluates ordering cost, holding cost, and shortage cost to minimize total inventory cost.

h) ***Reporting and Decision Support***

Generates reports (stock status, demand trends, turnover rate) to support managerial decisions.

i) ***Integration with Other Systems***

Integrates with ERP, MRP, and SCM systems for smooth information flow across departments.

Steps in CAIP

1. Data collection (demand, stock levels, lead time)
2. Demand forecasting
3. Inventory analysis (ABC, EOQ, etc.)
4. Decision making (order quantity & timing)
5. Implementation (placing orders)
6. Monitoring and control

Techniques Used in CAIP

- EOQ (Economic Order Quantity)
- ABC Analysis
- Safety Stock Calculation
- Reorder Point (ROP)
- Just-In-Time (JIT)

Benefits

- **Accuracy and reliability**: Using barcode scanning eliminates the 41.4% of errors typically associated with manual entry.
- **Cost Savings**: Proper planning prevents unnecessary purchases and reduces the capital tied up in slow-moving stock.
- **Scalability**: Computerized systems can handle hundreds of thousands of stock keeping units across multiple warehouse locations.
- **Faster processing of information**
- **Reduced human error**
- **Better inventory control**
- **Improved coordination**

computer-aided inventory planning (CAIP) software

Computer Aided Inventory Planning (CAIP) software helps industries manage inventory efficiently by automating stock control, forecasting, ordering, and reporting.

1. SAP (ERP – SAP MM Module)

- Widely used in large industries
- Handles procurement, inventory control, and material planning
- Features:
    - Real-time stock tracking
    - Automatic reorder (ROP)
    - Supplier management

2. Oracle ERP (Oracle SCM Cloud)

- Advanced inventory and supply chain management
- Features:
    - Demand forecasting
    - Inventory optimization
    - Automated replenishment

3. Microsoft Dynamics 365

- Suitable for medium to large enterprises
- Features:
    - Warehouse management
    - Inventory tracking
    - Integration with finance and sales

4. Tally ERP

- Popular in small and medium businesses (especially in India)
- Features:
    - Basic inventory control
    - Stock management
    - Order tracking

Key Features of CAIP Software

- Real-time inventory tracking

- Automatic reorder level (ROP) calculation
- Demand forecasting
- EOQ and ABC analysis
- Reporting and analytics
- Integration with ERP and SCM systems

FLEXIBLE MANUFACTURING SYSTEM (FMS)

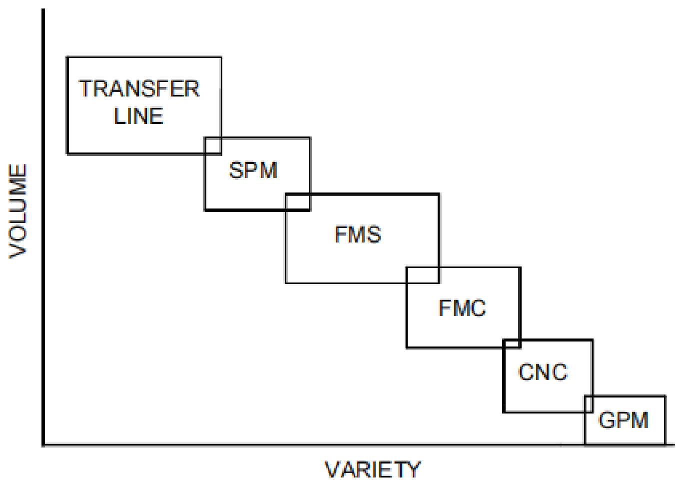
Flexibility – Flexibility is characterized by the system's ability to adapt to changes in the volumes in the product mix and of the machining processes and sequences. This means that a FMS will be able to respond quickly to changing market and customer demands.

A **Flexible Manufacturing System (FMS)** is a highly automated production method that can readily adapt to changes in the type and quantity of goods being manufactured.

A **Flexible Manufacturing System (FMS)** is a highly automated production system consisting of a group of CNC machines, material handling systems and computer control that can manufacture a variety of products with minimal human intervention.

It is designed to manufacture **different types of products efficiently with minimal changeover time**. FMS provides flexibility to handle variations in product design, production volume, and manufacturing processes.

FMS is best suited for applications that involve an intermediate level of flexibility and low or medium quantities. Fig. shows the different types of production systems and it can be seen from the figure that FMS fits into the intermediate range of production.



Types of production systems

FLEXIBLE MACHINING SYSTEMS

1. Flexible Machining Systems consists of ***several flexible automated machine*** tools of the ***universal or special type*** which are interlinked by an ***automatic workpiece flow system.***

2. Here different workpieces can be machined and different operations can be performed with the same machine configuration. Flexibility is applied to machines because of CNC control and flow of products from one machine to another which is possible through flexible transport system.

3. Flexibility is characterized by the system's ability to adapt to changes in the volumes in the product mix and of the machining processes and sequences. This means that a FMS will be able to respond quickly to changing market and customer demands.

COMPONENTS OF FMS

There are three major subsystems in FMS:

(i) Computer-controlled manufacturing equipment (e.g. numerically controlled machine tools, robots, gantry loaders, palletizing systems, washing stations, tool pre-setters, in-process inspection systems etc.)

(ii) Automated materials handling and storage system

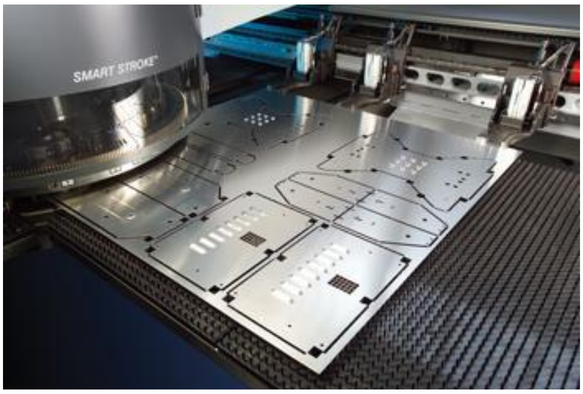
(iii) Manufacturing control system (including both machine tool, tool and logistics control)

Some FMS's have additional subsystems. For example, in a machining application there may also be systems for presetting tools, storing and retrieving tools, disposing of chips and cutting fluids, washing and inspection workpieces. These subsystems must be linked together to achieve integrated manufacturing operation.

1. ***COMPUTER CONTROLLED MANUFACTURING EQUIPMENT***

The production equipment used in FMS depends upon the product manufactured.

(i) ***FMS for sheet metal work:*** The work centres used in sheet metal FMS include turret punch presses, laser machining centres, press brakes, shearing machines etc. A typical FMC consists of sheet stacking system, sheet unloading device, turret punch press, right angle shear, loading device and automatic storage.



turret punch press

(ii) ***FMS for machining:*** This type of FMS typically has a number of machining centres and/or turning centres. Machining centers offer the greatest flexibility, since they can perform many different machining operations. (e.g. milling, drilling, and boring). This is made possible by a tool changing system that is either built into or supports the machining centre. A part can therefore undergo multiple machining processes at a single workstation. Special purpose machines may also be included in the FMS to perform operations which are unique or require more efficiency. Washing machines and inspection machines also form the equipment of FMS.

(iii) **Assembly workstations:** consists of a number of workstations with industrial robots that sequentially assemble components of the base parts.

(iv) **Inspection stations:** the parts manufactured are inspected here for quality purpose.

(v) Support systems : Automated machine tools typically require several systems to support their operation. Ex: ***Central tool facility system*** which can perform:

(i) Measurement of tool wear

(ii) Tool pre-setting

(iii) Tool regrinding, repair and maintenance

(iv) Replacement of broken or worn tools

Automated machining operations also need to have the chips cleaned off the workstation and the workpiece. This may be performed by robots or special washing stations. Cleaning may involve turning the workpiece over, vacuuming and washing.

2. MATERIAL HANDLING AND STORAGE SYSTEMS:

a) A transport system to move workpieces into and out of the FMS (e.g. overhead conveyors, gantry systems, AGVs)
b) A buffer storage system (temporary holding area) for queues of workpieces at the machines (e.g., pallets)
c) A transfer system to load and unload at 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).

A key part of any materials handling system is storage. Automated warehouses which use automatic storage and retrieval systems, conveyors and computers to control the materials handling machines. This system also track and control the inventory. The characteristics of such warehouses include:

(i) High density storage (in some cases, large, high-rise rack structures)

(ii) Automated handling systems (such as elevators, storage and retrieval carousels and conveyors).

(iii) Materials tracking systems (using optical or magnetic sensors)

The functions of the material handling and storage system in FMS are:

- Allows systematic and independent movement of the work parts between stations.
- Enables handling of a variety of work part configurations by means of pallet fixtures for prismatic parts and industrial robots for rotational parts.
- Provide temporary storage.

3.COMPUTER CONTROL SYSTEM:

It consists of a central computer and series of microcomputers that control individual machines in FMS. A central computer controls and coordinates all operations in the system.

It performs functions such as scheduling, routing of parts, machine monitoring, material handling, data management, tool management, etc.

This is done by integrating computer systems . The central computer must also communicate with the following systems:

• The CAD/CAM system which generates the CNC programs for the machine tools

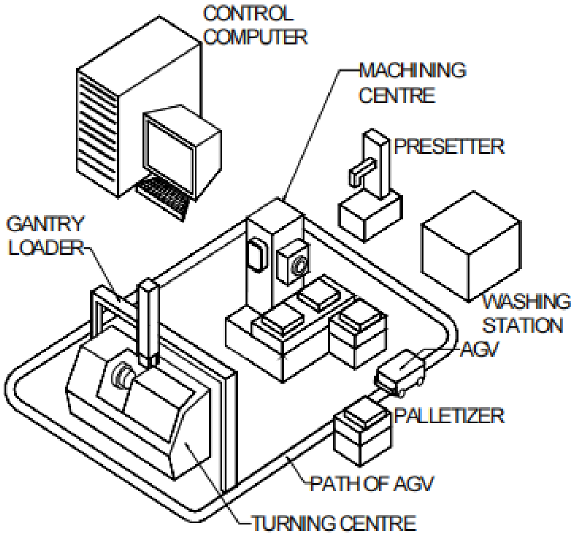
• The shop floor control systems which schedules loading and routing of the work

• The management information system (MIS) system which provides management with reports on the performance of the system

The various controllers and computers can be arranged in the form of a LAN for this purpose.

<u>FLEXIBLE MANUFACTURING CELLS (FMC)</u>

The simplest, hence most flexible type of FMS is a flexible manufacturing cell. It consists of one or more CNC machine tools, general purpose or of special design interfaced with automated material handling and tool changers. FMC's are capable of automatically machining a wide range of different workpieces. They are usually employed in one off and small batch production as independent machining centres, but are frequently the starting point for FMS.



Gantry (Robot) for Loading and Unloading (Automatic Part Changing)

A gantry device, a type of robot is used for loading raw workpiece (blank) and unloading finished components. The raw materials are loaded in a pallet and delivered in the loading arm of the gantry. The loading arm of the gantry robot picks up a raw blank and moves to a location near to the chuck. As soon as the machining of the component is over, it swaps the raw blank and the finished part. The finished part is returned to the pallet while machining starts on the new work piece. A separate pallet is used to receive the finished component. The gantry robot picks up another raw part and positions itself near the chuck, ready to swap it with the job that is currently being machined.

<u>TYPICAL FMS LAYOUT</u>

Figure shows the layout of a typical FMS. For the sake of clarity only a few representative component units are shown in the figure. The following major subsystems and components can be seen in the illustration:

(i) Automatic storage and retrieval system

(ii) CNC machines

(iii) Workpiece carriers (AGV's)

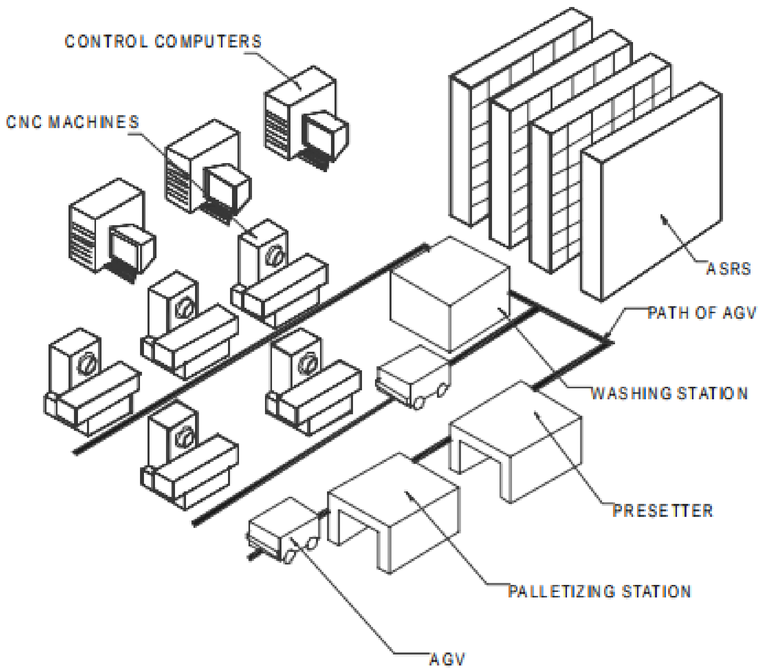
(iv) Palletizing station

(v) Washing station

(vi) Tool presetting station

(vii) Computer control system

The automatic guided vehicle takes the palletized workpieces from the palletizing station to the work centre. The guidance of the AGV is carried out through cables laid on the shop floor. The transfer of the palletized work from the AGV is effected through a special pallet changer device located in front of each of the machine tool.



ADVANTAGES OF FMS

- ✓ Reduced cycle times
- ✓ Lower work-in-process (WIP) inventory
- ✓ Low direct labour costs
- ✓ Ability to change over to different parts quickly
- ✓ Improved quality of product (due to consistency)
- ✓ Higher utilization of equipment and resources
- ✓ Quicker response to market changes
- ✓ Reduced space requirements
- ✓ Lower inventory levels
- ✓ Faster response to market demand

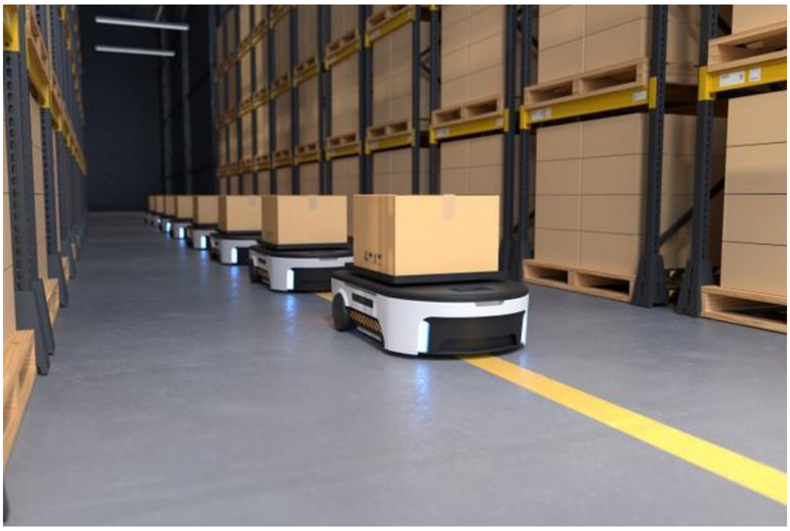
CHAPTER 5

Automatic Guided Vehicles (AGV)

AGV is one of the widely used types of material handling device in an FMS. These are battery-powered vehicles that can move and transfer materials by following prescribed paths around the shop floor.

They are neither physically tied to the production line nor driven by an operator like forklift. Such vehicles have on-board controllers that can be programmed for complicated and varying routes as well as load and unload operations.

The computer for the material handling system or the central computer provides overall control functions, such as dispatching, routing and traffic control and collision avoidance. AGVs provide the flexibility for complex and programmable movement around the manufacturing shop.



Advantages of using AGV systems in FMS

(i) **Flexibility:** The route of the AGVs can be easily altered, expanded and modified, simply by changing the guide path of the vehicles. This is more cost effective than modifying fixed conveyor lines or rail guided vehicles. It provides direct access materials handling system for loading and unloading.

(ii) **Real time monitoring and control:** Because of computer control, AGVs can be monitored in real time. If the FMS control system decides to change the sequence or the schedule, the vehicles can be re-routed and urgent requests can be served.

Some AGVs are controlled through wires implanted on the factory floor. The control is also effected using radio control.

*[Radio control, an alternative to in-floor mounted communication lines, **permits two way communications between the on-board computer and a remote computer,** independent of where the vehicle is i.e. whether it is in the parking place or whether it is in motion.*

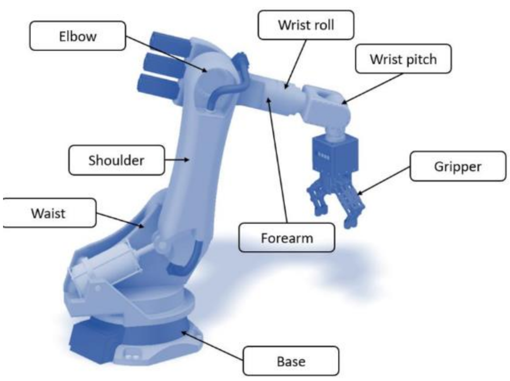
To issue a command to a vehicle, the central computer sends a signal via its transmitter using frequency shift keying methods to address a specific vehicle. The signal transmitted from the base station is, therefore, read by the appropriate vehicle only. The vehicle is also capable of sending signals back to the remote controller, to report the status of the vehicle, vehicle malfunction, battery status, and so on.]

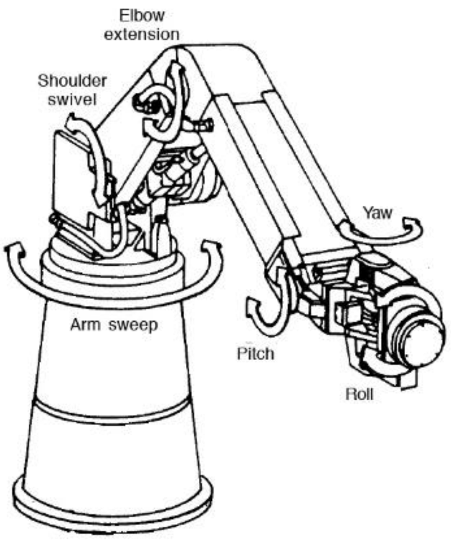
(iii) **Safety:** AGVs can travel at a slow speed but typically operate in the range 10 to 70 m/min. They have ***on-board microprocessor control to communicate*** with local zone controllers which direct the traffic and prevent collisions between vehicles as well as the vehicle and other objects. AGVs may also incorporate warning lights, fire safety interlocks and controls for safety in shops.

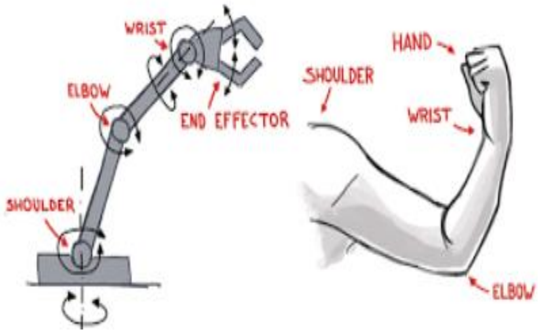
ROBOTS

RIA defines a robot as a ***"programmable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks."***

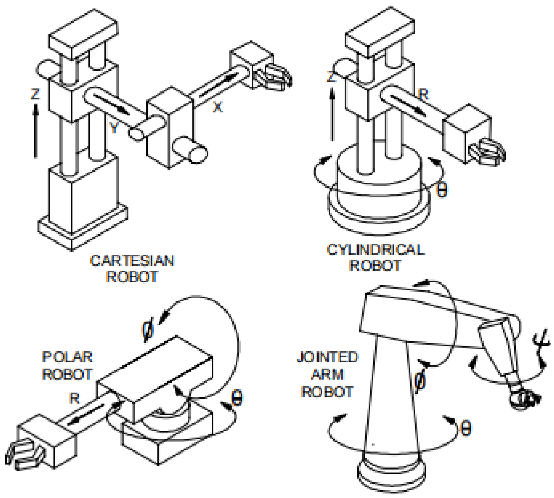
COMPONENTS OF A ROBOTIC SYSTEM

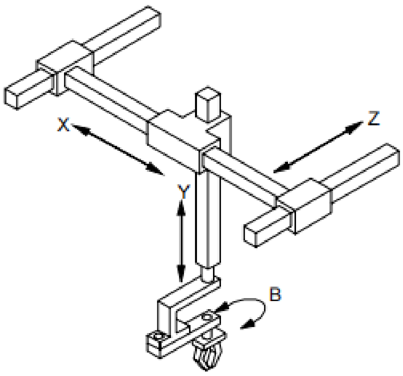






CLASSIFICATION OF ROBOTS BASED ON MECHANICAL CONFIGURATION





Gantry robot

ROBOTS IN CIM

Robots perform several tasks in factories. Some of them are:

i. Movement of materials on the shop floor (Automated guided vehicles (AGV) or rail guided vehicle (RGV)

ii. Loading and unloading of components in machines (Gantry robot, machine mounted robot, free-standing robot)

iii. Inspection using vision sensors

iv. Manufacturing operations like painting, welding, component insertion in printed circuit boards, sorting, automatic assembly, deburring, sampling, dispensing, marking, etc.

- Robots are programmable machines with some human like capabilities. They are made up of mechanical components, a control system and a computer. These elements can be arranged in different ways and can vary in size and complexity to perform different tasks. The major advantages are due to their re-programmability. Robots can be programmed by several techniques.
- Robot programs can be very simple or extremely complex, depending on the nature of the tasks and type of motion control involved. Robot programming is often done in high-level languages that provide functions for data processing, computation, sensing and manipulation.

PROGRAMMING ROBOTS

- The major advantage that robots have is their ability to be reprogrammed. They can perform complex tasks under the control of stored programs, which can be modified at will.

The following methods are commonly used to program robots:

1. Guiding:

Guiding, also known as **lead-through programming**, is a method where the robot is physically moved through the desired path by an operator. The robot records these movements and stores them as a program for later execution.

Manual Lead-through (Hand Guiding)

a. The operator physically holds and moves the robot arm.

b. No teaching pendant is required.
c. Common in simple robots or collaborative robots.

Working Principle

- The operator moves the robot along the required path.
- The robot's control system records: Position coordinates , Speed , Sequence of movements
- The stored program is replayed automatically when needed.

Example: Spray Painting Robot

In an automobile workshop:

- An operator **physically holds the robot arm**
- The operator **moves the robot along the surface of a car body**, following the exact path where paint needs to be applied.
- The robot **records the path, speed, and positions** during this movement.
- After teaching, the robot **repeats the same motion automatically** to paint multiple car bodies with uniform quality.

2. Off-line programming *(Computer assisted robot programming)*

Off-line programming is a method where robot programs are created, simulated, and tested **on a computer (without using the actual robot)** and then later transferred to the robot for execution.
The working of off-line programming is based on **creating and testing robot programs in a virtual environment before actual execution**.

Steps Involved

I. **Creation of Virtual Model** : A 3D virtual model of the robot, tools and work environment is created using CAD software. All components like fixtures, workpieces and obstacles are included.
II. **Program Development** : The robot path and operations are defined using programming software. Commands for movement, speed, and sequence are added.

III. **Simulation** : The program is executed in the virtual environment. The robot motion is visualized on the computer screen.

IV. **Collision Detection & Optimization:** The system checks for: Collisions and Reachability issues. Path and cycle time are optimized.

V. **Program Verification** : The program is validated for accuracy and efficiency. Errors are corrected without using the real robot.

VI. **Program Transfer** : The finalized program is uploaded to the actual robot controller.

VII. Execution on Real Robot : The robot performs the task as per the programmed instructions. Minor adjustments (if needed) are made on-site.

Features

- Uses **simulation software** (e.g., RoboDK, ABB RobotStudio, FANUC ROBOGUIDE).
- Includes **collision detection** and path optimization.
- Can integrate with **CAD/CAM systems**.

Advantages

- No need to stop production → **saves time**.
- High accuracy and precision.
- Safe testing (no risk to equipment).
- Suitable for **complex tasks and paths**.
- Easy modification of programs.

The purpose of a robot control program is to yield the individual motions required of each of links. Robot programming is usually done with high-level languages that use a limited number of basic commands.

Some of the basic types of commands are:

Motion and sensing functions (e.g., MOVE, MONITOR)

Computation functions (e.g., ADD, SORT)

Program-flow control functions (e.g., RETURN, BRANCH)

The most common command in most robot programs is to move the manipulator.

The syntax for the move command is:

MOVE [<JOINTS> <GOALS>]

E.g.: MOVE [<1, 3, 5> <5, 10, 20>]

The first command means that joints 1, 3 and 5 are to be moved by 5, 10 and 20 units, respectively. There are also a number of frequently used functions that are not involved in the path itself (e.g., WAIT, CONTINUE, BRANCH, OUTPUT).

Many robot languages are now available. Each is unique in its design and capabilities. Some are more powerful and versatile than others. Some were developed by robot users, others by robot manufacturers. Some of the most widely used languages are:

VAL (Unimation)

AML (IBM)

HELP (General Electric)

RAIL (Automatrix)

AL (Stanford University)

MCL (McDonnel-Douglas)

RPS (SRI)

JARS (Jet Propulsion Laboratory)

AS (Kawasaki)

3. <u>Online Programming of Robots</u>

Definition:

Online programming is a method where the robot is programmed **directly on the actual robot in real time**, usually using a **teach pendant or control panel**.

Working Principle

- The operator uses a **teach pendant** to control the robot.
- The robot is moved **point by point** to desired positions.
- Each position and motion is **recorded in the controller memory**.
- Commands like speed, delay, and sequence are added.
- The robot then **executes the stored program automatically**.

Features

- Programming is done on the **actual robot**.

- Uses **teach pendant (handheld device)**.
- Supports **point-to-point and continuous path programming**.

INTEGRATING NC MACHINES, ROBOTS, AGVS AND OTHER NC EQUIPMENT

Integrating NC (Numerical Control) machines, robots, and AGVs (Automated Guided Vehicles) is the core of **Computer Integrated Manufacturing (CIM)** and **Flexible Manufacturing Systems (FMS)**. This integration creates a fully automated production environment where information and materials flow seamlessly between digital design and physical output.

It involves linking all manufacturing resources through **computers, communication networks, and control systems** to achieve **automation, coordination, and efficiency**.

Objectives of Integration

- Improve **productivity**
- Reduce **manual intervention**
- Ensure **smooth material flow**
- Increase **flexibility**
- Reduce **lead time and errors**
- Enable **real-time monitoring and control**

Core Components of Integration

a) **NC/CNC Machines**: These are the primary "producers," performing high-precision operations like milling, turning, or drilling based on coded instructions.

b) **Industrial Robots**: Often used as the "connectors", robots automate the loading of raw materials and the unloading of finished parts from NC machines. Provide precision and repeatability. Also performs welding, painting, assemblies.

c) **AGVs**: These serve as the "transporters," moving workpieces, raw materials or cutting tools between storage, machining centers and inspection areas.

d) **Computer Control System**: The central "brain" that schedules operations, manages the fleet of AGVs and synchronizes the robot's movements with the machine's cycle.

e) **Other NC Equipment:** CNC inspection machines (CMM), Automated storage/retrieval systems (AS/RS), Conveyors and pallet systems.

How They Work Together:

1) **Production plan** is created in computer system.
2) Part programs are sent to NC machines via DNC.
3) **AGVs transport raw materials** to machines.
4) **Robots load/unload parts** into machines.
5) Machining is performed automatically.
6) Finished parts are moved to: Inspection (CMM) and Storage (AS/RS)
7) System continuously monitors and adjusts operations.

METHODS OF INTEGRATION

Integration in manufacturing refers to the **linking of NC machines, robots, AGVs, and other automated systems** into a unified and coordinated system.

1. Computer Control Integration

- A **central computer** controls all machines and equipment.
- Uses systems like **DNC (Direct Numerical Control)**.
- **Functions:** Sends NC programs to machines, Monitors machine status, Controls production flow, Ensures **centralized control and coordination**

2. Communication Integration

- All equipment is connected through **communication networks real time data exchange.**
- Technologies: LAN (Local Area Network), Industrial communication protocols (Ethernet, Modbus, Profibus)
- Enables Real-time data exchange, system to system communication and Machine-to-machine communication.

- Ensures **smooth information flow**

3. Database Integration

- A **central database** stores and manages all manufacturing data which includes Part programs, Tool data, Production schedules, Inventory details
- Accessible by all systems and Ensures **data consistency and easy access**

4. Material Handling Integration

Material handling systems are integrated with production equipment.

- Includes **AGVs, conveyors, robots, AS/RS**

- Provides automatic movement of materials between stations
- Ensures **continuous and efficient material flow**

5. Control System Integration

Input Data Collection

- Sensors collect real-time data from the system:
  - Position of parts
  - Machine status
  - Temperature, speed, tool condition
- Inputs are sent to **PLCs or controllers**

Data Processing and Decision Making

- PLC or computer processes the input data based on:
  - Predefined logic (ladder logic/program)
  - Production schedule
- Decisions are made regarding:

  - Machine operation
  - Material movement
  - Sequence of tasks

Command Execution

- Control signals are sent to:
    - **CNC/NC machines** → perform machining
    - **Robots** → loading/unloading, welding, etc.
    - **AGVs** → transport materials
    - **Actuators** → perform physical movements

Coordination and Synchronization

- All equipment operates in a **proper sequence**
- Example:

AGV delivers part → robot loads → CNC machine processes → robot unloads

Feedback and Monitoring

- Sensors continuously send feedback to the control system
- System checks for: Errors, Deviations, Tool wear or faults, etc.
- If any fault is detected System generates alarm and Stops or adjusts operation

Supervisory Control

- A central computer (SCADA/DNC system): Monitors overall system performance, Displays data on HMI and Stores production information.

ADVANTAGES OF INTEGRATION

- High **automation and efficiency**
- Reduced **labour cost**
- Improved **accuracy and consistency**
- Better **resource utilization**
- Real-time **production tracking**
- Flexible for **different product types**

<u>COMPUTER AIDED FORECASTING</u>

Computer Aided Forecasting (CAF) refers to the use of computer systems, software, and statistical techniques to predict future trends, demands, or outcomes based on historical data and analysis.

Computer Aided Forecasting is the application of computer-based tools and mathematical models to analyze past data and generate accurate predictions for future planning and decision-making.

Objectives

- To improve accuracy of forecasts
- To reduce manual effort and human error
- To support decision-making in industries
- To analyze large volumes of data quickly
- To provide timely and reliable predictions

<u>Components of Computer Aided Forecasting (CAF) System</u>

A Computer Aided Forecasting (CAF) system consists of several integrated components that work together to collect data, process it and generate accurate forecasts.

1. Data Collection Module: Gathers historical and current data. **Sources:** Past and current sales records, production data, market surveys.

2. Database Management System (DBMS): Stores and organizes large volumes of data. Allows easy retrieval, updating and maintains data security.

3. Data Preprocessing Module: Cleans and prepares data. Handles missing values, errors and inconsistencies. Converts raw data into usable format.

[**Deseasonalization**: Identifying and removing recurring seasonal patterns (like holiday spikes) to reveal the underlying trend.]

[**Smoothing**: Using techniques like **Moving Averages** to filter out random fluctuations.]

4. Forecasting Models (Model Base): Contains mathematical and statistical models.

- Examples:
    - Moving Average
    - Exponential Smoothing
    - Regression Models
- Core component where forecasting logic is applied
- Choosing the right mathematical approach (e.g., **Linear Regression** or **Exponential Smoothing**) based on the data's complexity and time horizon.

5. Processing/Computation Unit: Performs calculations using selected models. Executes algorithms quickly and accurately. Uses computer software or programs.

6. Model Management System: Helps select, modify, and evaluate forecasting models. Compares different models for accuracy. Allows updating models as needed.

[**Verification & Monitoring**: Comparing predictions against actual outcomes using tools like **MAPE** (Mean Absolute Percentage Error) to refine the model over time.]

7. Output/Reporting System: Presents forecast results in user-friendly format Graphs, charts, tables, and reports. Helps in decision-making

8. Feedback and Control System: Evaluates forecast accuracy. Compares predicted vs actual results. Helps improve future forecasts

TYPES OF FORECASTING METHODS

In **Computer-Aided Forecasting (CAF)**, forecasting methods are broadly classified based on how data is used and analyzed. These methods are implemented using software tools like Excel, ERP systems, and specialized forecasting software.

1. QUALITATIVE (JUDGMENTAL) METHODS

Qualitative forecasting methods are based on **human judgment, experience, and opinions** rather than numerical data. These methods are especially useful when **historical data is unavailable, insufficient, or unreliable**, such as for new products or changing market conditions.

Key Characteristics

- Relies on **expert knowledge and intuition**
- Suitable for **long-term forecasting**
- Used in **new product launches or uncertain environments**

Types of Qualitative Forecasting Methods

A. Delphi Method

- A group of experts provides forecasts **independently and anonymously**
- Responses are collected, summarized, and shared for further refinement
- Process continues until a **conclusion** is reached

CAF Role: Software helps collect, analyze, and refine expert opinions efficiently.

B. Market Research Method

- Data collected through **surveys, interviews and questionnaires.**
- Used to understand **customer preferences and demand trends**

CAF Role: Tools like online survey platforms and analytics software process large datasets quickly.

C. Historical Analogy Method

- Forecast is based on the **performance of similar products in the past**
- Useful for new products with no prior data

CAF Role: Databases and software help identify comparable cases.

D. Jury of Executive Opinion

- Forecasts are made by a **panel of experienced managers or executives**
- Combines knowledge from different departments

CAF Role: Decision-support systems assist in compiling and comparing opinions.

2. QUANTITATIVE FORECASTING METHODS

Quantitative methods use **mathematical models and historical data** to predict future outcomes. These methods are widely used in CAF because computers can process large datasets quickly and accurately.

Key Characteristics

- Based on **past numerical data**
- Uses **statistical and mathematical techniques**
- Provides **objective and accurate results**
- Suitable for **short-term and medium-term forecasting**

Types of Quantitative Forecasting Methods

A. Time Series Methods

These methods analyze past data patterns over time and assume that future trends will follow similar patterns.

Types:

- **Moving Average Method**

  The **Moving Average Method** is a quantitative forecasting technique that calculates the average of a fixed number of past observations to predict future values. It helps **smooth out short-term fluctuations** and highlight trends.

Formula

$$\text{Moving Average} = \frac{A_1 + A_2 + A_3 + \cdots + A_n}{n}$$

Where:

- $A_1, A_2, \ldots, A_n$ = past data values
- n = number of periods

Example

Suppose demand data for 5 days:

Day	Demand
1	10
2	12
3	14
4	16
5	18

3-Day Moving Average Forecast for Day 6:

$$\frac{14 + 16 + 18}{3} = \frac{48}{3} = 16$$

Forecast for Day 6 = 16 units

- **Exponential Smoothing**

  Exponential Smoothing is a **quantitative time series forecasting method** that gives **more importance (weight) to recent data** and less to older data. It is widely used in Computer-Aided Forecasting due to its simplicity and accuracy.

Basic Idea

- Recent observations are **more relevant** for forecasting
- Older data gradually becomes **less important**
- Weights decrease **exponentially**

Formula (Simple Exponential Smoothing)

$$F_{t+1} = \alpha A_t + (1 - \alpha) F_t$$

Where:

- F_{t+1} = Forecast for next period
- A_t = Actual value of current period
- F_t = Previous forecast
- α = Smoothing constant (0 < α < 1)

· **High α (0.7–0.9)** → More weight to recent data → fast response

· **Low α (0.1–0.3)** → Smooth forecast → slow response

- **Seasonal Models**

  Accounts for seasonal variations

CAF Role:

Software like Excel, ERP systems automatically calculates values, plots graphs, and updates forecasts.

B. **Associative (Causal) Models:** These models analyze relationships between a dependent variable (e.g., sales) and one or more independent variables (e.g., price, ad spend).

Simple Linear Regression: Regression Analysis is a **quantitative (causal) forecasting method** used to study the relationship between a **dependent variable** (e.g., demand) and one or more **independent variables** (e.g., price, income, advertising).

➢ It analyzes the relationship between **one independent variable (X)** and **one dependent variable (Y).**

Linear Regression Equation

$$Y = a + bX$$

Where:

- Y = Forecasted value
- X = Time period (independent variable)
- a = Intercept (value of Y when X = 0)
- b = Slope (rate of change or trend)

Formulas for a and b

$$b = \frac{n\sum XY - (\sum X)(\sum Y)}{n\sum X^2 - (\sum X)^2}$$

$$a = \frac{\sum Y - b\sum X}{n}$$

Example

Year (X)	Demand (Y)
1	10
2	15
3	20
4	25

After calculation:

- $a = 5, b = 5$

Regression equation:

$$Y = 5 + 5X$$

Forecast for Year 5:

$$Y = 5 + 5(5) = 30$$

Forecast = 30 units

Multiple Regression

Definition

It analyzes the relationship between **one dependent variable (Y)** and **two or more independent variables (X_1, X_2, X_3, …)**.

Equation

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \dots$$

Where:

- Y = Dependent variable
- X_1, X_2, X_3 = Independent variables
- b_1, b_2, b_3 = Coefficients

Econometric Modeling: Solves complex systems of equations to forecast broad economic shifts. Econometric modeling involves the use of **economic theory + mathematical equations + statistical techniques** to forecast variables such as demand, sales, price, and production.

3. ARTIFICIAL INTELLIGENCE (AI) BASED METHODS IN FORECASTING

AI-based forecasting methods use **intelligent algorithms and machine learning techniques** to analyze large datasets, identify patterns, and make accurate predictions. These methods are widely used in modern **Computer-Aided Forecasting (CAF)** systems.

Basic Idea

- Learns from **historical data automatically**
- Identifies **hidden patterns and complex relationships**
- Improves accuracy over time (**self-learning**)

Types of AI-Based Forecasting Methods

1. Machine Learning Models

- Algorithms learn from past data and make predictions
- Common models:

- Decision Trees
- Random Forest
- Support Vector Machines (SVM)

Use: Demand forecasting, sales prediction

2. Artificial Neural Networks (ANN)

- Inspired by the human brain
- Consists of layers of interconnected nodes (neurons)
- Handles **non-linear and complex relationships**

Use: Weather forecasting, stock prediction

3. Deep Learning Models

- Advanced form of neural networks with multiple layers
- Examples:
  - RNN (Recurrent Neural Network)
  - LSTM (Long Short-Term Memory)

Use: Time series forecasting with large datasets

Popular Software Used in Computer-Aided Forecasting (CAF)

Computer-Aided Forecasting relies on various software tools to perform calculations, analyze data, and generate accurate forecasts.

1. Spreadsheet Software

Microsoft Excel

- Most widely used tool
- Functions like:
  - Moving Average
  - Exponential Smoothing
  - Regression (Data Analysis Toolpak)

- Easy to use and widely available

Google Sheets

- Cloud-based alternative to Excel
- Supports basic forecasting functions
- Useful for collaboration

2. Statistical Software

SPSS (Statistical Package for Social Sciences)

- Used for regression, time series, and econometric analysis
- User-friendly interface

R Programming

- Open-source software
- Advanced forecasting packages (e.g., *forecast*, *ts*)
- Highly flexible and powerful

SAS (Statistical Analysis System)

- Used in large industries
- Strong data handling and forecasting capabilities

3. Enterprise Software (ERP Systems)

SAP

- Integrated forecasting in supply chain management
- Used in large industries

Oracle ERP

- Demand forecasting and planning tools
- Handles large-scale business data

4. Specialized Forecasting Software

Minitab

- Statistical analysis and forecasting
- Easy for students and professionals

Forecast Pro

- Dedicated forecasting software
- Supports multiple forecasting models

Tableau

- Data visualization with forecasting features
- Useful for trend analysis

5. AI-Based Forecasting Tools

- Tools using machine learning and AI
- Examples:
    - IBM Watson Analytics
    - Microsoft Azure ML
    - Google AI Platform

OFFICE AUTOMATION

Office automation refers to the integrated use of computer hardware, software, and network systems to digitally create, collect, store, and manipulate information needed to accomplish basic office tasks. At its core, it aims to streamline workflows by replacing manual, repetitive processes with automated technology.

Office Automation is essential for modern organizations, enabling **efficient handling of office tasks** and supporting decision-making through computer-based systems.

Key Components of Office Automation

Modern office automation systems typically consist of four primary pillars:

1. **Hardware:** Essential devices such as computers, scanners, printers, and reliable network equipment like routers and switches.
2. **Software:** Applications used for core tasks, including word processors (e.g., Microsoft Word), spreadsheets (Excel), and specialized project management tools.
3. **Communication Systems:** Platforms for instant messaging, video conferencing (Microsoft Teams, Slack), and email that facilitate seamless information exchange.
4. **Data Management:** Centralized systems like Document Management Systems (DMS) and cloud storage (Google Drive, OneDrive) for secure data retention and retrieval.

Major Benefits

i. **Increased Productivity:** By automating routine data entry and administrative tasks, employees can focus on high-value, strategic work.
ii. **Reduced Human Error:** Automated systems perform calculations and data transfers with high accuracy, minimizing costly mistakes.
iii. **Cost Efficiency:** While initial setup costs can be significant, automation reduces long-term operational expenses by lowering labor needs and physical storage requirements.
iv. **Enhanced Collaboration:** Real-time document editing and shared digital workspaces allow multiple team members to work together effectively, regardless of location.

Examples Across Business Functions:

Function	**Automation Examples**
HR & Payroll	Automated attendance tracking, payroll processing, and streamlined employee onboarding workflows.
Finance	Invoice processing, expense report management using OCR, and automated budget monitoring.

Sales & Marketing	CRM lead tracking, automated email sequencing, and social media post scheduling.
Facility Management	Desk and meeting room booking systems, and automated visitor management.