VEER SURENDRA SAI UNIVERSITY OF TECHNOLOGY
BURLA, ODISHA, INDIA

DEPARTMENT OF PRODUCTION ENGINEERING

Lecture Notes on

COMPUTER INTEGRATED MANUFACTURING (CIM)

COURSE CODE: BMS 406: PE-II

7th Semester B. Tech in Production Engineering

BMS 406: PE-II: COMPUTER INTEGRATED MANUFACTURING (3-1-0): Syllabus

Module-I

Introduction: The meaning and origin of CIM, The changing manufacturing and management scenario, External communication, Islands of automation and software, Dedicated and open systems, Manufacturing automation protocol, Product related activities of a company, Marketing engineering, Production planning, Plant operations, Physical distribution, Business and financial management. [06 Lectures]

Computer Aided Process planning: Role of process planning in CAD/CAM integration, Approaches to computer aided process planning- Variant approach and Generative approaches, CAPP and CMPP process planning systems. [04 Lectures]

Module-II

Shop Floor Control and FMS: Shop floor control-phases, Factory data collection system, Automatic identification methods- Bar code technology, Automated data collection system, FMS-components of FMS - types -FMS workstation, Material handling and storage systems, FMS layout, Computer control systems-application and benefits. [10 Lectures]

Module-III

CIM Implementation: CIM and company strategy, System modeling tools-IDEF models, Activity cycle diagram, CIM open system architecture (CIMOSA), Manufacturing enterprise wheel, CIM architecture, Product data management, CIM implementation software. [06 Lectures]

Data Communication: Communication fundamentals, Local area networks, Topology, LAN implementations, Network management and installations. [04 Lectures]

Module-IV

CIM System: Open System Open systems inter connection, Manufacturing automations protocol and technical office protocol (MAP /TOP). [04 Lectures]

Database for CIM: Development of databases, Database terminology, Architecture of database systems, Data modeling and data associations, Relational data bases, Database operators, Advantages of data base. [06 Lectures]

TEXT BOOK(S):

1. Automation, Production Systems and Computer Integrated Manufacturing- M.P.Groover, Pearson Education.
2. Computer Integrated Manufacturing System- Y. Koren, McGraw-Hill.

REFERENCE(S):

1. CAD/CAM/CIM- P. Radhakrishnan, S. Subramanyan and V. Raju- New Age International.
2. Computer Integrated Manufacturing- Paul G. Ranky, Prentice Hall International.

Computer Integrated Manufacturing (CIM)

Module-I

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1. Introduction to CIM

Initially, machine tool automation started with the development of numerical control in 1950s. In less than 50 years, it is amazing that today's manufacturing plants are completely automated. However, establishment of these plants gave relatively a few varieties of product. At first we define what do we mean by a manufacturing plant? Here, we are considering a several categories of manufacturing (or production) for the various manufacturing plants. Manufacturing can be considered in three broad areas:

(i) Continuous process production,

(ii) Mass production, and

(iii) job-shop production.

Among these three, mass production and job-shop production can be categorized as *discrete- item production.*

Continuous Process Production

Such type of product flows continuously in the manufacturing system, e.g. petroleum, cement, steel rolling, petrochemical and paper production etc. Equipment used here are only applicable for small group of similar products.

Mass Production

It includes the production of discrete unit at very high rate of speed. Discrete item production is used for goods such as automobiles, refrigerators, televisions, electronic component and so on. Mass production contains the character of continuous process production for discrete products. That's why mass production has realized enormous benefits from automation and mechanization.

Job Shop Production

A manufacturing facility that produces a large number of different discrete items and requires different sequences among the production equipments is called job shop. Scheduling and routine problems are the essential features of job shop. As a result automation has at best been restricted to individual component of job shop. But there have been few attempts in the field of total automation. Physical components of an automated manufacturing system do not include continuous flow process as it only consists of a small percentage of manufacturing system. Mass production of discrete items is included in this category, where segments of production line are largely automated but not the entire line. Job shop facilities have used automated machines, but transfer of work among these machines is a difficult task. Apart from some physical equipment needed, a major component of the automated information that needs to be made available to the manufacturing operation must come from product design. This allows a plant to be automated and integrated. However, manufacturing is more concerned with process design rather than product design.

The characteristic of present world market include higher competition, short product life cycle, greater product diversity, fragmented market, variety and complexity, and smaller batch sizes to satisfy a variety of customer profile. Furthermore, non price factors such as quality of product design innovation and delivery services are the preliminary determinant for the success of product. In today's global arena, to achieve these requirements manufacturing company needs to be flexible, adaptable and responsive to changes and be able to produce a variety of products in short time and at lower cost. These issues attract manufacturing industries to search for some advanced technology, which can overcome these difficulties. Computer integrated manufacturing (CIM), which emerged in 1970, was the outcome of this protracted search.

A CIM System consists of the following basic components:

I. Machine tools and related equipment

II. Material Handling System (MHS)

III. Computer Control System

IV. Human factor/labor

CIM refers to a production system that consists of:

1. A group of NC machines connected together by
2. An automated materials handling system
3. And operating under computer control

In Production Systems CIM is appropriate for batch production as shown in Fig. 1.

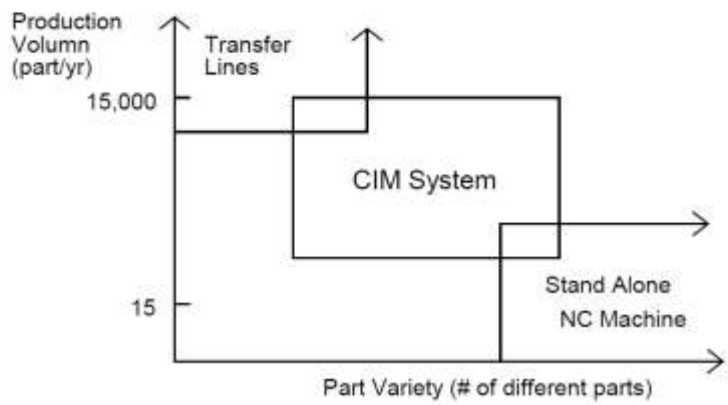


Fig. 1 Application of CIM in Production systems

Transfer Lines: is very efficient when producing "identical" parts in large volumes at high product rates.

Stand Alone: NC machine: are ideally suited for variations in work part configuration.

CIM involves a fundamental strategy of integrating manufacturing facilities and systems in an enterprise through the computer and it's peripheral. CIM can be defined in different ways depending upon its application. CIM involves integration of advanced technologies in various functional units of an enterprise, in an effective manner to achieve the success of the manufacturing industries. A deep knowledge and understanding of all the technology is required for an effective integration. At first integration of advanced manufacturing technology (AMT) is required to get success in the application of CIM. Computers act as a subordinate to the technologies. Computers help, organize, and restore information in order to achieve high accuracy and speed. Their basic aim is to achieve the goals of the objectives within limited available capital. Traditionally, all the efforts were focused on achieving single goal to improve the effectiveness and competitiveness of the organization. But they failed because they didn't satisfy the overall objectives of the manufacturing companies. Hence, a multiple goal selection or mult- criteria optimization is proposed to make the CIM an effective tool to improve the economy of the company. The new approach should be developed for improving the existing multi-criteria optimization mechanism, so that CIM can be realized globally. In addition, global integration approach should be applied to make globally distributed company as a single entity. This concept is applied to make virtual CIM more effective and hence helps in meeting the present global economic circumstances using intelligent manufacturing. Therefore, manufacturing technology should be blended with intelligence. This will help manufacturing enterprise to produce better quality. It will also facilitate the manufacturing equipments to solve problems posed during normal course of the operations.

Computer technology is the necessary input to implement automation in manufacturing system. The term CIM denotes the widespread use of computer systems to design the product, to plan the production, control the operation, and perform the business related functions required in the manufacturing firm. True CIM includes integration of these functions in the system that operates throughout the enterprise. Other words are used to identify specific element of the CIM system. For example, computer aided design (CAD) denotes the use of computer system to support the product design system.

Computer aided manufacturing (CAM) denotes the use of computer system to perform the functions related to manufacturing engineering, such as process planning and numerically controlled (NC) part programming. Some computer system performs the CAD and CAM, and so the term CAD/CAM is used to indicate the integration of the two systems into one. In addition to CAD/CAM, CIM also includes the firm business function that is related to manufacturing.

Computer Integrated Manufacturing (CIM) encompasses the entire range of productdevelopment and manufacturing activities with all the functions being carried out with the help of dedicated software packages. The data required for various functions are passed from one application software to another in a seamless manner. For example, the product data is created during design. This data has to be transferred from the modeling software to manufacturing software without any loss of data. CIM uses a common database wherever feasible and communication technologies to integrate design, manufacturing and associated business functions that combine the automated segments of a factory or a manufacturing facility. CIM reduces the human component of manufacturing and thereby relieves the process of its slow, expensive and error-prone component. CIM stands for a holistic and methodological approach to the activities of the manufacturing enterprise in order to achieve vast improvement in its performance. This methodological approach is applied to all activities from the design of the product tocustomer support in an integrated way, using various methods, means and techniques inorder to achieve production improvement, cost reduction, fulfillment of scheduled delivery dates, quality improvement and total flexibility in the manufacturing system. CIM requires all those associated with a company to involve totally in the process of product development and manufacture. In such a holistic approach, economic, social and human aspects have the same importance as technical aspects. CIM also encompasses the whole lot of enabling technologies including total quality management, business process reengineering, concurrent engineering, workflow automation, enterprise resource planning and flexible manufacturing. The challenge before the manufacturing engineers is illustrated in Fig. 2

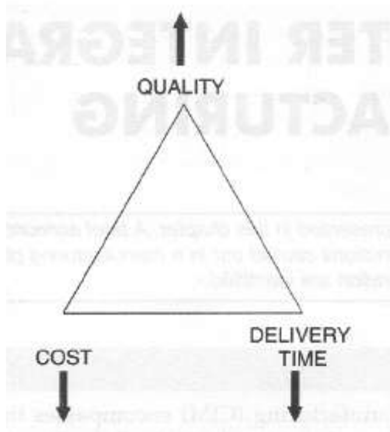


Fig 2 Challenges in manufacturing

Manufacturing industries strive to reduce the cost of the product continuously to remain competitivein the face of global competition. In addition, there is the need to improve the quality and performance levels on a continuing basis. Another important requirement is on time delivery. In the context of global outsourcing and long supply chains cutting across several international borders, the task of continuously reducing delivery times is really an arduous task. CIM has several software tools to address the above needs.

Manufacturing engineers are required to achieve the following objectives to be competitive in a global context.

- Reduction in inventory
- Lower the cost of the product
- Reduce waste
- Improve quality
- Increase flexibility in manufacturing to achieve immediate and rapid response to:
    - Product changes
    - Production changes
    - Process change
    - Equipment change
    - Change of personnel

CIM technology is an enabling technology to meet the above challenges to the manufacturing.

1.1 *Evolution of Computer Integrated Manufacturing*

Computer Integrated Manufacturing (CIM) is considered a natural evolution of thetechnology of CAD/CAM which by itself evolved by the integration of CAD and CAM. Massachusetts Institute of Technology (MIT, USA) is credited with pioneering the development in both CAD and CAM. The need to meet the design and manufacturing requirements of aerospace industries after the Second World War necessitated the development these technologies. The manufacturing technology available during late 40's and early 50's could not meet the design and manufacturing challenges arising out of the need to develop sophisticated aircraft and satellite launch vehicles. This prompted the US Air Force to approach MIT to develop suitable control systems, drives and programming techniques for machine tools using electronic control.

The first major innovation in machine control is the Numerical Control (NC), demonstrated at MIT in 1952. Early Numerical Control Systems were all basically hardwired systems, since these were built with discrete systems or with later first generation integrated chips. Early NC machines used paper tape as an input medium. Every NC machine was fitted with a tape reader to read paper tape and transfer the program to the memory of the machine tool block by block. Mainframe computers were used to control a group of NC machines by mid *60's.* This arrangement was then called Direct Numerical Control (DNC) as the computer bypassed the tape reader to transfer the program data to the machine controller. By late 60's mini computers were being commonly used to control NC machines. At this stage NC became truly soft wired with the facilities of mass program storage, offline editing and software logic control and processing. This development is called Computer Numerical Control (CNC). Since 70's, numerical controllers are being designed around microprocessors, resulting in compact CNC systems. A further development to this technology is the distributed numerical control (also called DNC) in which processing of NC program is carried out in different computers operating at different hierarchical levels - typically from mainframe host computers to plant computers to the machine controller.

Today the CNC systems are built around powerful 32 bit and 64 bit microprocessors. PC based systems are also becoming increasingly popular. Manufacturing engineers also started using computers for such tasks like inventory control; demand forecasting, production planning and control etc. CNC technology was adapted in the development of co-ordinate measuring machine's (CMMs) which automated inspection. Robots were introduced to automate several tasks like machine loading, materials handling, welding, painting and assembly. All these developments led to the evolution of flexible manufacturing cells and flexible manufacturing systems in late 70's.

Evolution of Computer Aided Design (CAD), on the other hand was to cater to the geometric modeling needs of automobile and aeronautical industries. The developments in computers, design workstations, graphic cards, display devices and graphic input and output devices during the last ten years have been phenomenal. This coupled with the development of operating system with graphic user interfaces and powerful interactive (user friendly) software packages for modeling, drafting, analysis and optimization provides the necessary tools to automate the design process.

CAD in fact owes its development to the APT language project at MIT in early 50's.Several clones of APT were introduced in 80's to automatically develop NC codes from the geometric model of the component. Now, one can model, draft, analyze, simulate, modify, optimize and create the NC code to manufacture a component and simulate the machining operation sitting at a computer workstation. If we review the manufacturing scenario during 80's we will find that the manufacturing is characterized by a few islands of automation. In the case of design, the task is well automated. In the case of manufacture, CNC machines, DNC systems, FMC, FMS etc provide tightly controlled automation systems. Similarly computer control has been implemented in several areas like manufacturing resource planning, accounting, sales, marketing and purchase. Yet the full potential of computerization could not be obtained unless all the segments of manufacturing are integrated, permitting the transfer of data across various functional modules. This realization led to the concept of computer integrated manufacturing. Thus the implementation of CIM required the development of whole lot of computer technologies related to hardware and software.

1.2 *CIM Hardware and CIM Software*

CIM Hardware comprises the following:

i. Manufacturing equipment such as CNC machines or computerized work centers, robotic work cells, DNC/FMS systems, work handling and tool handling devices, storage devices, sensors, shop floor data collection devices, inspection machines etc.

ii. Computers, controllers, CAD/CAM systems, workstations / terminals, data entry terminals, bar code readers, RFID tags, printers, plotters and other peripheral devices, modems, cables, connectors etc., CIM software comprises computer programmes to carry out the following functions:

- Management Information System
- Sales
- Marketing
- Finance
- Database Management
- Modeling and Design
- Analysis
- Simulation
- Communications
- Monitoring
- Production Control
- Manufacturing Area Control
- Job Tracking
- Inventory Control
- Shop Floor Data Collection
- Order Entry
- Materials Handling
- Device Drivers

- Process Planning
- Manufacturing Facilities Planning
- Work Flow Automation
- Business Process Engineering
- Network Management
- Quality Management

1.3 *Nature and Role of the Elements of CIM System*

Nine major elements of a CIM system are in Fig 3 they are,

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

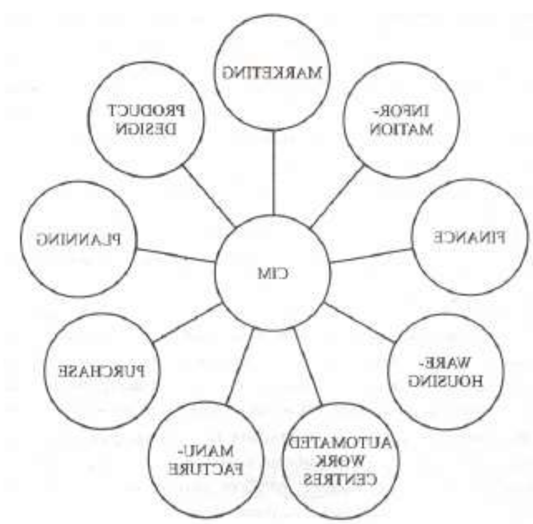


Fig 3 Major elements of CIM systems

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

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

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

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

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

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

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

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

ix. *Information Management:* Information Management is perhaps one of the crucial tasks in CIM. This involves master production scheduling, database management, communication, manufacturing systems integration and management information systems. It can be seen from Fig 4 that CIM technology ties together all the manufacturing and related functions in a company. Implementation of CIM technology thus involves basically integration of all the activities of the enterprise.

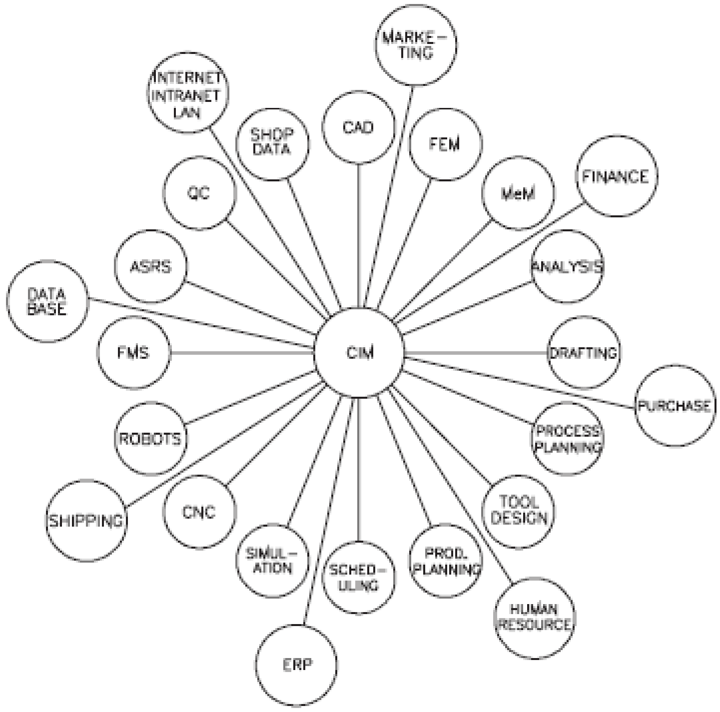


Fig. 4 Various Activities in CIM

1.4 *The Scope of Computer-Integrated Manufacturing*

When all of the activities of the modern manufacturing plants are considered as a whole, it is impossible to think that a small portion might be automated, let alone trying to envisage automation of the whole. In systems approach, a large and complex system with interacting components are analyzed and improved. Anyone vested with the responsibility of implementation of automation for complex system is advised to implement a technique similar to the traditional systems approach.

Following steps are involved in the systems approach:

(a) Objectives of the system are determined.

(b) Structuring the system and set definable system boundaries.

(c) Significant components for a system are determined.

(d) A detailed study of the components is carried out keeping in view the overall integration of the system.

(e) Analyzed components are synthesized into the system.

(f) On the basis of the performance criteria, predetermined system is evaluated.

(g) For continuous improvement, Step „b‟ to Step „f‟ are constantly repeated.

No task, however small, should be tackled without knowledge of the task objective. This is the key ingredient which, when lacking, causes members of the same team to pull in different directions. In considering factory automation, there could be many possible objectives. One might be to improve the performance of a specific process. Boundary conditions would then be limited to that process (as well as other processes that might be affected by increased output, such as material supply and assembly after production). Another objective might be to minimize cost in a segment of the operation, while a third might be profit maximization; obviously it is rare that such multiple objectives can all be optimized, even though politicians seem to think so when it comes close to election day. When considering moving to a computer integrated manufacturing operation, the objective would probably be related to being competitive, a problem that manufacturing plants are having at the micro level and a situation that is almost catastrophic for the nation at the macro level.

Setting system boundaries for a CIM project might at first appear to be concerned only with the engineering design and actual manufacture of the products. While the integration of these two components is a major task which is not satisfied in most of the facilities, CIM goes beyond these activities.

1.5 *Definition of CIM*

Joel Goldhar, Dean, Illinois Institute of Technology gives CIM as a computer system in which the peripherals are robots, machine tools and other processing equipment.

Dan Appleton, President, DACOM, Inc. defines CIM is a management philosophy, not a turnkey product.

Jack Conaway, CIM Marketing manager, DEC, defines CIM is nothing but a data management and networking problem.

The computer and automated systems association of the society of Manufacturing Engineers (CASA/SEM) defines CIM is the integration of total manufacturing enterprise by using integrated systems and data communication coupled with new managerial philosophies that improve organizational and personnel efficiency.

Dr. J. Harrington, Jr. introduces the concept of Computer Integrated Manufacturing (CIM) in the year 1973. He demonstrated the integration approach to an enterprise. Keeping in mind the current and future market trend for customized product and in order to stand in the competitive edge over long time, virtual organizations are used as an important weapon. Hence, in order to achieve corporate goal and objectives, integration approach is required for customer as well as suppliers. CIM, in general, may be defined as follows :

CIM is the integration of total manufacturing enterprise through the use of integrated system and data communication mixed with new managerial philosophies which results in the improvement of personnel or organizational efficiencies.

From the definition mentioned above, the ultimate goal of CIM is the integration of all the enterprise operation and activities around a common data collection. In this context, society of manufacturing engineers (SME) introduces the CIM wheel, which gives a clear cut picture of relationship among all parts of the enterprise. Outer layer constitutes of general management which includes marketing, strategic planning, finance, manufacturing management and human resource management. The middle layer consists of three process segments: product and process determination, manufacturing planning and control, and factory automation. These process segments represent all the activities in the design and manufacturing phase of a product life cycle taking the product from concept to assembly. The center of wheel represents the third layer which includes information resources management and common database. Table 1 depicts that fall under the broad purview of the components discussed so far.

Table 1 Scope of Computer-Integrated Manufacturing

	Business		Production				Design		
	Resource Management	**Economic Accounting**	**Production Planning**	**Part Planning**	**Production Control**	**Part Processing**	**Document Preparation**	**Test**	**Synthesis and Analysis**
Industry	Trend analysis Resource availability Economic Indicators		Capacity and delivery planning R&D	Machining technology database R&D		R & D Testing	Standards Design CAD Interface Parts database		Design standards
Corporation	Trend analysis Facility planning Strategic planning Merger/acquisition Synergistic product Production level Data management	Projection Simulations	Scheduling Facility planning Material requirement planning R&D	Machining technology database Group technology R&D	Data Management	R & D Testing	Parts database Bills of materials GT/ part classification Data management	Test database Field report database Computer - aided engineering	Computer - aided engineering Producibility analysis Design standards
Plant	Plant layout Inventory Scheduling Manpower utilization Make/buy decision Data management	Cost tracking Customer billing Customer order Normal accounting Make/ buy/ economic order quantity	Material requirment planning Bill of materials time standards Scheduling Make/buy decision Facility	Machining technology database GT/plan retrieve Computer assisted process planning R&D Part	Inventory Routine/scheduling Material handling QC/QA Maintenance Purchase/receive Data management Standard methods	R&D Testing	Parts database Computer aided design and drafting Bills of materials GT/part classification Tool/fixture Design and	Computer aided engineering Testing	Design analysis System modelling Producible Analysis GT/design retrieval Design standards
		Cost estimating Process justification	planning Capacity planning , Plant layout Manpower utilization GT/operation sequence	programme Cost estimating			…tooling Data management		
Cell	Job sequencing Inventory Data management	Job tracking Economic data collection	Line balance Machine loading	Machining technology Database Computer assisted processing planning Part programme NC verification	Material handling Routing/scheduling QC/QA inspection Standards methods Inventory data management	Automatic assembly Adaptive control Robotics And data collection	Process instructions	Data acquisition	GT/design retrieval Design standards
Work stations		Economic data collection		Computer assisted process planning	Maintenance/diagnostic	NC. DNC CNC, adaptive control Automatic inspection, sensors diagnostic, data collection	Process instruction	Data acquisition	

1.6 *Operational Flow within CIM*

In this section, the operational flow of functions needed to process an item through a manufacturing facility has been briefly discussed. These operation flows within the CAD/CAM environment have been shown by a flow chart (Fig 5). The box number in figure refers the sequence number.

1, 2. All planning must be the function of known customer orders and sales forecasts. If expected demand are not known/or estimated, the enterprise will be working in a vacuum.

3. Management decisions depend on expected orders leading to long-term order requirement that must be satisfied by either production or by subcontracting to outside sources (vendors).

4. A relatively low term evaluation of facility requirement is needed to plan which parts can be manufactured. For example, enough machines of known capacity available, will material be available, can we perform our needs with the current workforce, and so on. The aggregate planning function determines what product quantities should be produced in what time periods to satisfy the long-term requirements. The result of this activity is called the *master production schedule or master schedule.* It is a schedule for *final product,* not for the components that go into the final product.

5. The master schedule is affected by current status conditions, so feedback loops come from many sources including problems that might occur with deliveries from vendors, trouble in the shop floor, analysis that reveals demands cannot be satisfied due to capacity problems, lack of vendors, and so on.

6. The material requirements planning (MRP) function takes into consideration the current inventory levels for *all* components needed to make the final products (a plant might have 20,000 part numbers and perhaps 100 final products for which master schedules have been determined) as well as the components‟ bills-of-materials and

lead time information (obtained from design and process planning data) and evolves component master schedules for all components according to the demand requirements agreed upon. MRP does not take into account whether manufacturing has sufficient capacity to handle the job releases, therefore capacity planning (6a) evaluates shop loading in terms of the requirements and feedback to the master schedule for corrective actions if any problems occur. A further function of MRP based on such analysis is determining whether components should be produced in-house (6b) or subcontracted to outside vendors (6c).

7. Computer aided design is the function that must be completed after a demand for a product has been determined. Thus, the sequence in which it is discussed in this section is not the same as that of sequence or cycle starting from customer to inception through design, manufacturing, assembly and testing, and back to the customer. The design engineer cannot talk in the same terms as the manufacturing engineer. For example, lines, splines, circles, and arcs come under geometrical design whereas pockets chamfer, holes and so on come under manufacturing design. Process planning function is to accomplish the language transition from design to manufacturing.

8. Some of the functions carried out by process planning modules are as :

(a) Sequence of operations required to manufacture a part

(b) Assessing the time requirement to complete the operations.

(c) Determining the type of machines and tooling required.

(d) Enumerate tolerance stacking problems that are credited due to multiple cuts/multiple components related to a part type.

The profitability and non-profitability of a part being manufactured can be ensured by the process planning function because it takes into account the several ways in which a part being manufactured. In order to achieve a detailed schedule, the information related to process planning is fed into MRP analysis and also in the shop floor scheduling (6b). This step may result in the production of a detailed schedule for machines, tooling, fixtures, people and material handling devices, etc. To avoid the damage, all these have to come together at the right time.

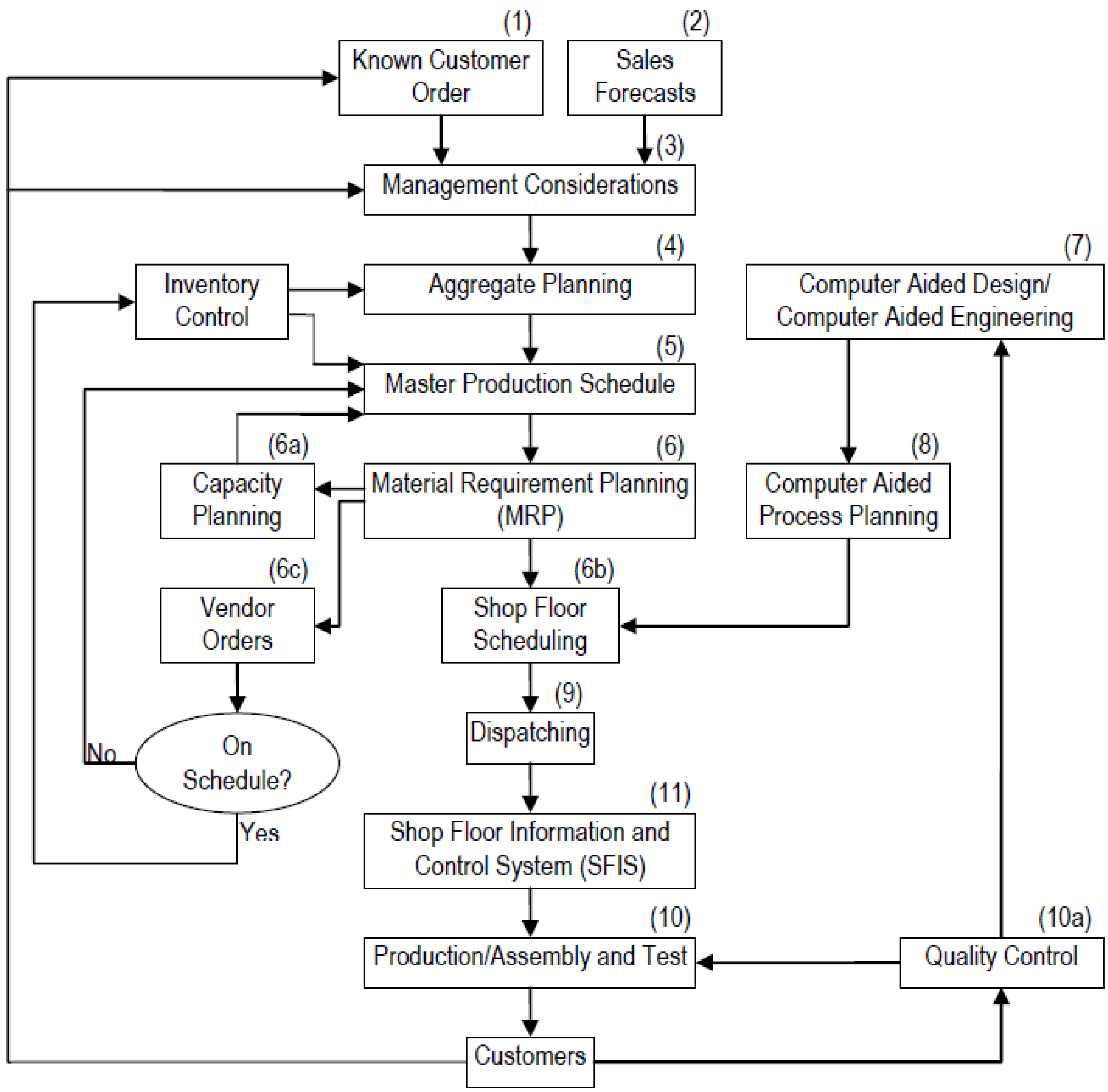


Fig 5: Flow of Operations in CIM

9. Dispatching is the function of releasing all required items needed to perform an operation on a part so that part production must be completed within the schedule time.

10. Production and assembly is accomplished through local control computers and /or programmable controllers.

11. At last, shop floor information system is responsible for getting the required information passed to the downstream entities such as processing equipment, local controllers and sequencing controllers, etc. In this way, real time status records are captured from the various equipments, machines and parts to activate feedback tools so as to ensure the correction or normal continuation of operations in the desired manner.

1.7 *Computer Aided Manufacturing*

The effective use of computer technology in manufacturing planning and control is known as computer aided manufacturing (CAM). Manufacturing engineering functions such as process planning and numeric control (NC) are included in CAM. The application of CAM is divided in two categories:

(i) Manufacturing planning, and

(ii) Manufacturing control.

Manufacturing Planning

The applications of CAM in manufacturing planning are those in which computers are used directly to support the production function, but there is no direct connection between the computer and the process. The computer is used “offline” to provide information for the effective planning and management of the production activities. The following list surveys the application of CAM in this category:

Computer Aided Process Planning (CAPP)

The route sheets listing the operation sequences and workstations required for manufacturing the products and its components are prepared in process planning. These route sheets are prepared now a days using CAPP.

Computer Assisted NC Part Programming

Computer assisted part programming represents a method to generate the control instructions for the machine tools for complex geometries rather than manual part programming. Part Programming for NC machines is step by step instructions according to which tool movements on the part for metal removal is carried out.

Computerized Machinability Data System

Determination of speed and feed in metal cutting for the given machine tools is a major problem. Computer program is written to propose the suitable condition to use for different materials. Estimation of tool life needs information about material of tools and workpiece, speed, feed and depth of cut etc. As per the cutting conditions, such calculations are to be repeated. Therefore, application of computers for such purposes may assist process planner to a great extent.

Development of Work Standard

Responsibility for setting time standards on direct labour jobs performed in the factory is taken by time study department. It is a very tedious and time consuming task to establish standards by direct time study. There are several computer packages also available in market for setting up the work standards. These computer programs use standard time data that have been developed for basic work element that comprise any manual task. By summing the times for the individual elements required to perform a new job, the program calculates the standard time for the job.

Cost Estimating

In many industries, cost estimation of a new product is being simplified by computerizing several key steps needed to prepare the estimate. Suitable labour and overhead rates are applied with the help of the computer programs to the sequence of planned operations involved in the components of new products. Individual components cost which range from the engineering bill of the materials to determine the overall product cost is summed up by the program.

Production and Inventory Planning

Extensive application in many of the functions in inventory planning and production control is being executed by the computer. The aforementioned functions are maintenance of inventory records, automatic recording of stock items in the case when inventory is depleted, production scheduling, maintaining current priorities for the different production orders material requirements planning, and capacity planning etc.

Computer Aided Line Balancing

It is a very tough job to find the best allocation of work elements among stations on an assembly line if the line is of significant size. The problems are solved with the help of computer program.

Manufacturing Control

Another category of CAM application is development of computer supported system for implementing the manufacturing control functions. These control functions manage and control the physical operation in the factory. These functions are as follows:

Process Monitoring and Control

Process monitoring and control concerned with observing and regulating the production equipment of manufacturing processes in the plant. The applications of the process control are absorbed in automated production system. Which includes the example cases like transfer line assembly system, NC, robotics, material handling and flexible manufacturing systems. All these will be discussed later on. Process monitoring and the control functions are deployed to regulate the actions of various production equipments. Some of the well known control systems used in the industry are as follows.

Quality Control

There are varieties of approaches that insure highest possible quality level in the manufacturing system and products and these are included in quality control.

Shop Floor Control

Production management techniques for collecting data from factory operations and using these data to help control production and inventory in the factory comes under shop floor control. Shop floor control and computerized factory data collection systems are discussed in detail later on.

Inventory Control

The important thing about inventory control is that it maintains the most appropriate level of inventory in the face of two opposing objectives: minimizing the investment and storage cost of holding inventory and maximizing service to customer.

Just in Time Production System

A production system that is planned to deliver exactly the right number of each component to downstream workstations in the manufacturing sequence just at the time when that component is needed is known as just in time production system. This term is applicable to production operation and supplier delivery operation.

1.8 *Functions of Computer in CIMS*

- **Machine Control** –CNC

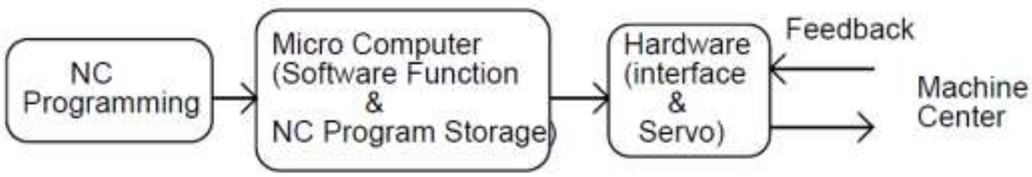


Fig. 6 Schematic diagram of CNC

- **Direct Numerical Control (DNC)** - Amanufacturing system in which a number of m/c are controlled by a computer through direct connection & in real time.

Consists of 4 basic elements:

- Central computer
- Bulk memory (NC program storage)
- Telecommunication line
- Machine tools (up to 100)

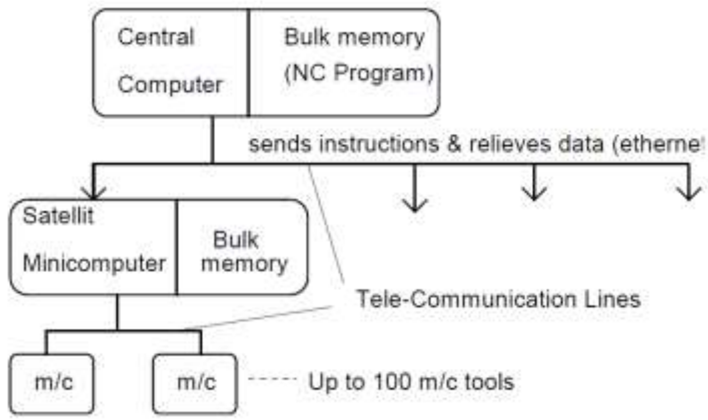


Fig. 7 Schematic representation of Direct Numerical Control

- **Production Control** - This function includes decision on various parts onto the system.

Decision is based on:

- production rate/day for the various parts
- Number of raw work parts available
- Number of available pallets

- **Traffic & Shuttle Control** - Refers to the regulations of the primary & secondary transportation systems which move parts between workstation.

- **Work Handling System Monitoring** - The computer must monitor the status of each cart & /or pallet in the primary & secondary handling system.

- **Tool Control**
- Keeping track of the tool at each station
- Monitoring of tool life

- **System Performance Monitoring & Reporting** - The system computer can be programmed to generate various reports by the management on system performance.
- Utilization reports - summarize the utilization of individual workstation as well as overall average utilization of the system.

- Production reports - summarize weekly/daily quantities of parts produced from a CIMS (comparing scheduled production vs. actual production)
- Status reports - instantaneous report "snapshot" of the present conditions of the CIMS.
- Tool reports - may include a listing of missing tool, tool-life status etc.

- **Manufacturing data base**
- Collection of independent data bases
- Centralized data base
- Interfaced data base
- Distributed data base

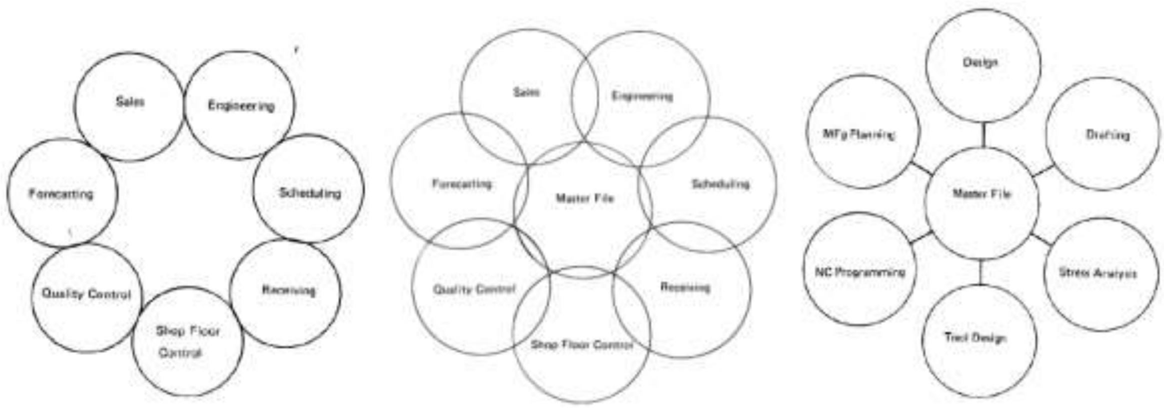


Fig. 8 Functions of Computer in CIM

1.9 *Development of CIM*

CIM is an integration process leading to the integration of the manufacturing enterprise. Fig 9 indicates different levels of this integration that can be seen within an industry. Dictated by the needs of the individual enterprise this process usually starts with the need to interchange information between the some of the so called islands of automation.Flexible manufacturing cells, automatic storage and retrieval systems, CAD/CAM based design etc. are the examples of islands of automation i.e. a sort of computer based automation achieved completely in a limited sphere of activity of an enterprise. This involves data exchange among computers, NC machines, robots, gantry systems etc. Therefore the integration process has started bottom up. The interconnection of physical systems was the first requirement to be recognized and fulfilled.

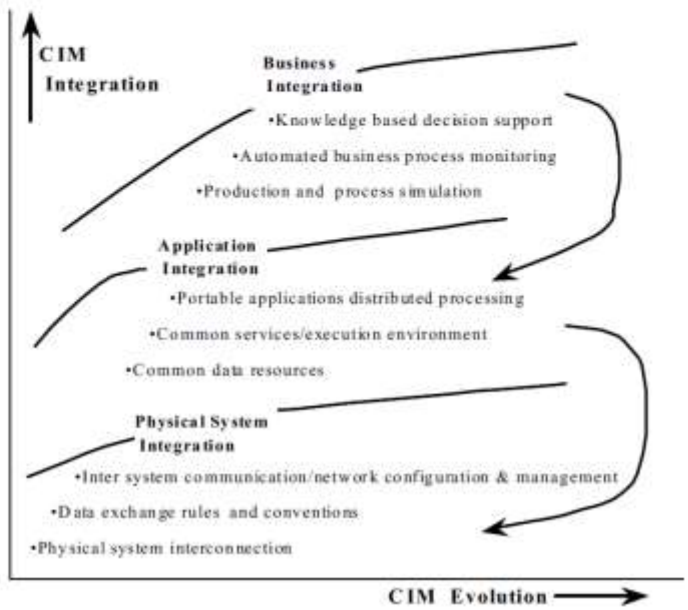


Fig. 9 Levels of Integration against Evolution of CIM

The next level of integration, application integration in Fig 6 is concerned with the integration of applications, the term applications being used in the data processing sense. The applications are those which are discussed under the heading CIM hardware and software. Application integration involves supply and retrieval of information, communication between application users and with the system itself. Thus the application integration level imposes constraints on the physical integration level.
There has to be control of the applications themselves also.

1.10. *Benefits of CIM* -

There are four basic techniques to determine what the tangible benefits from any capital investment, including CIM, are to a business

1. Payback period
2. Return on investment
3. Net present value
4. Internal rate of return.

These are traditional financial formulas which management can use to determine the value of CIM to the company. However, the justification process for advanced manufacturing technologies in CIM must be viewed differently from the traditional process for three reasons:

a. Project Size. CIM investments are projects without ends. Investments made today eventually will be replaced by new technology. Most benefits from CIM accrue with time as advances in both hardware and software take hold.

b. Project components. Since CIM requires various successful installations of advanced manufacturing technology, benefits will accrue due to the synergism of various pieces on the shop floor. The integration of advanced manufacturing technology long term is what makes CIM a self-liquidating expense.

c. Identification of CIM soft benefits. The installation of advanced manufacturing technology in a manufacturing environment can provide significant intangible benefits that traditional financial justification methods don't recognize. The benefits most often cited by business executives are reduced manufacturing costs, improved flexibility on the shop floor, responsiveness to the market, improved product quality, improved product design, small lot manufacturing, reduced inventories, and optimal customer service.

While these benefits are hard to quantify, they can reduce operating costs, improve customer relations, and stimulate sales. The key to evaluating these soft benefits is to understand that a CIM environment allows for fewer levels of management and therefore provides for better use of the business's assets, both human and mechanical. The result for the company is improved decision making and significantly improved profitability.

Computer integrated manufacturing, by joining all the functional areas in the business, can provide a variety of automated services in the factory. For businesses to remain competitive, advanced manufacturing technologies must characterize the factory of the future. In this regard, computer integrated manufacturing have many applications:

Order management: CIM allows for faster delivery and responsiveness to customers and to customer orders through electronic data interchange. In essence, customers will electronically secure and lock in supplier capacity for the product. Additionally, a business will be able to respond to inquiries from its customers instantaneously through electronic data interchange. Being able to respond to customers with rapid information will result in extra business, retaining customers, and getting closer to the customer.

Computer-aided design (CAD). Through CAD, CIM allows the computer to assist in minute details and specifications of a customer order or to simulate variations of the order.

Manufacturing resource planning (MRP II): This allows the production schedule to be simulated and integrated using one information base to direct the operations on the plant floor to balance supply and demand.

Computer technology: CIM allows different hardware to be integrated to communicate with one another (open system). It provides a database foundation for both artificial intelligence and expert systems.

Computer-aided manufacturing (CAM): CAM allows for factory machinery to be programmed through numeral controls (NC) tape preparation and computer numerical control (CNC).

Robotics: Robotics allow for the minimization of human activity in the areas of pick/pack, excessive lifting, transportation, and repetitive manufacturing operations.

Automated guided vehicle systems (AGV's). AGV's allow for driverless forklifts and automated storage and retrieval systems. As JIT becomes more imbedded in future manufacturing disciplines, the role of computerized material-bundling equipment will become more vital.

Group technology: Allows for the coding and classification system to group various families of parts or activities, and to aid in both inventory use and part standardization.

Vendor scheduling: CIM provides for improved scheduling of customer orders to improve delivery and internal processing. In the future, orders will be booked directly via electronic data interchange into a vendor’s upcoming production schedule.

Although this is just a partial list of the uses for computer integrated manufacturing in the factory, it shows that CIM is much more than a means of computers controlling machines.

1.11 *Principles of CIM*

For CIM to be successful businesses must consider the following five fundamental issues involved:

> People and their crucial contribution to manufacturing

> Top management's commitment to the philosophy

> CIM should be put in the context of a well-defined business
Strategy or vision

> The technology plan, the system architecture for cim, must
Include all elements of the company

> It is extremely important when choosing suppliers to access both
The breadth and depth of their support capabilities

People and their crucial contribution to manufacturing -

"Manufacturing, in general, has not done a very good job of understanding how you link the people and the process into this CIM In the past, CIM projects became automated disasters because management became enamored with the technology and computer side of the program. They completely forgot about the people side and neglected to incorporate people into the development process. Information technology will reshape every company that survives through the 90s. However, businesses will not be able to incorporate technology advances if they do not find a way to make workers comfortable with computers. Additionally, workers will not have the requisite skills and abilities to succeed and advance if they are not able to work with computers.

Almost every white-collar job in America requires some level of familiarity with computers. Additionally, it is estimated that 75% of industrial workers also need at least elementary computer skills. Management must understand what enables workers at any skill level to be able to master their computers. Companies that have transformed their work forces with technology have distilled a set of principles that apply equally to workers on an assembly line or in the front office. These principles include the following:

- *Think of How to Empower Your Workers, Instead Of Dumping*
- *Technology on Them*- The most advanced enterprises have realized that they have got to deal with the people side at the same time they deal with the technology.
- *Listen to Your Employees When Designing a System (Bottom Up)* -Managers of highly automated operations are unanimous, if you don't involve the users, you will develop the wrong system. Nobody understands the job like the people who do it. They can tell you how to design the tools that will let them work more efficiently. They will trust new technology more if they had a say in it and knew it was coming. The company wins more commitment from its workers when they feel their contributions were valuable in the design of the system.
- Understand and Communicate Your Business Objectives- Employees will accept and learn new technologies if they understand their importance. Fancy computers seldom make much difference in productivity if workers do not understand how the technology helps achieve business goals. It is important to see new technology as only part of a total vision of changed organizations. Therefore, management must look at the information employees need, the materials they need, the incentives they need, and all other aspects of the business, not just automating.
- Teach Your Employees by Helping Them Improve Their Performance-The most important aspect of incorporating new technology is learning to do the job better, not learning how to operate the computer. Traditional classroom instruction is seldom the best way to go. The most useful training comes only when workers need it.

Three common approaches are:

a - Mentors, other employees in the organization who know a little more than most, who can help others when questions arise.

b - On-line help programs within the software.

c - Simultaneous interactive video training for workers.

- Don't Ignore the Generation Gap - People who grew up in the Nintendo generation have an advantage over their elders. These younger workers adapt more readily to technological incorporation into the workplace. Conversely, big-time computer klutzes may slip in the pecking order if they can't handle the new technology deftly. Some companies introduce workers to computers by using computer games to make them comfortable interacting with a screen. To implement CIM you have to design technology that is usable by people. If people do not use the systems, you might as well throw them away. According to Lee Sage, national director of automotive services at Ernst & Young, "it became apparent that the manufacturing companies that were doing the best job were those that didn't necessarily have the best technology. What they had was a heavy orientation towards people.

- Top Management's Commitment to the Philosophy - "The biggest obstacle to CIM implementation...is getting the necessary cross-functional and senior-management support for the fundamental change required to implement CIM across the business. The most important part of successful technological integration is top management commitment and participation. It is estimated that technological illiteracy at the top plagues 90% of American companies. Yet there is no better way to get middle management and supervisors to use computerized tools than to let them see the boss using it first. Therefore, the first worker who has to be brought up to techno-speed is the person on top. In many cases, the major stumbling block to implementation of CIM is a lack of familiarity with the technologies at the upper levels of management. "Of the company presidents, chairmen, and CEOs who responded to a Industry Week survey, 58.3% said they are only 'vaguely familiar' with CIM technologies".
- CIM should be put in the Context of a Well-Defined Business Strategy or Vision - The most important elements of CIM are the business processes and strategies that are developed to support it. They are what drive the whole process. Secondary to all of that is the computer hardware and software. In order for CIM to function properly, it must significantly advance the company's ability to improve quality, increase productivity, provide flexibility in lot sizes and schedules, reduce costs, and help shorten the time it takes to get products designed and to the market. "CIM should never be viewed as being the objective or ultimate goal. The purpose of undertaking the CIM journey is not to have a CIM system. Rather, the purpose of implementing

CIM is to help the firm survive by developing a distinctive corporate advantage through its manufacturing capabilities. To this end, CIM requires, as a prerequisite, a well-developed, well understood, and widely known corporate strategy. The entire company needs to be represented in CIM planning. Walls and boundaries between departments and functions must come down. Making CIM an integral part of the overall business strategy and involving people from all parts of the company in planning for CIM will greatly enhance its chances for success. "The thing that most people missed in implementing CIM is the fact that, by itself, CIM isn't enough. The critical missing piece is the concept of an enterprise strategy, which repositions your company to do that which it does best. Many executives are still sorting out their definitions of CIM and its functional role in the overall operation of the business. There has been a gradual shift in thinking in recent years away from a strict technology focus and towards an overall business strategy focus. Managers are asking themselves what are their business objectives and how does CIM fit into these objectives. However, according to an Industry Week Magazine poll, only 32.9% of managers report that their companies have a long-term strategy for implementing CIM. The lack of long-term strategies may have an explanation in the fact that information technologies have been mushrooming at a rapid pace, and manufacturing planners are faced with an unmanageable array of new hardware and software applications. Additionally, the trend toward open-system computing and its implications for selection of computer systems is not fully understood by the top-level executives who will eventually make the go/no-go decisions regarding technology purchases.

- The Technology Plan, the System Architecture for CIM, must include all Elements of the Company--The ideal system architecture for CIM will ensure that information can flow where it is needed when it is needed. It must also be flexible enough to be adaptable to the changing needs business and rapidly advancing technologies, while protecting the value of existing investments in the system and technology. Overall, many manufacturing businesses have not been extremely successful at integrating people, processes and functions into an overall CIM concept. "What we are really talking about is going beyond CIM to computer-integrated business management, and hitting on all the key things you need to do to succeed as a business.

- It is extremely important when Choosing (Hardware and Software System) Suppliers to Access both The Breadth and depth of their Support Capabilities-- In today's marketplace, a business must look beyond products and pricing when selecting suppliers. Slow start-up, downtime, and other production-related problems cut the very heart out of profitability, and can greatly reduce any competitive advantage attained with CIM. Manufacturing companies must look for supplier-support capabilities that include: application engineering, training, installation and start-up, coordination with the equipment manufacturer, proper documentation, maintenance, repair-return depots, phone support, on-line system support, and emergency service. Support should be available 24 hours a day, seven days a week, year around. If the company is global, the supplier's ability to support world-wide operations must be taken into consideration prior to the purchase decision.

1.12 *Objectives and Implementation of a CIM System*

The overall job of computer integrated manufacturing strategic planning requires a comprehensive look at the process equipment, facilities, personnel structure and roles, plus the scheduling and control requirements. Implementation of CIM requires the development of a CIM master plan, which encompasses a critical look at the current plant scheduling and control hierarchy (if in an existing facility), a detailed description of the desired plant scheduling and control system hierarchy, and a plan to manage the transition from the current state to the desired future state. This plan must incorporate all functions of the operation (marketing, personnel, engineering, etc.) in their relationships to manufacturing and production control. In order to provide for the overall objectives must be defined of the organization, objectives for the various technology systems expected to be required to meet the business's long range needs. These systems include database management systems, communications networks, process controls, process optimization, and process improvement and decision support systems. Database management systems should be open in nature and must interconnect, interrelate, and integrate all department and area databases of the business, including corporate, division, research, and marketing strategies, as well as plant operations and production control. Communication networks must provide plant-wide information exchanges with appropriate interactive work stations and permit ready access to plant information by all users of the data. Additionally, they must provide for intra-plant, intra-division, and intra-organization communication as needed. Process control must make computer automated control available in all areas of the manufacturing process. In addition, the technology must expand the scope of conventional control to include the following supporting goals:

a. Minimize the manual entry and recording of all measurements and operational decisions to minimize errors and expedite data acquisition.

b. Simplify the conducting of economic and operational studies to permit quick analysis of unusual operating conditions.

c. Increase the process and system engineer's productivity through readily accessible, efficient and comprehensive analysis and design tools.

d. Increase the scope and interactive access to history data to permit thorough analysis of process and operational problems.

e. Expedite the process of system expansion and growth. Process optimization must permit the expansion of efforts in simulation, optimization, and scheduling of process operations. Process improvement must make use of the available plant-wide information to modify the overall process so as to reduce the number of rejects which are produced. After completion of the objectives analysis the major steps in the implementation of a CIM system are:

i. Analysis of the existing manufacturing system (if existing plant) or new facility design for compatibility with CIM technology.

ii. Analysis of the existing and proposed management and personnel structure for the plant in view of its compatibility with the proposed CIM system.

iii. Development of the system master plan for designing and implementing the CIM scheduling and control hierarchy.

iv. Develop expected systems costs and project timing in conjunction with systems benefits and projections, thereby establishing justification concerning systems costs and anticipated payout.

v. Iterate the steps outlined above until acceptance is obtained from all personnel concerned and company justification criteria is satisfied.

vi. Implement and execute system master plan

vii. Follow up and adjust as necessary.

Summary: Computer integrated manufacturing (CIM) is a broad term covering all technologies and soft automation used to manage the resources for cost effective production of tangible goods.

- Integration – capital, human, technology and equipment
- CIM – This orchestrates the factors of production and its management.

Computer Aided Design (CAD)

Computer Aided Manufacturing (CAM)

Flexible Manufacturing Systems (FMS)

Computer Aided Process Planning (CAPP)

- CIM is being projected as a panacea for Discrete manufacturing type of industry, which produces 40% of all goods.

"CIM is not applying computers to the design of the products of the company. That is computer aided design (CAD)! It is not using them as tools for part and assembly analysis. That is computer aided engineering (CAE)! It is not using computers to aid the development of part programs to drive machine tools. That is computer aided manufacturing (CAM)! It is not materials requirement planning (MRP) or just-in-time (JIT) or any other method of developing the production schedule. It is not automated identification, data collection, or data acquisition. It is not simulation or modeling of any materials handling or robots or anything else like that. Taken by themselves, they are the application of computer technology to the process of manufacturing. But taken by themselves they only crate the ***islands of automation****."*

- Leo Roth Klein, Manufacturing Control systems, Inc.

Definition of CIM:

It describes integrated applications of computers in manufacturing. A number of observers have attempted to refine its meaning:

One needs to think of ***CIM as a computer system*** *in which the peripherals, instead of being printers, plotters, terminals and memory disks are robots, machine tools and other processing equipment. It is a little noisier and a little messier, but it's basically a computer system.*

- Joel Goldhar, Dean, Illinois Institute of Technology

CIM is a management philosophy*, not a turnkey computer product. It is a philosophy crucial to the survival of most manufacturers because it provides the levels of product design and production control and shop flexibility to compete in future domestic and international markets.* - Dan Appleton, President, DACOM, Inc.

CIM is an opportunity for realigning your two most fundamental resources: people and technology. CIM is a lot more than the integration of mechanical, electrical, and even informational systems. It's an understanding of the ***new way to manage****.*

- Charles Savage, president, Savage Associates

CIM is nothing but a ***data management and networking*** *problem.*

- Jack Conaway, CIM marketing manager, DEC

The preceding comments on CIM have different emphases (as highlighted).

An attempt to define CIM is analogous to a group of blind persons trying to describe an elephant by touching it.

"CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency."

- Shrensker, Computer Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME)

Concept or Technology

"Some people view CIM as a concept, while others merely as a technology. It is actually both. A good analogy of CIM is *man*, for what we mean by the word man presupposes both the mind and the body. Similarly, CIM represents both the concept and the technology. The concept leads to the technology which, in turn, broadens the concept."

- According to Vajpayee

The meaning and origin of CIM

The CIM will be used to mean the integration of business, engineering, manufacturing and management information that spans company functions from marketing to product distribution.

The changing and manufacturing and management scenes

The state of manufacturing developments aims to establish the context within which CIM exists and to which CIM must be relevant. Agile manufacturing, operating through a global factory or to world class standards may all operate alongside CIM. CIM is deliberately classed with the technologies because, as will be seen, it has significant technological elements. But it is inappropriate to classify CIM as a single technology, like computer aided design or computer numerical control.

External communications

Electronic data interchange involves having data links between a buying company's purchasing computer and the ordering computer in the supplying company. Data links may private but they are more likely to use facilities provided by telephone utility companies.

Islands of automation and software

In many instances the software and hardware have been isolated. When such computers have been used to control machines, the combination has been termed an island of automation. When software is similarly restricted in its ability to link to other software, this can be called an island of software.

Dedicated and open systems

The opposite of dedicated in communication terms is open. Open systems enable any type of computer system to communicate with any other.

Manufacturing automation protocol (MAP)

The launch of the MAP initiates the use of open systems and the movement towards the integrated enterprise.

Product related activities of a company

1. **Marketing**
    - Sales and customer order serviceing
2. **Engineering**
    - Research and product development
    - Manufacturing development
    - Design
    - Engineering release and control
    - Manufacturing engineering
    - Facilities engineering
    - Industrial engineering
3. **Production planning**
    - Master production scheduling
    - Material planning and resource planning
    - Purchasing
    - Production control
4. **Plant operations**
    - Production management and control
    - Material receiving
    - Storage and inventory
    - Manufacturing processes

- Test and inspection
- Material transfer
- Packing, dispatch and shipping
- Plant site service and maintenance

5. **Physical distribution**
    - Physical distribution planning
    - Physical distribution operations
    - Warranties, servicing and spares
6. **Business and financial management**
    - Company services
    - Payroll
    - Accounts payable, billing and accounts receivable

2. Introduction to Process Planning

Process planning is concerned with determining the sequence of individual manufacturing operations needed to produce a given part or product. The resulting operation sequence is documented on a form typically referred to as operation sheet. The operation sheet is a listing of the production operations and associated machine tools for a work part or assembly. Process planning is an important stage of product development since production tooling like jigs, fixtures, special tools etc. can be designed only after the process is finalized.

Role of process planning

1. Interpretation of product design data
2. Selection of machining processes.
3. Selection of machine tools.
4. Determination of fixtures and datum surfaces.
5. Sequencing the operations.
6. Selection of inspection devices.
7. Determination of production tolerances.
8. Determination of the proper cutting conditions.
9. Calculation of the overall times.
10. Generation of process sheets including NC data.

Approaches to Process planning

1. Manual approach
2. Variant or retrieval type CAPP system
3. Generative CAPP system

CAPP and CMPP (Computer Managed Process Planning)

2.1 *Process Planning*

Manufacturing planning, process planning, material processing, process engineering and machine routing are a few titles given to the topic referred to here as process planning. Process planning is that function within a manufacturing facility that establishes which machining process and process parameters are to be used to convert a work material (blank) from its initial form (raw material) to a final form defined by an engineering drawing. Process planning is a common task in small batch, discrete parts metal working industries. The process planning activity can be divided into the following steps:

- Selection of processes and tools
- Selection of machine tools/Manufacturing equipment
- Sequencing the operations
- Grouping of operations
- Selection of work piece holding devices and datum surfaces (set ups)
- Selection of inspection instruments
- Determination of production tolerances
- Determination of the proper cutting conditions
- Determination of the cutting times and non-machining times (setting time, inspection time) for each operation
- Editing the process sheets.

All the information determined by the process planning function is recorded on a sheet called process plan. The process plan is frequently called an operation sheet, route sheet or operation planning sheet. This provides the instructions for the production of the part. It contains the operation sequence, processes, process parameters and machine tools used. Fig 9.1 shows a typical process planning sheet.

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. However, individual engineers will have their own opinions about what constitutes the best routing. Accordingly there are differences among the operation sequences developed by various planners. Efficient process planning requires the service of experienced process planners.

Because of the problems encountered with manual process planning, attempts have been made in recent years to capture the logic, judgment and experience required for this important function and incorporates them into computer programmes. Based on the features of a given part, the program automatically generates the sequence of manufacturing operations. The process planning software provides the opportunity to generate production routings which are rational, consistent and perhaps even optimal.

It has the following advantages:

i. Reduces the skill required of a planner.

ii. Reduces the process planning time.

iii. Reduces the process planning and manufacturing cost.

iv. Creates more consistent plans.

v. Produces more accurate plans.

vi. Increases productivity.

The current approaches for computer aided process planning can be classified into two groups:

i. Variant

ii. Generative

2.2 *Structure of a Process Planning Software*

Fig. 10 represents the structure of a computer aided process planning system. In Fig. 10 the 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.

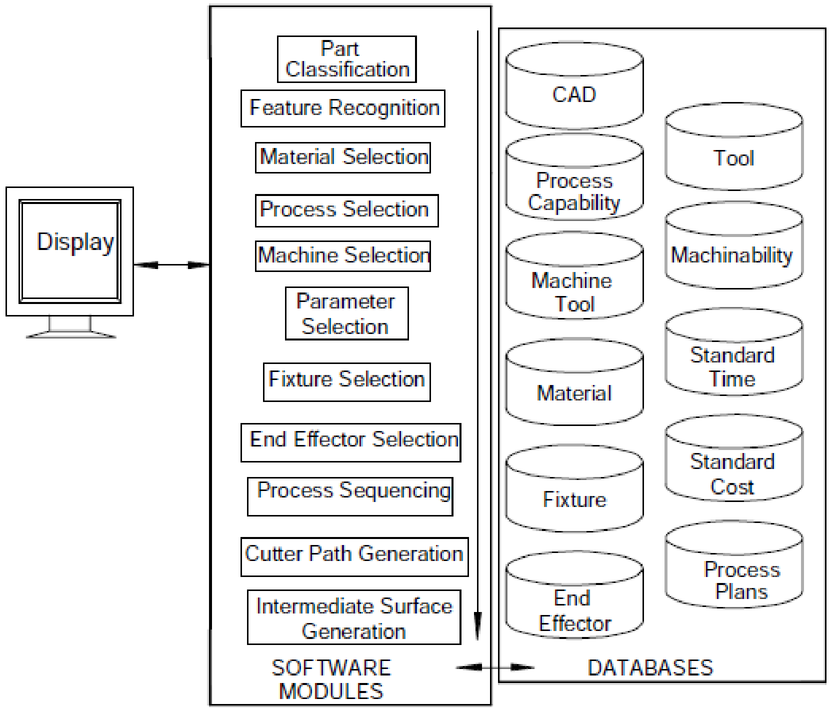


Fig. 10 Structure of a Computer Aided Process Planning System

2.3 *Information required for Process Planning*

The geometric model of the part is the input for the process planning system. The system outputs the process plan (Fig. 11). The input to the process planning system may be engineering drawing or CAD model. The other prerequisites for process planning are given below:

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

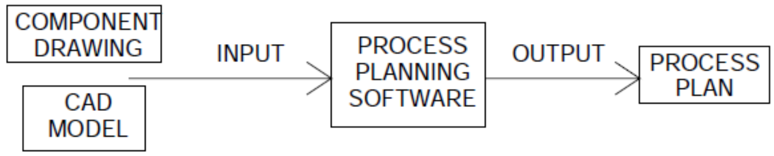


Fig. 11 Activities in Process Planning

In a computerized process planning system a formal structure and a knowledge database are required in order to transform the engineering design information into the process definition. A brief description of the operation of a computer aided process planning software is given in the following section.

2.4 *Methods of Computer Aided Process Planning*

The ultimate goal of a system is to integrate design and production data into a system that generates useable process plans. As already mentioned there are two approaches:

i. Variant process planning

ii. Generative process planning

- ***Variant Process Planning***

A variant process planning system uses the similarity among components to retrieve the existing process plans. 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. A family is represented by a family matrix which includes all possible members. The variant process planning system has two operational stages:

• A preparatory stage and

• A production stage.

During the preparatory stage, existing components are coded, classified, and subsequently grouped into families. The process begins by summarizing process plans already prepared for components in the family. Standard plans are then stored in a data base and indexed by family matrices (Fig. 12).

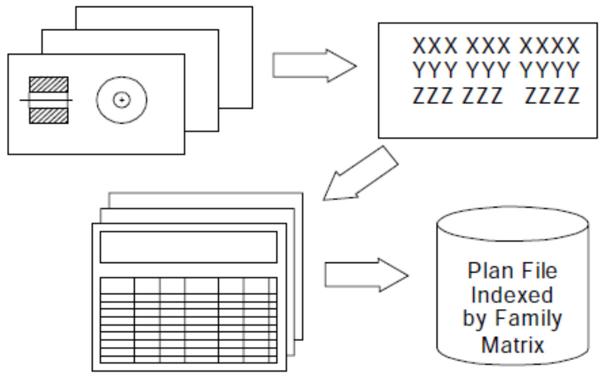


Fig. 12 Process Family Matrix

The operation stage occurs when the system is ready for production. An incoming part is first coded. The code is then input to a part family search routine to find the family to which the component belongs. The family number is then used to retrieve a standard plan. Some other functions, such as parameter selection and standard time calculations, can also be added to make the system more complete (Fig. 13). This system is used in a machine shop that produces a variety of small components.

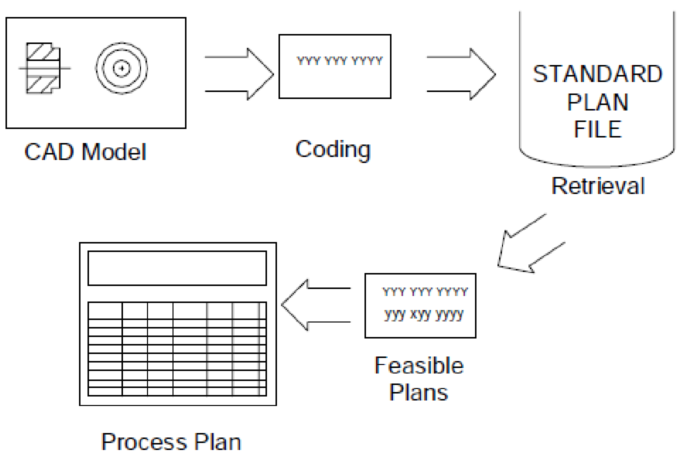


Fig. 13 Part Search and Retrieval

Design of Variant Process Planning System

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

i. Family formation

ii. Data base structure design

iii. Search algorithm development and implementation

iv. Plan editing

v. Process parameter selection/updating

- Family Formation

Part family classification and coding were discussed earlier. This is based on the manufacturing features of a part. Components requiring similar processes are grouped into the same family. A general rule for part family formation is that all parts must be related. Then, a standard process plan can be shared by the entire family. Minimum modification on the standard plan will be required for such family members.

Data Base Structure Design

The data base contains all the necessary information for an application, and can be accessed by several programs for specific application. There are three approaches to construct a data base: hierarchical, network, and relational.

Search Procedure

The principle of a variant system is to retrieve process plans for similar components. The search for a process plan is based on the search of a part family to which the component belongs. When, the part family is found, the associated standard plan can then be retrieved. A family matrix search can be seen as the matching of the family with a given code. Family matrices can be considered as masks. Whenever, a code can pass through a mask successfully, the family is identified.

Plan Editing and Parameter Selection

Before a process plan can be issued to the shop, some modification of the standard plan may be necessary, and process parameters must be added to the plan. There are two types of plan editing: One is the editing of the standard plan itself in the data base, and the other is editing of the plan for the component. For editing a standard plan, the structure of the data base must be flexible enough for expansion, additions, and deletions of the data records.

A complete process plan includes not only operations but also process parameters. The data in the process parameter files are linked so that we can go through the tree to find the speed and feed for an operation. The parameter file can be integrated into variant planning to select process parameters automatically.

- ***Generative Process Planning***

Generative process planning is a system that synthesizes process information in order to create a process plan for a new component automatically. In a generative planning system, process plans are created from information available in manufacturing data base without human intervention. Upon receiving the design model, the system can generate the required operations and operation sequences for the component. Knowledge of manufacturing must be captured and encoded into efficient software. By applying decision logic, a process planner’s decision making can be imitated. Other planning functions, such as machine selection, tool selection, process optimization, and so on, can also be automated using generative planning techniques. The generative planning has the following advantages:

i. It can generate consistent process plans rapidly.

ii. New process plans can be created as easily as retrieving the plans of existing components.

iii. It can be interfaced with an automated manufacturing facility to provide detailed and up-to-date control information.

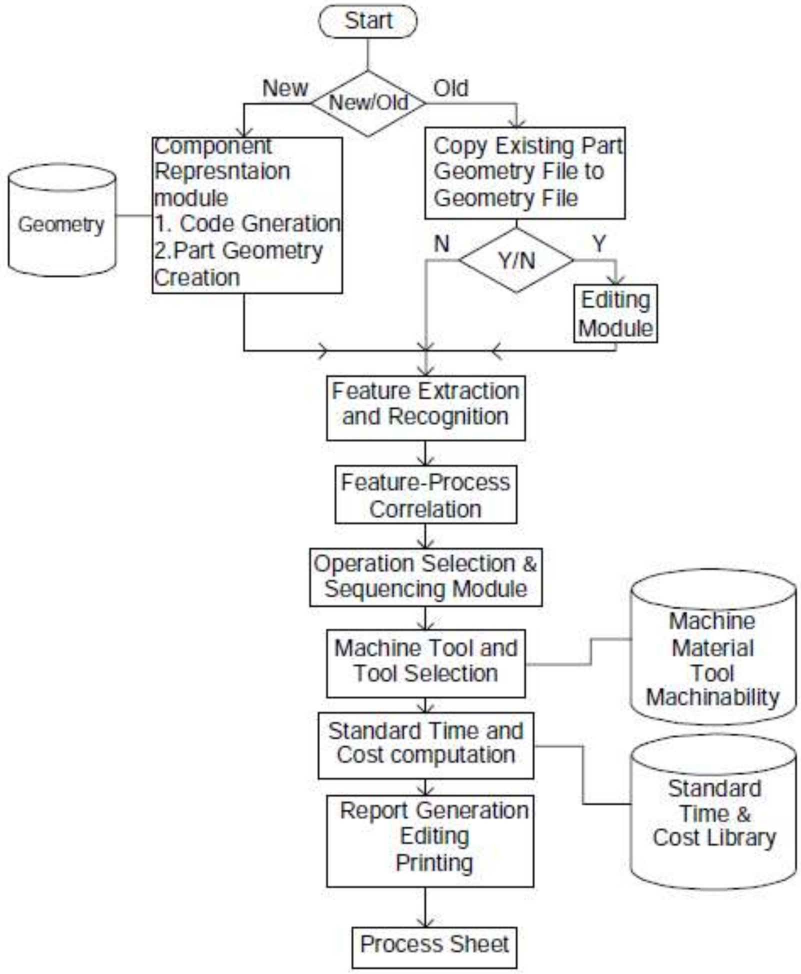


Fig. 14 shows the modular structure of a generative CAPP system.

The generative part consists of:

• Component representation module

• Feature extraction module

• Feature process correlation module

• Operation selection and sequencing module

• Machine tool selection module

• Standard time / cost computation module

• Report generation module

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

i. Forward and backward planning

ii. Input Format

iii. CAPP based on CAD models

iv. CAPP based on decision logic either using decision trees or decision tables

v. CAPP based on artificial intelligence

Forward and Backward Planning

In generative process planning, when process plans are generated, the system must define an initial state in order to reach the final state (goal). The path taken represents the sequence of processes. For example, the initial state is the raw material and the final state is the component design. Then a planner works in modifying the raw workpiece until it takes on the final design qualities. This is called forward planning.

Backward planning uses a reverse procedure. Assuming that we have a finished component, the goal is to go back to the un-machined workpiece. Each machining process is considered a filling process. Forward and backward planning may seem similar. However they influence the programming of the system significantly. Planning each process can be characterized by a precondition of the surface to be machined and a post condition of the machining (the end result). For forward planning, we must know the successor surface before we select a process, because the post condition of the first process becomes the precondition for second process. Backward planning eliminates this problem since it begins with the final surfaces from and processes are selected to satisfy the initial requirements. In forward planning, the steps to obtain the final surface with the desirable attributes must be carefully planned to guarantee the result. On the other hand, backward planning starts with the final requirements and searches for the initial condition.

2.5 *Process Planning Systems*

The majority of existing process planning systems is based on variant process planning approach. Some of them are: CAPP, MIPLAN, MITURN, MIAPP, UNIVATION, CINTURN, COMCAPPV, etc. However, there are some generative system, such as METCAPP, CPPP, AUTAP, and APPAS. Some of the planning systems are discussed in the following paragraph. These are systems continuously evolving in many cases. The descriptions are therefore only approximate.

CAM-I CAPP

The CAM-I (Computer Aided Manufacturing-International) system (CAPP) is perhaps the most widely used of all process planning systems. CAPP is a database management system written in ANSI standard FORTRAN. It provides a structure for a data base, retrieval logic, and interactive editing capability. The coding scheme for part classification and the output format are added by the user. PI-CAPP, an extension of CAPP, has its own (built-in) coding and classification system. This eliminates the requirement of a user developed coding scheme. A typical CAPP system is shown in Fig. 15.

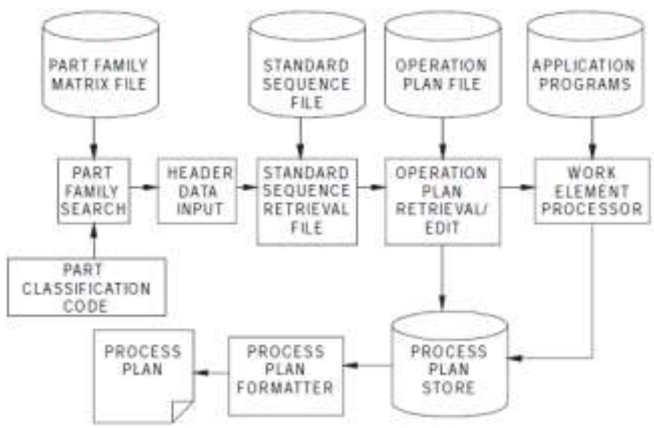


Fig. 15 CAPP System

MIPLAN and MULTICAPP

Both MIPLAN and MULTICAPP were developed in conjunction with OIR (Organization for Industrial Research). They are both variant systems that use the MICLASS coding system for part description. They are data retrieval systems which retrieve process plans based on part code, part number, family matrix, and code range. By inputting a part code, parts with a similar code are retrieved. The process plan for each part is then displayed and edited by the user. A typical MULTICAPP system is shown in Fig. 16.

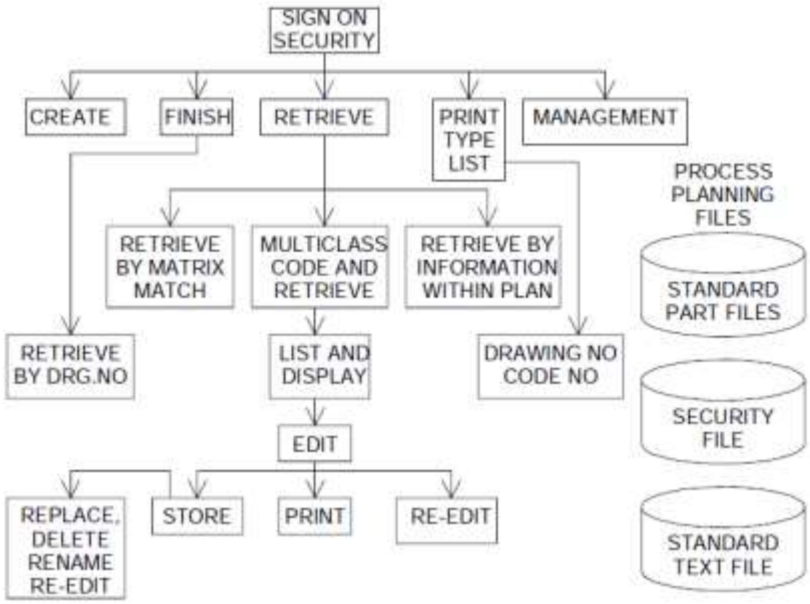


Fig. 16 MULTICAPP System

APPAS and CADCAM

APPAS is a generative system for detailed process selection. CADCAM is an example of APPAS. CADCAM operates using a CAD "front end" to interface with APPAS. APPAS describes the detailed technological information of each machined surface by means of a special code. CADCAM provides an interactive graphics interface to APPAS. Components can be modeled graphically and edited interactively.

AUTOPLAN and RPO

AUTOPLAN is generative only in the detailing of the part. The process selection and process sequencing level do not differ significantly from CAPP or MIPLAN. The four major modules of the system are:

i. Group technology retrieval-process plan retrieval.

ii. Graphical planning aides- tooling layout, verification and work instruction and preparation.

iii. Generative process planning.

iv. Process optimization.

AUTAP System

The AUTAP system is one of the most complete planning systems in use today. AUTAP uses primitives to construct a part similar to a constructive solid geometry (CSG). AUTAP is a system designed especially to interface with a CAD system. It can be installed as part of an integrated CAD/CAM system.

CPPP

CPPP (computerized production process planning) was designed for planning cylindrical parts. CPPP is capable of generating a summary of operations and the detailed operation sheets required for production. The principle behind CPPP is a composite component concept. A composite component can be thought of as an imaginary component which contains all the features of components in one part family. CPPP incorporates a special language, COPPL, to describe the process model. CPPP allows an interactive mode whereby the planner can interact with the system at several fixed interaction points.

GARI

GARI is an experimental problem solver which uses artificial intelligence (AI) techniques. The unique feature of the GARI is the representation of planning knowledge. GARI employs a production rule knowledge base to store process capabilities.

TIPPS

Although the process planning steps have been discussed, an integrated approach to generative process planning has yet to be presented. TIPPS is acronym for Totally Integrated Process planning. TIPPS is generative process planning system that has evolved from the APPAS and CAD/CAM systems. In TIPPS, the logical divisions of process planning are broken into functional modules. TIPPS has the following features:

- It has a modular structure
- It can interact with a CAD system
- It allows for interactive surface identification
- It contains a process/knowledge description language

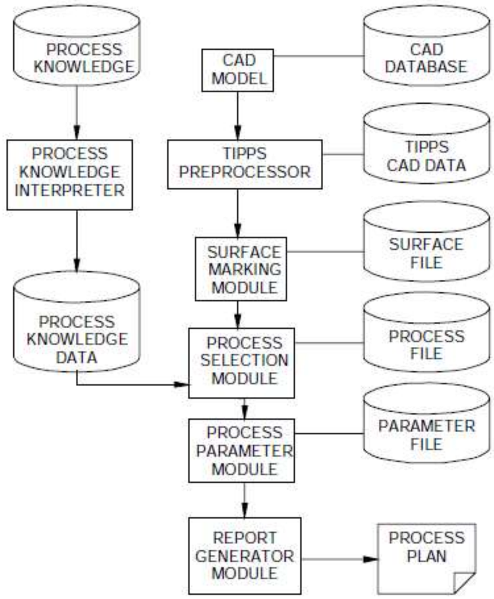


Fig. 17 TIPPS

Computer Aided Process Planning (CAPP): ***Summary***

Process planning with the aid of computer

• Process planning is concerned with the preparation of route sheets that list the sequence of operations and work centers require to produce the product and its components.

• Manufacturing firms try to automate the task of process planning using CAPP systems due to many limitations of manual process planning. These includes:

– Tied to personal experience

– and knowledge of planner of production facilities, equipment, their capabilities, process and tooling. This results in inconsistent plans.

– Manual process planning is time consuming and slow.

– Slow in responding to changes in product design and production.

• The experience of manufacturing of different engineers, who are likely to retire, can be made available in future by CAPP.

• CAPP is usually considered to be part of CAM, however this results CAM as stand-alone system.

• Synergy of CAM can be achieved by integrating it with CAD system and CAPP acts as a connection between the two.

• Readymade CAPP systems are available today to prepare route sheets.

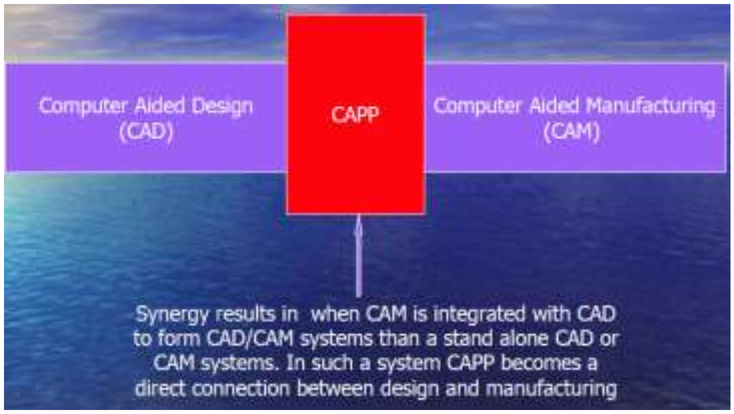


Fig. 18 Schematic representation of CAPP

Benefits derived from CAPP

• Process rationalization and standardization

• Increased productivity of process planners

• Reduced lead time for process planning

• Improved legibility

• Incorporation of other application programs

CAPP Model

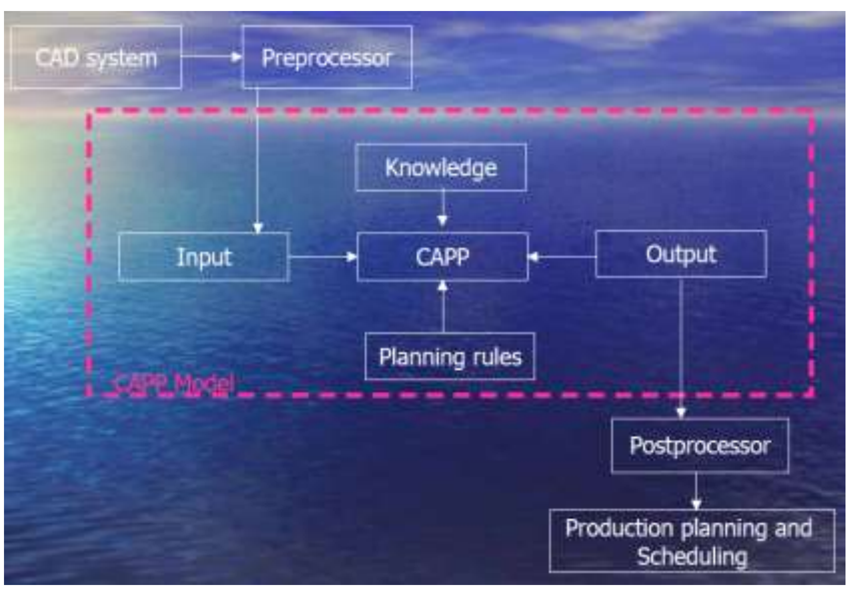


Fig. 19 CAPP Model

CAPP System Architecture

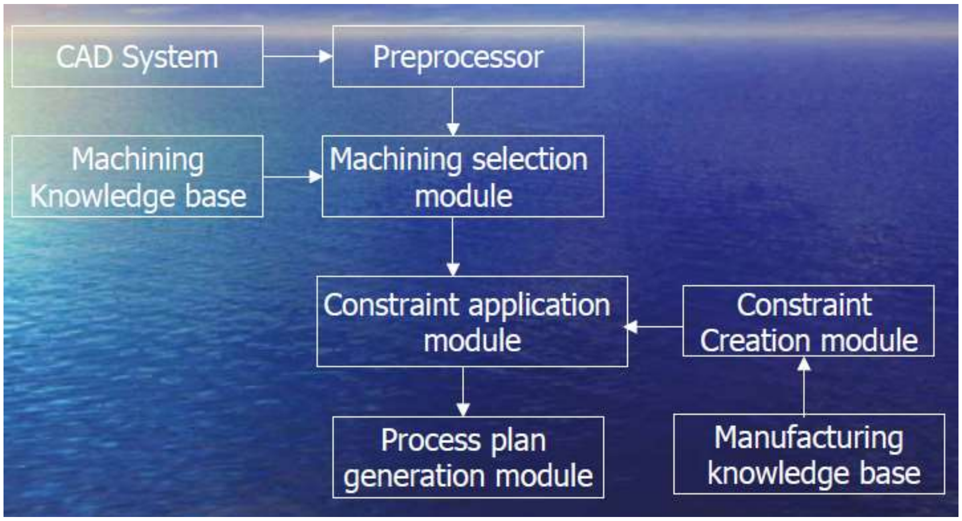


Fig. 20 CAPP System Architecture

Design approaches of CAPP systems

Retrieval CAPP systems/ Variant CAPP

– This has evolved out of the traditional manual process planning method. A process plan for a new part is created by identifying and retrieving an existing plan for a similar part, followed by the necessary modifications to adapt it to the new part.

– It is based on GT principles, i.e., part classification and coding. These coding allow the CAPP system to select a baseline process plan for the part family and accomplish about 90% of the planning work. The planner adds the remaining 10% of the planning by modifying the baseline plan.

– If the code of the part does not match with the codes stored in the database, a new process plan must be generated manually and then entered into database to create a new baseline process plan for future use.

Advantages and limitations of Variant CAPP

– Investment in hardware and software is not much.

– The system offers a shorter development time and lower manpower consumption to develop process plan.

– The system is very reliable and reasonable in real production environments for small and medium size companies.

– Quality of process plan depends on knowledge and background of process planner.

Generative CAPP

• Process plans are generated by means of decision logics, formulas, algorithms, and geometry based data that are built or fed as input to the system.

• Format of input

– Text input (interactive)

– Graphical input (from CAD models)

• First key: to develop decision rules appropriate for the part to be processed. These rules are specified using decision trees, logical statements, such as if-then-else, or artificial intelligence approaches with object oriented programming.

• Second key: Finding out the data related to part to drive the planning. Simple forms of generative CAPP systems may be driven by GT codes.

A pure generative system can produce a complete process plan from part classification and other design data which does not require any further modification or manual interaction.

• In generating such plans, initial state of the part (stock) must be defined in order to reach the final state i.e., finished part.

• Forward or backward planning can be done.

• Forward and backward planning apparently appear to be similar but they effect programming significantly. The requirement and the results in of a setup in forward planning are the results and requirements, respectively, of the set up in backward planning.

• Forward planning suffers from conditioning problems; the results of a setup affect the next set up.

• In backward planning, conditioning problems are eliminated because setups are selected to satisfy the initial requirements only.

• The generative CAPP has all the advantages of variant CAPP however it has an additional advantage that it is fully automatic and a up-to-date process plan is generated at each time.

• It requires major revisions if a new equipment or processing capabilities became available.

• The development of the system in the beginning is a difficult

What is CAPP?

Process planning acts as a bridge between design and manufacturing by translating design specifications into manufacturing process details

Process Plan

- Refers to a set of instructions that are used to make a component or a part so that the design specifications are met
- Determines how a component will be manufactured
- Is a major determinant of manufacturing cost and profitability of products

Process Planning

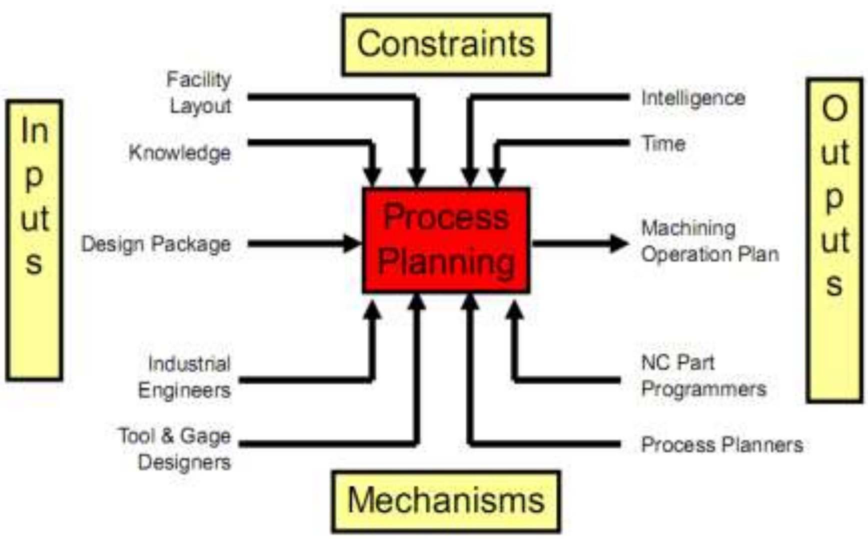


Fig. 21 working principle of Process Planning

Basic Process in developing a process plan

1. Analysis of part requirements
2. Selection of raw workpiece
3. Determining manufacturing operations and their sequence
4. Selection of machine tools
5. Selection of tools, work-holding devices, and inspection equipment
6. Determining machining conditions (cutting speed, feed, depth of cut) and manufacturing times (setup time, processing time, and lead times)

- Process Planning Approaches
  - Manual Systems
  - Computer Aids
    - Variant System
    - Experimental Generative System

Manually Prepared Process Plans

- A skilled individual examines a part drawing to develop the necessary instructions for the process plan
- Requires knowledge of the manufacturing capabilities of the factory (many times undocumented)
  - Machine and process capabilities, tooling, materials, standard practices, and associated costs
- Widely used, time consuming, plans developed over a period of time may not be consistent nor objective
- Excessive time and cost may be required to develop necessary skills for successful planners

Computer Aids

- "Computer-aided" is a key factor in the integration of CAD and CAM
- The use of computers in process planning can:
  - Systematically produce accurate and consistent process plans
  - Reduce the cost and lead time of process planning
  - Reduce skill requirements of process planners
  - Increase productivity of process planners
  - Interface application programs such as work standards, cost estimation, and lead time estimation
  - Consistently optimize process routings
  - Reduce preproduction lead times
  - Increase responsiveness to engineering changes

Variant (Retrieval) CAPP Methodology

- Recall, identify, and retrieve and existing plan for a similar part and make necessary modifications
- Interactive environment between the planner and the computer
- Process planning for a new part starts with coding and classifying the part into a similar family
- Requires the establishment and maintaining of a database of standard process plans that contains operations, tools, notes, etc.
- Requires recall and editing capability

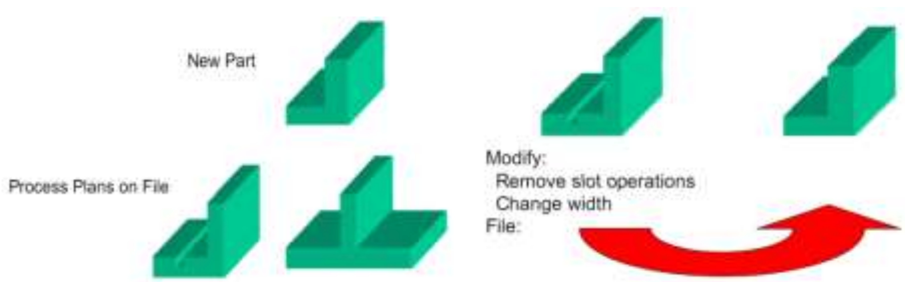


Fig. 22 Variant (Retrieval) CAPP Methodology

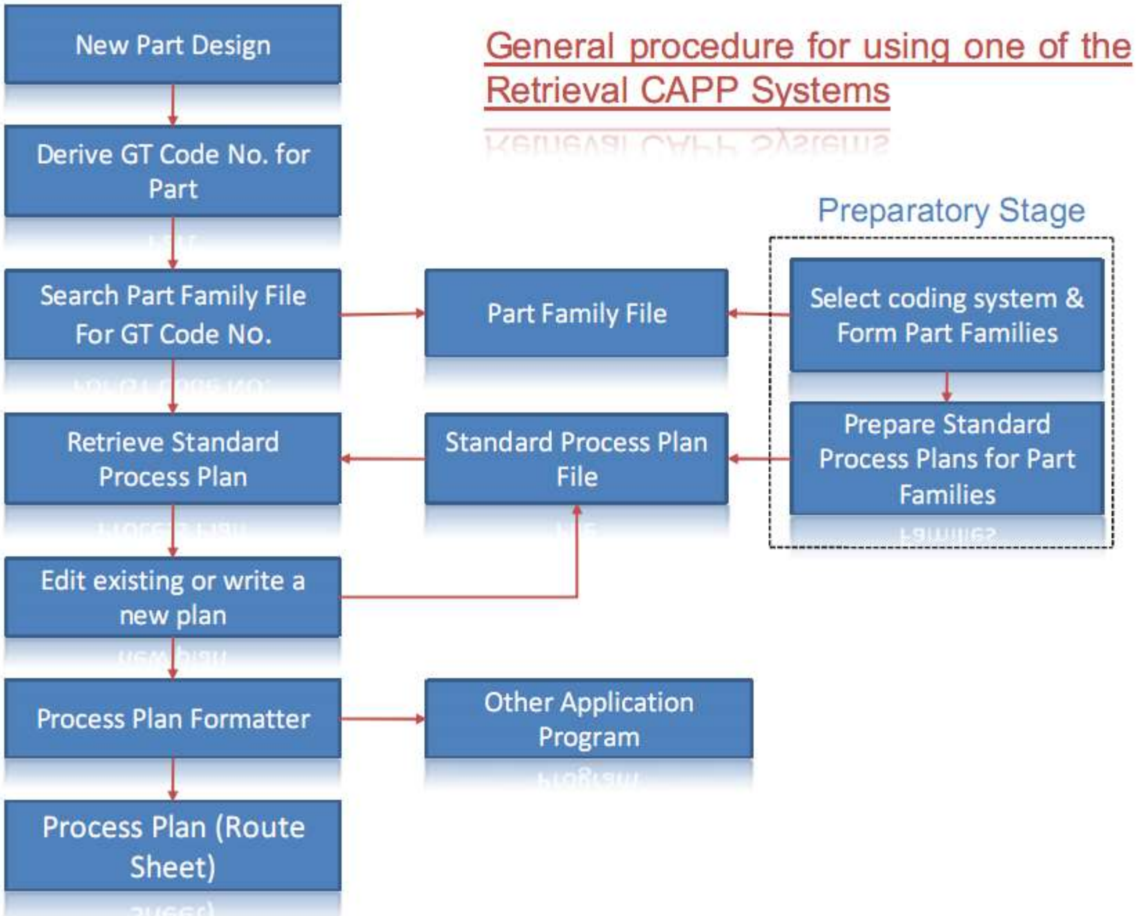


Fig. 23 Variant CAPP procedure

- **Advantages:**
  - Efficient processing and evaluation of complicated activities and decisions
  - Standardized procedures
  - Lower development and hardware costs
  - Shorter development times
- **Disadvantages:**
  - Inconsistency in editing
  - Quality is dependent on knowledge and skill of planner
  - Optimization of variables such as material, geometry, size, precision, quality, alternative processing sequences, and machine loading is difficult

Generative CAPP Methodology

- Process plans are automatically generated by means of decision logic, formulae, technology algorithms, and textual and geometry-based data
- Truly universal system not yet developed
- There are essentially two major components
  - Geometry-based -- define all geometric features for all process related surfaces together with feature dimensions, locations, and tolerances and the surface finish desired on the features.
  - Knowledge-based -- the automatic matching of part geometry requirements with the manufacturing capabilities using process knowledge in the form of decision logic and data.

Knowledge based process planning

- Knowledge-based; Artificial Intelligence; Expert System; Rule-based…
- "Mimic the decision-making process of a human expert"
- Experience ➔ Knowledge
- Human experts "learns" ➔ How about software?
- Knowledge Representation:

  IF <CONDITIONS> THEN <ACTION>

Decision Tables

A table of rows and columns, separated into four quadrants

- Conditions
- Condition alternatives
- Actions to be taken
- Rules for executing the actions

The standard format used for presenting a decision table

Conditions and Actions	Rules
Conditions	Condition Alternatives
Actions	Action Entries

Developing Decision Tables

- Determine conditions that affect the decision
- Determine possible actions that can be taken
    - Determine condition alternatives for each condition
    - Calculate the maximum number of columns in the decision table
    - Fill in the condition alternatives
    - Complete table by inserting an X where rules suggest actions
    - Combine rules where it is apparent
    - Check for impossible situations
    - Rearrange to make more understandable

Constructing a decision table for deciding which catalog to send to customers who order only from selected catalogs

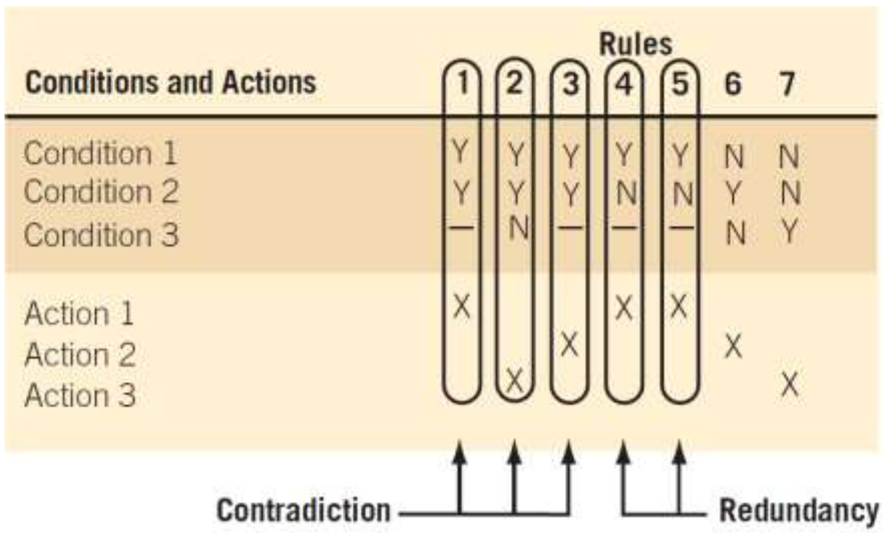
Conditions and Actions	Rules 1	2	3	4	5	6	7	8
Customer ordered from Fall catalog.	Y	Y	Y	Y	N	N	N	N
Customer ordered from Christmas catalog.	Y	Y	N	N	Y	Y	N	N
Customer ordered from specialty catalog.	Y	N	Y	N	Y	N	Y	N
Send out this years Christm as catalog.		X		X		X		X
Send out specialty catalog.			X				X	
Send out both catalogs.	X				X			

Checking for Completeness and Accuracy

Four main problems

- Incompleteness
- Impossible situations
- Contradictions
- Redundancy

Checking the decision table for inadvertent contradictions and redundancy is important



Module-II

Shop Floor Control and FMS: Shop floor control-phases, Factory data collection system, Automatic identification methods- Bar code technology, Automated data collection system, FMS-components of FMS - types -FMS workstation, Material handling and storage systems, FMS layout, Computer control systems-application and benefits.

3. Introduction to Shop Floor Control

Monitoring the progress of the jobs is an integrated part of CIM. Collection of machine data statistics, estimation of the non-production times and machine utilization, tracking of flow of materials, determination of job completion times and realization of schedules, etc., are necessary to evaluate the efficiency of the functioning of the system. This requires automatic or direct data collection from the shop floor. The techniques and technologies by which the status of production is collected are called shop floor data collection. Fig. 24 illustrates various types of information/data to be collected from the shop floor. These include:

(i) Machine data

(ii) Operator data

(iii) Tooling data

(iv) Data relating to jobs to be done

(v) Materials data

(vi) Materials handling data

(vii) Scheduling data

(viii) Process planning data

(ix) Inspection data

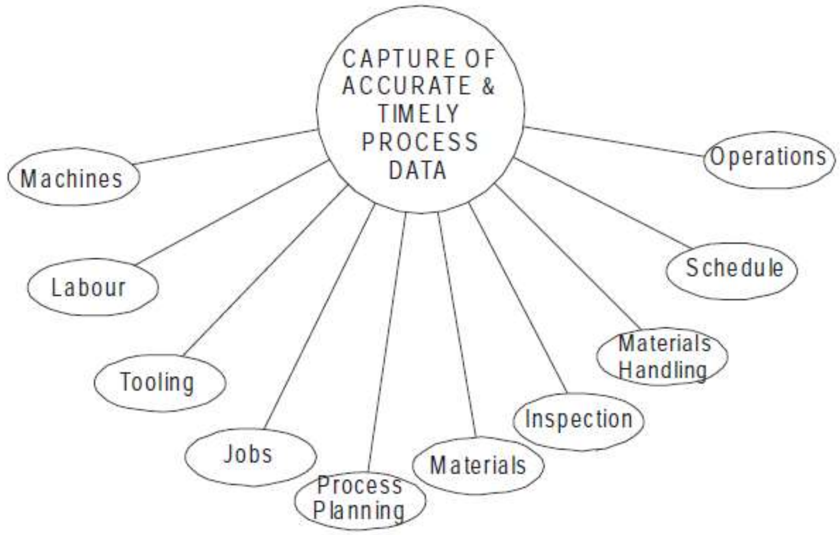


Fig. 24 Components of Shop Floor Information System

Material processing is a typical example of data collection. The various process planning methods described in Chapter 9 are used to plan the execution of the work before the actual manufacturing commences. It is necessary to monitor the process of the work to make sure that the work is performed as planned. This necessitates collection of shop floor data which includes machine data, actual completion time, and movement of the materials and the utilization of other resources. There are several variables affecting the manufacturing productivity. These are shown in Fig. 25. Monitoring of shop floor data helps to identify factors which adversely affect productivity

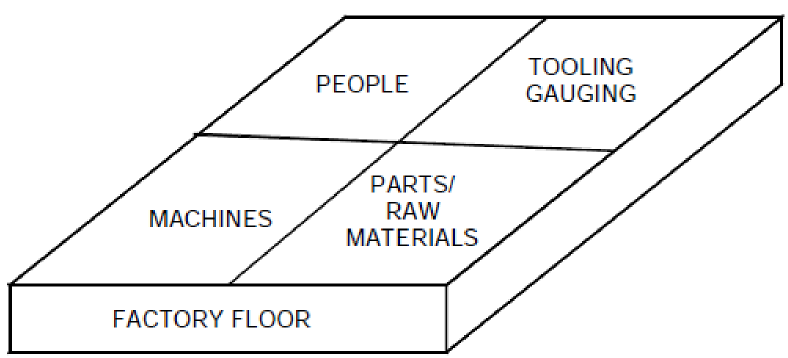


Fig. 25 Variables Affecting Manufacturing Productivity

Shop Data Requirements

People - Availability

a: Workstations

b: Idle

c: Absent

Machines - Status

a: Idle

b: Setup

c: Production

d: Delay

e: Downtime

Parts/Raw Materials Location

a: Raw Stores

b: Transit

c: On-machine

d: Waiting

e: Finished stores

f: Assembly

g: Missing

3.1 *Shop Floor Control*

Shop floor control deals with managing the work-in-process. This consists of the release of production orders to the factory, controlling the progress of the orders through the various work stat ons, and getting the current information of the status of the orders. This can be shown in the form of a factory information system. (Fig. 26). The input to the shop floor control system is the collection of production plans. These can be in the form of master schedule, manufacturing capacity planning and ERP data. The factory production operations are the processes to be controlled.

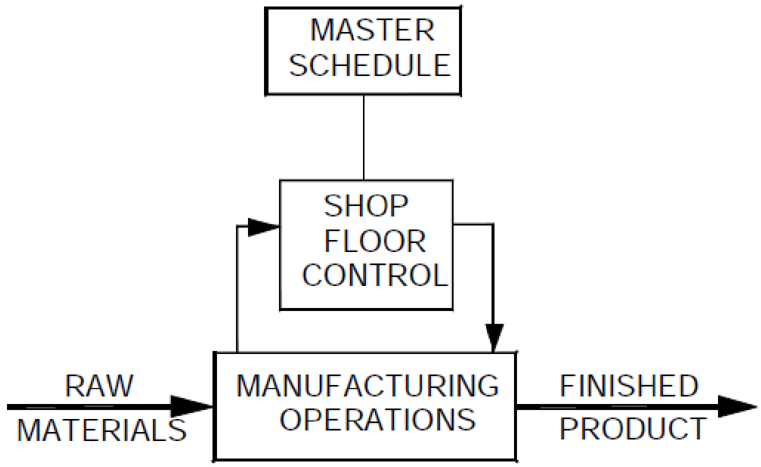


Fig. 26 Factory Information System

A typical shop floor control system consists of three phases. In a computer integrated manufacturing system these phases are managed by computer software. These three phases connected with the production management is shown in Fig. 27. In today's implementation of shop floor control, these are executed by a combination of computers and human resources. The following sections describe the important activities connected with this task.

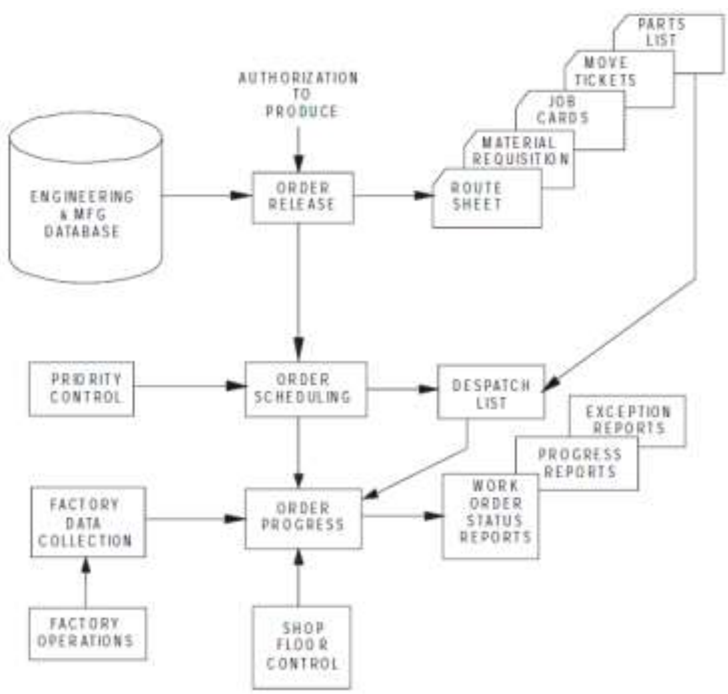


Fig. 27 Phases in Shop Floor Control

Order Release

The order release in shop floor control provides the documentation needed to process a production order. The documents in the shop floor order may consists of the following documents

(i) Route Sheet

(ii) Material requisition to draw necessary materials from the stores

(iii) Job cards or other means to report direct labour time given to the order.

(iv) Instructions to material handling personnel to transport parts between the work centres in the factory

(v) Parts list for assembly, in the case of assembly operations.

In a typical factory which works on manual processing of data these documents move with the production order and are used to track the progress through the shop. In a CIM factory, more automated methods are used to track the progress of the production orders. The order release is connected with two inputs. Authorization proceeds through the various planning functions (MRP, capacity planning). These provide timing and scheduling information. The engineering and manufacturing database provides the product structure and process planning information needed to prepare the various documents that accompany the order through the shop.

Order Scheduling

This module assigns the production orders to various work centres, machine tools, welding stations, moulding machines etc., in the plant. It follows directly from the order release module. Order scheduling executes the dispatch function in production planning and control. The order scheduling module prepares a dispatch list that indicates which production order should be accomplished at the various work centres. It provides the information on the relative priorities of the various jobs by showing the due dates for each job. By following the dispatch list in making work assignments and allocating resources to different jobs the master schedule can be best achieved. The order schedule module addresses to two important activities in shop floor production control.

(i) Machine loading

(ii) Job sequencing.

Allocating the orders to the work centres is termed as machine loading or shop loading, which refers to the loading of all machines in the plant. In most cases each work centre will have a queue of orders waiting to be processed. This queue problem can be solved by job sequencing. This involves determining the order in which the jobs will be processed through a given work centre. To determine this sequence, priorities are given to jobs in the queue and the jobs are processed according to the priorities. Several queuing models are available in operations management to solve this problem. This control of priorities is an important input to the order scheduling module. Rules to establish the priorities are:

(i) Earliest due date: These are given high priority

(ii) Shortest processing time: Shorter processing time orders are given high priority.

(iii) Least slack time: Orders with least slack time are given high priority.

Fluctuations in market demand, equipment breakdown, cancellation of the order by customer and defective raw material or delay in the receipt of materials affect the priority. The priority control plan reviews the relative priorities of the orders and adjusts the dispatch list accordingly.

Order Progress

The order progress module in the shop floor control system monitors the status of the various orders in the plant work-in-process and other characteristics that indicate the progress and performance of production. The function of the order progress module is to provide the information that is useful in managing the factory based on the data collected from the factory. The order progress report includes:

(i) Work order status reports: These reports indicate the status of the production orders. Typical information in the report includes the current work centre where each order is located, processing hours remaining before completion of each order, whether the job is on-time or behind schedule, and priority level.

(ii) Progress report: A progress report records the performance of the shop during the period of master schedule and reports the number of operations completed and not completed during the time period.

(iii) Exception reports: These reports bring out the deviations from the production schedule (ex. overdue jobs).

The above reports are useful to production management in making the decisions about allocation of resources, authorization of the overtime hours, and other capacity issues, and in identifying areas of problems in the plant that adversely affect the implementation of the master production schedule.

3.2 *Shop Floor Data Collection*

There are several of data collection techniques to gather data from the shop floor. Some of the data are keyed by the employees and the rest are recorded automatically. Later the data is compiled on a fully automated system that requires no human intervention.

These methods are collectively called as shop floor data collection systems.

These data collection systems consist of various paper documents, terminals and automated devices located through the plant in a plant. The shop floor data collection system serves as an input to the order progress module in shop floor (Fig.20.4).

Examples of the data collection in shop floor are:

(i) To supply data to the order progress module in the shop floor control system.

(ii) To provide up to date information to the production supervisors and production control personnel.

(iii) To enable the management to monitor implementation of master schedule.

To carry out this, the factory data collection system inputs the data to the computer system in the plant.

Types of Data Collection Systems

The shop floor data collection systems can be classified into two groups.

(i) On-line data collection systems

(ii) Off-line data collection systems

On-Line Data Collection Systems

In an on-line system, the data are directly entered to the computer and are available to the order progress module. The advantage lies in the fact that the data file representing the status of the shop is always at the current state. As and when the changes in the order progress module are reported they can be fed to computer and in turn to the status file. In this way the production personnel are provided with most up-to-data information.

Off-Line (Batch) Data Collection Systems

In this the data are collected temporarily in a storage device or a stand-alone computer system to be entered and processed by plant computer in a batch mode. In this mode there is delay in the entry and processing of the data. The delay may vary depending upon the situation. So this system cannot provide real time information of shop floor status. The advantage of this system is that it is easier to install and implement.

Data Input Techniques

As stated earlier, the data collection techniques include manual procedures and computer terminals located on the shop floor. The manual data collection methods require the production workers to fill out paper forms indicating order progress data. These forms are compiled using a combination of clerical and computerized methods.

The manual data collection methods rely on the co-operation and clerical accuracy of the employees to record a data property on a proper document. Errors may creep in this type of method. The common forms of errors that can be checked and rectified are wrong dates, incorrect order numbers and incorrect operation numbers. These can be detected and corrected. There are, however, other errors which are difficult to identify.

Another problem is that there may be a delay in submitting the order progress for compiling. The reason is that there will be always a time lapse between when occurrence of events and recording of events.

These problems necessitate the location of the data collection equipment in the factory itself. The various input techniques include manual input by push-button pads or keyboards. Error checking routines can be incorporated to detect the syntax errors in the input. The data entry methods also include more automated technologies, such as bar code reader, magnetic card readers etc.

An important type of equipment used in shop floor data entry is keyboard based systems. There are various types of such systems. They are discussed in the following sections.

Centralized Terminal

A single terminal is located centrally in the shop floor. This requires the employees to go to the terminal and input the data. So employee’s time will be wasted and in a big shop, this becomes inconvenient.

Satellite Terminals

These are multiple data collection centres located throughout the shop floor. In this arrangement a balance is to be struck between the minimization of the investment cost and maximization of the convenience of the employees in the plant.

Work Centre Terminals

The most convenient arrangements to the employees are to have a data collection terminal at each work centre. This reduces the time to go to the central terminal. This can be applied when the amount of data to be collected is very large.

Automatic Data Collection System

The recent trend in industry towards use of more automation necessitates putting in human participation is unavoidable in many cases. The advantages of the automatic data collection methods are:

(i) The accuracy of data collected increases

(ii) The time required by the workers to make the data entry can be reduced.

The basic elements in data collection systems are:

(i) Machine readable media

(ii) Terminal configuration

(iii) Software for data collection.

Machine Readable Media

Typical machine readable media include:

(i) Bar Code Technology

(ii) Optical Character Recognition (OCR)

(iii) Magnetic Ink Character

(iv) Voice Recognition (VR)

(v) Magnetic Strip Technology

(vi) Smart Cards

Bar Code Technology

Bar code technology is primarily an automatic identification technique. The data is simply reduced to a printed form, which consists of a symbol made of successive line segments. A bar code reader is used to illuminate the bar code symbol and examine successive segments of the symbol. The detected area may be a highly reflected area (space) or a non-reflective (bar). As the reader moves reader over the bar code symbol, due to reflectivity and nonreflectivity, alternate transitions from light to dark and dark to light occur. These are detected and the time it will take will be converted to digital representations of ones and zeros of the bar code messages. Most commonly used bar codes are:

(i) Universal Product Code (UPC)

(ii) Interleaved 2 of 5 (ITF)

(iii) Code 39

There are two types of bar code readers. They are classified as:

(i) Fixed Beam Reader

(ii) Moving Beam Reader

Fixed Beam Reader

Bar code readers are either fixture mounted or hand held. The simplest form of bar code reader is a light pen. The tip of the light pen is moved in contact with the symbol and moves the tip from leading zone through trailing zone in a smooth sweeping motion. The fixed beam light pen nearly or actually touches the symbol. In fixture mounted reader the beam reader is fixed and the symbol moves. The reader is mounted on a conveyor or a transport system, observing a symbol while it passes through a reader beam. The fixed beam reader reads the symbol only once. In hand-held fixed beam reader the symbol can be rescanned easily. In the fixture mounted bar code reader some mechanism which moves the symbol towards the symbol is necessary i.e., an intervention by operator is needed.

In fixed beam reader the contact with the symbol may erase the symbol and so it is less readable in subsequent attempts to read the symbol. Contact scanning of the symbol requires a smooth surface. So it is not suitable to read all the surfaces on which the symbols are printed. Light pens interpret a narrow section of the symbol printed on a surface. This may cause the distortion of the image. Fixed beam reader takes more time to read the symbol. Speed of fixed beam readers is a function of conveyor speed and height of the bar code symbol. Faster scanners are required for shorter symbols and slower scanners are required for larger symbols.

Moving Beam Reader

These minimize limitations of the fixed beam reader i.e., intervention problem and contact with the symbol. Moving beam reader, as the name indicates, scans the symbol by a line of light emitted from the reader. This is actually a spot which moves at faster rates appearing as a straight line. A moving beam reader takes less time to scan the symbol depending on the type of equipment. The light emitted from the moving beam reader can be drawn through the symbol in both the configurations i.e., hand held and conveyor configurations. Multiple viewing of the symbol provides quick and correct information to convert the image to computer data.

Elements of Bar Code Readers

The hardware of a bar code reader consists of a detector and a light source.

(i) All fixed, moving beam readers will have a single detector which samples very small areas of the symbol. The detector used is linear charge coupled device. These employ a line of detectors which takes a snap shot of the symbol and projects the image on photo sensitive device. Then the detector is amplified to know whether it has observed a space or a bar. This is applied for a bar code of maximum length of 5 cm or less. This cannot be used for larger bar codes. A matrix charge coupled device has a matrix of detectors (64 pixels long and 64 pixels high). These can be used either hand held or moving configurations or eliminates the problems associated with the voids, spots and edge roughness of the code. These can be used to detect long narrow bars as well as wide bars.

(ii) The light source employed in a bar code reader to illuminate the symbol may be a red light or infrared light.

Red light is obtained from Helium-Neon lamp transmitting at 633 nanometres. The problem associated with this is that red and white colors appear to be same for the detector. Infrared light source operates at 900 nm and is invisible to the human eye but can be detected by the photo detector. Limitations of this type are the ink used to print bar code should have high carbon content. A light source which operates at 800 nm or nearly infra red range will be able to read dye and colour based inks having high carbon content. The cost of bar code system depends on the manufacturing facility. If the same manufacturing organization is printing and reading the symbol, the cost may be less.

Optical Character Recognition

The optical character recognition (OCR) employs special fonts which can be read by man and machine. This is more reliable than key entry but less reliable compared to bar code technology. OCR fonts or characters are 'read' by software template techniques or feature extraction or combination of both. So each character is to be unique compared to other characters in the set.

When a number of pages of data are to be input to a computer system, optical page readers are very useful. Optical page readers are similar to the office copiers. In OCR, entire page is to be scanned before next page is presented to the reader. The characters in a page are identified by the reader by the specific font styles and sizes. In OCR, the reading device is to be passed over the OCR character a number of times. Here, the reader must be precisely positioned over the string which is to be read. The poses a problem when long strings of information are to be read. OCR is very sensitive to the motion of the operator's hand during reading. OCR cannot read the symbols on the moving objects. To read the information on the moving objects a strobe light is to be synchronized with object.

OCR techniques identify the horizontal and vertical strokes, curves and endings peculiar to each character. The absence of vertical redundancy and repeating character pattern causes OCR to be prone to errors. These are caused by poor print quality and those introduced through scanning process.

Magnetic Ink Character Recognition

Magnetic Ink Character Recognition (MICR) uses stylized OCR fonts. The fonts are printed with a magnetic ink to permit readability after being overprinted or even smudged. MICR is used to read smaller documents of size 7 to 20 cm. Like OCR, these also require precise orientation and registration.

Voice Recognition

Speech is the most natural way of communication. This eliminates the need of the user to understand a computer system. Voice technology is intelligently packaged and applied in several applications. Moreover the training can be minimized and the key board entry can be eliminated and hand and eye co-ordination is no longer needed.

Voice recognition (VR) is of two types:

(i) Speaker dependent

(ii) Speaker independent

Most voice recognition systems are speaker independent systems. VR systems recognize the user's vocabulary and store a computer image of each utterance and compare later the input words to the computer stored words. If the input matches the stored pattern, recognition is achieved. This provides larger vocabulary and accurate recognition. Commercial VR systems are having around a few hundred words in active vocabulary and skilful programming can develop application dependent vocabularies.

Real application of VR systems rests on the fact that user need not be trained to use the system. Speaker independent system uses recognition template from memories of the previously recorded images. The templates represent speech patterns of both male and female speakers. These are now available with limited vocabularies.

Smart Cards

Smart cards are made of plastic. They are of the size of a credit card and are embedded with one or more microchips. These have an 8-bit or higher level microprocessors and will have a storage capacity of about 8 kB. Recent cards can carry up to 256 kB with the contacts removed and integrated with keypads. Personal identification numbers (PIN) prevent unauthorized use of smart cards.

Data Acquisition Systems (DAS)

The trend in shop floor data collection is towards the more use of the automated systems. Some of the bar code reading methods and other automatic identification methods discussed earlier can be operated in a fully automated mode. Computer process monitoring system involves a computer which is directly connected with the manufacturing process for the purpose of collecting the data on the process and the equipment.

The hardware components of the computer process monitoring system used to input the data from the process are sensors and transducers, analog-to-digital converters, limit switches and photo detectors, pulse generators etc. A data acquisition system is a computer system used to collect the data from a process or piece of equipment. These perform an analysis of data or transmit the data to another computer for processing and analysis. A microprocessor is used as the controller/processor in a DAS. Other controllers use minicomputers or single board computers. The function of the controller/processor is to synchronize the data sampling and storage and tabulate data for presentation and statistical and other analysis. Components of DAS include analog transducers, Analog-to-digital converters, digital transducers, and digital input interfaces. Separate data acquisition modules are often attached with FMS elements to enable operation to send status information to the control computer.

4. Introduction to FMS

Intense competition in the global market for mechanical parts manufactured on machine tools and other metal working equipment has compelled manufacturers to reduce delivery times and quote competitive prices even for relatively small orders. In many situations, manufacturers have to deliver customized products to the consumers. The batch size is ever-decreasing, and the need to meet specific customer needs calls for considerable flexibility in the working of the manufacturing system. In this situation, the requirements that a modern manufacturing facility has to meet can be detailed as follows:

- High productivity for all batch sizes, large or small
- Shorter throughput times
- Lower storage costs
- Reduced labour if not altogether avoiding labour
- Reduced handling
- Flexible production system to incorporate product changes at short notice to meet customer's specific requirements
- Sensing and taking care of such eventualities like tool breakage.

Conventional high volume production facilities such as automatic equipment and transfer lines do not fulfill these requirements. This provided sufficient reason for manufacturing engineers to turn attention to alternative approaches to manufacturing.

Flexible manufacturing cells and flexible manufacturing systems have been evolved to meet the requirements listed above.

The functions of many manufacturing equipment have already been automated through the use of CNC and PLC. The next stage is to automate the wider manufacturing environment comprising the following activities:

- Management of resources
- Storage, preparation and transport of raw workpieces and finished components
- Acquisition, processing and evaluation of production data
- Inspection of workpieces and continuously monitoring the performance of production equipment
- Testing of products

• Developing software to control all the above operations.

In such a process of integrated automation it is necessary to combine a number of machines, both mechanically and in terms of data processing into a closely linked manufacturing unit. In this way, highly automated manufacturing units (cells) are created which are capable of handling a number of different workpieces without interruptions due to operations like setting up workpieces, tool change, inspection etc.

Monitoring and process correction facilities through appropriate sensors are also part of the system so that operator intervention is kept to a bare minimum. Manufacturing cells normally contain 1 to 4 production machines. In addition to various “service machines” such as measuring machines and washing machines) and transport systems like automated guided vehicles, rail guided vehicles and conveyors for the workpieces and for the tools. The cell computer simultaneously controls the manufacturing operations within the manufacturing cell.

4.1 *Subsystems 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 storage, retrieval, transport and transfer 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.

4.2 *Scope of FMS*

Although this was initially developed for machining applications, the concept of FMS has subsequently been used in a variety of other manufacturing applications, such as:

• Assembly of equipments

• Semiconductor component manufacturing

• Plastic injection moulding
• Sheet metal fabrication
• Welding
• Textile machinery manufacture

Such systems have proved to be practical and economical for applications with the following characteristics:

• Families of parts with similar geometric features that require similar types of equipment and processes
• A moderate number of tools and process steps
• Low to medium quantities of parts
• Moderate precision requirements

4.3 *FMS Compared to other types of Manufacturing Approaches*

One-off and low volumes of production are normally carried out by conventional general purpose machine tools. When the number of parts in a production run is more it is called batch production. A batch production shop is best suited for small quantities of many different types of parts. The very nature of production makes the operation of a job shop less efficient than an automated production line.

Since the job shop must be provided the greatest degree of flexibility, most of its operations are manual. They are normally equipped with general purpose CNC machine tools. Hard automation with dedicated equipment is best suited for the production of very large quantities of identical parts. Production of automobile components in a transfer line falls under this category. A large portion of the manufacturing industry involves the intermediate level of batch operations that lend themselves to the FMS approach. In this case volume is less but varieties are more.

FMS thus basically attempts to efficiently automate batch manufacturing operations. They are an alternative that fits in between the manual job shop and hard automation. FMS is best suited for applications that involve an intermediate level of flexibility and low or medium quantities. Fig. 28 shows the different types of production systems and it can be seen from the figure that FMS fits into the intermediate range of production.

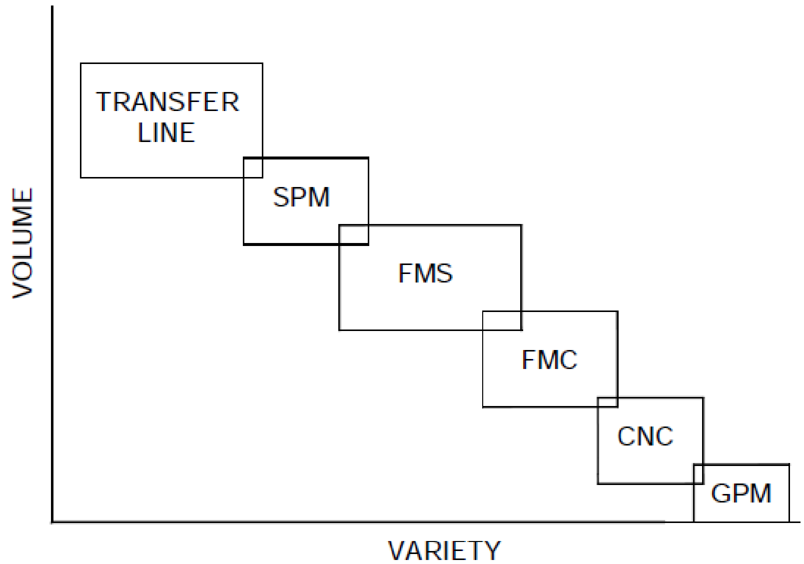


Fig. 28 Types of Production Systems

General purpose machines can accommodate a large variety of parts. They are manually operated and therefore production volumes are low. CNC machines can accommodate variety but the production volume is less as the machines are not optimized for the highest productivity for a specified type of job. It can be seen that FMC and FMS satisfy both variety and volume equally well. If we take special purpose machines, variety is much restricted. Transfer lines are dedicated usually to manufacture a component and hence can be said to have the minimum variety.

4.4 *Types of FMS*

FMS has been classified in several ways. Some of these classifications are still valid but the discussion in this book is restricted to three basic types:

Flexible Manufacturing Cells (FMC)

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.

A turning centre fitted with a gantry loading and unloading system and pallets for storing work pieces and finished parts is a typical flexible turning cell. If the turning centre is incorporated with either in-process or post process metrology equipment like Renishaw probes or inductive measuring equipment for automatic offset correction, the productivity of the system improves and wastage due to rejection is reduced. Automatic tool changers, tool magazines, block tooling, automatic tool offset measurement, and automatic chuck change and chuck jaw change etc. help to make the cell to be more productive.

One or two horizontal machining centres with modular fixturing, multiple pallets, advanced tool management system, automatic tool changer, automatic head changer or automatic magazine changer, robots or other material handling systems to facilitate access of the jobs to the machine also constitute a flexible machining cell.

An FMC can also comprise a turning centre, machining centre and pick and place robots or other materials handling systems. Fig. 29 shows the block diagram of a flexible manufacturing cell. This consists of a CNC lathe, a machining centre, a small automatic storage and retrieval system, two robots for loading and unloading the machines and a small rail guided vehicle to carry the component from one machine tool to another. The system is controlled by a PLC and a couple of personal computer.

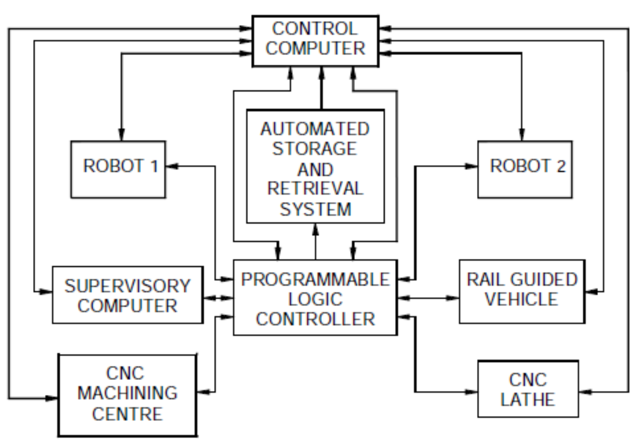


Fig. 29 Flexible Manufacturing Cell

Flexible Turning Cells

One of the most important advantages of CNC machines is their flexibility. The flexibility in this particular context means that these work centres enable the production of components in short batches. The production can be planned to meet immediate requirements because the change over time is short. In order to enable the production set up to change over from one component to another component in the shortest possible time, several technological features have to be added to the turning machines. This section describes some of these important features.

There are several ways to cut down idle time and component change over time and improve the productivity and flexibility of CNC turning centres. Flexible turning cells generally employ turning centres instead of CNC lathes. The availability of C-axis and the live tools in the turret enable the process designer to complete not only turning but also operations like milling, off-centre drilling, tapping, and helical groove cutting etc in one set up. This means that all operations required to completely machine a component can be carried out in one set up itself.

The relatively high cost of CNC machines means that the machine hour rate is several times that of conventional machines. This necessitates not only increasing the utilization by cutting down idle time but also working on all the three shifts of the day as well as during holidays. This calls for a high degree of automation. By using automatic part changer, automatic tool changer and adopting process automation through sensing and feedback devices like tool breakage sensors, automatic tool length offset compensation, in-process or post-process gauging and program correction, automatic chuck changing and chuck jaw changing, it will be possible to achieve fully automatic unmanned machining.

Flexible Transfer Lines (FTL)

Flexible transfer lines are intended for high volume production. A part in a high volume production may have to undergo large number of operations. Each operation is assigned to and performed on only one machine. This results in a fixed route for each part through the system. The material handling system is usually a pallet or carousel or conveyor. In addition to general purpose machines, it can consist of SPM’s, robots and some dedicated equipment. Scheduling to balance the machine loads is easier. Unlike conventional transfer lines, a number of different workpieces can be manufactured on the FTL. The resetting procedure is largely automatic.

Flexible Machining Systems

Flexible Machining Systems consists of several flexible automated machine tools of the universal or special type which are flexibly interlinked by an automatic workpiece flow system so that different workpieces can be machined with the same machine configuration. The characteristic feature is the external interlinkage of the machines, unrestricted by cycle time considerations. Different machining times at the individual stations are compensated for by central or decentralized workpiece buffer stores. 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. 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.

4.5 *Benefits of FMS*

FMS's are designed to provide a number of advantages over alternative approaches (Fig. 30). These are listed below:

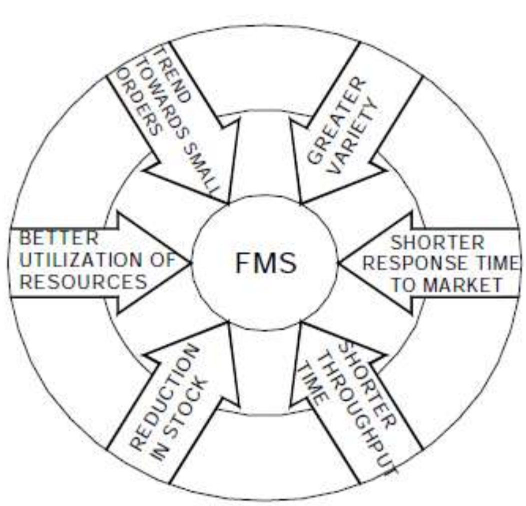


Fig. 30 Benefits of FMS

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 (Utilization better than standalone CNC machines)

• Quicker response to market changes

• Reduced space requirements

• Ability to optimize loading and throughput of machines

• Expandability for additional processes or added capacity

• Reduced number of tools and machines required

• Motivation for designers to add variations and features to meet customer requirements.

• Compatible with CIM

Some of these advantages can lead to significant cost savings. Direct labour can be eliminated almost entirely. Cycle time and WIP can be reduced to a fraction of what is normally experienced in a manual operation. An FMS is designed to have the production machines working most of the time rather than standing idle.

This can be explained with the help of Fig. 31. On any manually controlled work centre, the total time available for production per year is 8760 hours. Out of which the company loses 14.3 % of the time on account of Sunday being a weekly holiday. Paid holidays result in production loss of roughly 1.5%. An employee may also be eligible for paid leave (casual leave, earned leave etc.) and this may reduce the available working hours by 8%. The efficiency of production in the third shift is usually less and the production loss due to it is about 14% (assuming only 50% of the normal efficiency in the third shift). In India, a major cause for loss of production is employee absenteeism due to medical or other reasons. A factory employee is eligible to avail unto 90 days leave a year, enjoying the benefits from Employee’s State Insurance. The average absenteeism in many industries varies. If we assume that the loss of production due to absenteeism is approximately 7%, the net available production time is only 55%. Assuming an efficiency of production of 80%, the work centre time utilized comes down to 44%.

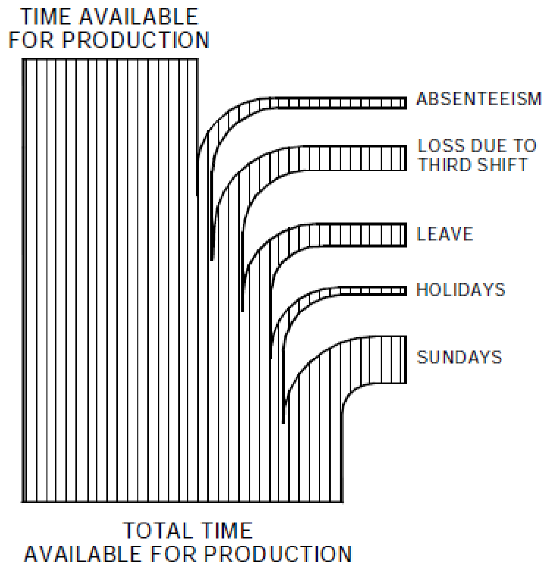


Fig. 31 Loss of Production Time

In the case of conventional manually operated metal cutting machines, the actual time utilized for removal of material is about 30-35% of the working time. The rest of the time is spent on non-productive operations like setting up of work and tools, inspection or procuring tools etc.

In the case of efficient operation of CNC machines this percentage increased to 80 to 85%. In FMS, one can achieve as high as 90-95% efficiency. Another important feature of FMS is that an FMS can produce parts even if the employee is absent or even if it is a holiday. The significance of FMS must be apparent from this fact. An automated material handling system and a computer-based production scheduling system are needed to keep the machines fed with parts. FMS uses computer automation techniques to lower the overall cost of production operations.

4.6 *Major Elements of FMS*

Each of the major subsystems in an FMS performs a number of functions and is dependent on the others to make the entire system work. The functions will vary, depending upon the type of equipment and manufacturing operations involved.

Production 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, guillotines etc. A typical FMC consists of sheet stacking system, sheet unloading device, sorting conveyor, turret punch press, right angle shear, loading device and automatic storage.

(ii) FMS for machining: This type of FMS typically has a number of machining centres and/or turning centres to provide general purpose machining capabilities. 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 toolchanging 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 (e.g. turning, grinding). Washing machines and inspection machines also form the equipment of FMS. The family of parts which the FMS is designed to produce will determine the capabilities required from the machine tools (e.g. accuracy, size, power etc).

Support Systems

Automated machine tools typically require several systems to support their operation.

The tools required to perform the multiple processes of a machining centre or a turning centre may be stored in magazines at each machine or in central tool storage. Local magazines provide fast access as well as backup capability but in a large FMS a central tool facility may be more efficient. Centralization not only permits the total number of tools to be minimized; it also provides the opportunity to perform additional functions automatically, such as:

(i) Measurement of tool wear

(ii) Tool pre-setting

(iii) Tool regrinding, repair and maintenance

(iv) Replacement of broken or worn tools

Many automated machine tools have built-in systems to monitor tool wear and detect tool breakage. They may use probes or non-contact techniques such as acoustic emission for this purpose. When a tool needs replacement, the machine can signal the tool room for the delivery of a replacement. This may be performed by an AGV or gantry set up or RGV. Elaborate tool management support is an integral part of FMS software. With this software, operating personnel can have effective centralized control of a large tool inventory. 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.

Materials Handling System

• A FMS typically needs several materials handling systems to service the machines.

• A transport system to move workpieces into and out of the FMS (e.g. overhead conveyors, gantry systems, AGV’s, RGV’s)

• A buffer storage system for queues of workpieces at the machines (e.g., pallets)

• A transfer system to load and unload the machines (e.g. robots, transfer fixtures)

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

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 materials handling system or the central computer provides overall control functions, such as dispatching, routing and traffic control and collision avoidance. AGV's usually complementing an automated production line consisting of conveyor or transfer systems by providing the flexibility of complex and programmable movement around the manufacturing shop.

Advantages of using AGV systems in FMS

(i) Flexibility: The route of the AGV's 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 FMS cells and accessing the automated storage and retrieval system.

(ii) Real time monitoring and control: Because of computer control, AGV's can be monitored in real time. If the FMS control system decides to change the schedule, the vehicles can be re-routed and urgent requests can be served. AGV's are usually controlled through wires implanted on the factory floor. The control is effected using a variable frequency approach. 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 bit stream 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: AGV's 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. A bumper is attached to some designs of AGV's to prevent collision. AGV's may also incorporate warning lights, fire safety interlocks and controls for safety in shops. During design, the use of simulation can help detect whether there are enough vehicles to perform the necessary load, unload and transportation tasks and thus optimize the utilization of the AGV system. Because these vehicles have to work in a tandem with highly organized FMS cells as well as with automated warehouses under computer control, their level of performance will affect the entire efficiency of the FMS.

Automated Storage and Retrieval Systems

A key part of any materials handling system is storage. Major advances have been made in recent years to automate the storage and retrieval of product and materials by employing sophisticated materials handling machines, high-density storage techniques and computer control. Such systems come in a variety of forms and sizes depending on the materials handling and storage job that has to be done. They often take the form of automated warehouses which use automatic storage and retrieval systems, conveyors and computers to control the materials handling machines and to 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)

In such a storage system, the computer can keep track of a large number of different parts, products and materials and can assign bin locations to optimize the use of storage space. When such a system is tied into the production control system, parts and materials can be replenished as they are consumed on the factory floor, keeping the work in process (WIP) to a minimum.

Categories of AS/RS

The automatic storage and retrieval system can be classified into several types. Some of them are:

- Unit load AS/RS
- Mini load AS/RS
- Man-on-board AS/RS

• Automated item retrieval system

• Deep lane AS/RS

Basic Components of AS/RS

An AS/RS normally consists of:

• Storage structure

• Storage and retrieval machine

• Storage modules

• Pick-up and deposit stations

Special Features of AS/RS

Some of the special features of AS/RS are:

• Aisle transfer cars

• Full/empty bin detectors

• Sizing stations

• Load identification stations

Buffer Storing of Parts

In an FMS, parts move from one work cell to another where the various processing tasks are performed. Because of the almost random production facilities of FMS, the destination cell might not always ready to accept the incoming part and the part has to wait in a buffer store. These and other bottlenecks in the materials handling problems can be successfully detected by simulation. Buffer stores for parts will always be desirable. Figure 19.8 shows a typical FMC cell layout where buffer stores are used as an integral part of the cell as well as the overall materials handling system.

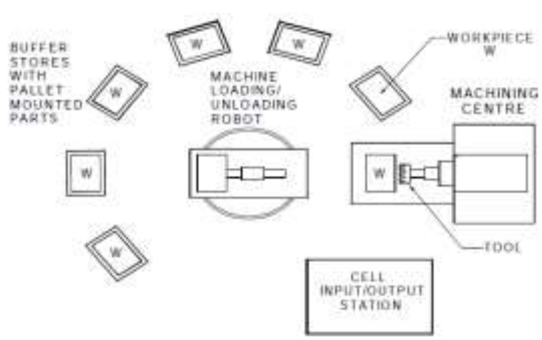


Fig. 32 Typical FMC Layout

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

Chip Removal and Washing Stations

Workpiece cleaning is important, especially before the part goes to the inspection station or assembly station, because un-removed swarf can cause problems during the inspection cycles or assembly. The swarf removal is done at the washing station of the FMS. The pallet with fixture part is loaded on to the washing station, where it is located as if it was a table of any other machining station. It is tilted, by a hydraulic mechanism, while being rinsed under high pressure coolant or pressurized air supply. Then, while reverting to its load/unload position, the pallet is blown clean with compressed air. Once the part is clean, it can be taken away by a robot or AGV together with its pallet.

Computer Control System

The computer control system of an FMS integrates several sub-systems including:

CNC systems

Support system controllers

Materials handling system controller

Monitoring and sensing devices

Data communication system

Data collection system

Programmable logic controllers

Supervisory computer

This control system must also integrate other computer systems if existing in the factory. The FMS system 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. The type of the supervisory computer depends upon the size of FMS. A powerful server will be adequate as a control computer.

4.7 *Optimization of FMS*

An FMS requires considerable investment. Thorough planning and analysis should precede the purchase of a FMS as the FMS should be designed to provide efficient operation. Following are some approaches which should be considered in order to optimize the overall efficiency and effectiveness of FMS:

i. Minimizing the process cycle time: The process must be designed to minimize machining and handling.

ii. Maximizing the utilization of each machine: This can be done by balancing the work load in the system and real time scheduling.

iii. Use of automated storage systems to keep work ready for machines to process:

The raw work parts must be replenished as and when needed to avoid starving the work centres.

iv. Provision of adequate sensors for the detection of errors or problems: This includes the detection of the presence and absence of parts, jamming, tool wear, machine failures, and so on. This can be done with the use of vision systems, limit switches, proximity switches etc. In some cases special sensors like tool monitoring systems are used.

v. Backup capabilities: Redundancy is important in ensuring trouble-free operation of the FMS. The system should be able to run even when failures occur (e.g., use spare tools, provision to isolate defective machines, supply of alternative materials and transport paths, additional machine capacity).

vi. Incorporation of in-process or post-process measurement and inspection techniques: These assure product quality and reduce scrap and rework.

vii. Use of identification marking techniques: Bar codes and RFID tags are now popular for identifying products as well as components. This permits automatic tracking of workpieces and tools.

A great deal of effort is required to implement FMS. They are complex systems that require careful planning and thorough design. Some of the major tasks in selecting a FMS are:

• Selecting a family of parts that is both similar in design as well as in application. Group technology concepts can be used for this purpose.

• Specifications of the capabilities and performance requirements of the subsystem and total system.

• Bench marking the performance of the alternative proposals.

• Economic justification of the system.

• Determining the size of the system.

• System simulation for optimization.

• Selection of the equipment for the FMS.

• Design of the control systems.

• Selection and training of the personnel to run the system.

4.8 *Operational Elements of a typical Flexible Manufacturing Cell*

Figure 33 shows a flexible manufacturing cell. The various functional elements of the FMC are discussed below:

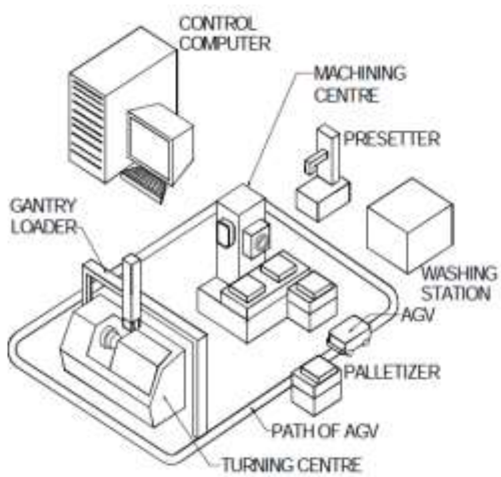


Fig. 33 Flexible Manufacturing Cell

The FMC Software

The software system for the flexible manufacturing cell is designed on the basis of the functions the FMC expected to perform. The basic system offers standard interfaces to various software functions. It also handles communication between the individual software modules and between the software modules and any peripherals (printers, other computers).

The CNC controls associated with the cell are accessed via appropriate programs.

The basic system also supports or performs the following functions:

- System generation and parameterization
- System initialization
- Collection and display of error messages
- Log functions

Types of Data Associated with the Flexible Manufacturing Cell

A typical FMC system handles four different types of data: Master data, control data, status data and general management data. These data are generated from CAD, CAP and CAM functions (Fig. 34).

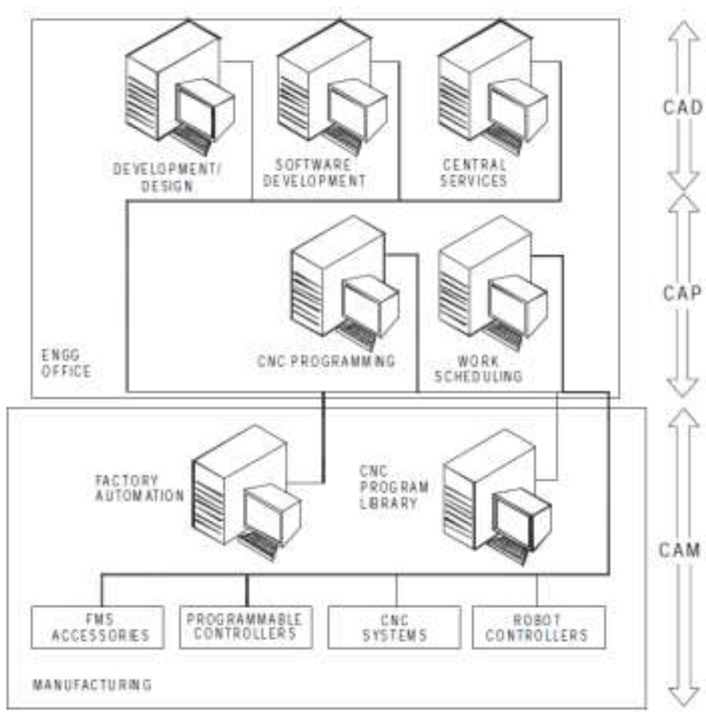


Fig. 34 Generation of FMS data

These are discussed below:

(i) Master data: Master data have to be set up only once when the flexible manufacturing cell is put into operation and this comprise:

System-specific data (related to the architecture of the system) and Resource master data which include:

(a) Tool master data

(b) Workpiece carrier master data (data relating to the workpiece carriers and clamping fixtures)

(ii) Control data: Control data are product-specific data.

(a) CNC programs, tool layouts and work schedules (technical control data)

(b) manufacturing orders (organizational control data)

(iii) Status data: Status data describes the current situation with regard to resources:

(a) Plant status data

(b) Resources data

(c) Work piece carrier data

(d) Tool data

(e) Work piece data

(iv) Log data: All operational data and machine data required for later analysis and diagnostics are recorded, evaluated by the software function modules and filled with details of data and time of day. Such data include the following:

(a) Machine specific messages

(e.g. from CNC, PLC, handling devices, transport system)

• Status and operational messages

(e.g. NC start, NC end, NC program run time)

• Alarms

(e.g. machine fault)

(b) Tool specific messages

(e.g. tool break, end of tool life)

(c) NC messages

(e.g. load NC program)

(d) Entry and description of fault by way of a dialogue

There are system statuses in which the data are not in a defined stated, namely:

• Initial start (all data), and

• Restart after complete or partial loss of data

Job Scheduling

Manufacturing orders are entered into the cell computer by the operator interactively.

In the input routine, the operator enters the job number, the parts number, the production quantities and deadlines. Manufacturing orders can be completed on a batch basis or may involve a parts mix. Figure 35 shows the various FMC functions.

By setting appropriate identifiers it is possible to link manufacturing orders in such a way that parts are finished in the correct order for assembly. The fundamental planning method used is such that with as few workpiece carriers as possible in the cell the machines can be well utilized and throughput times can be kept to a minimum.

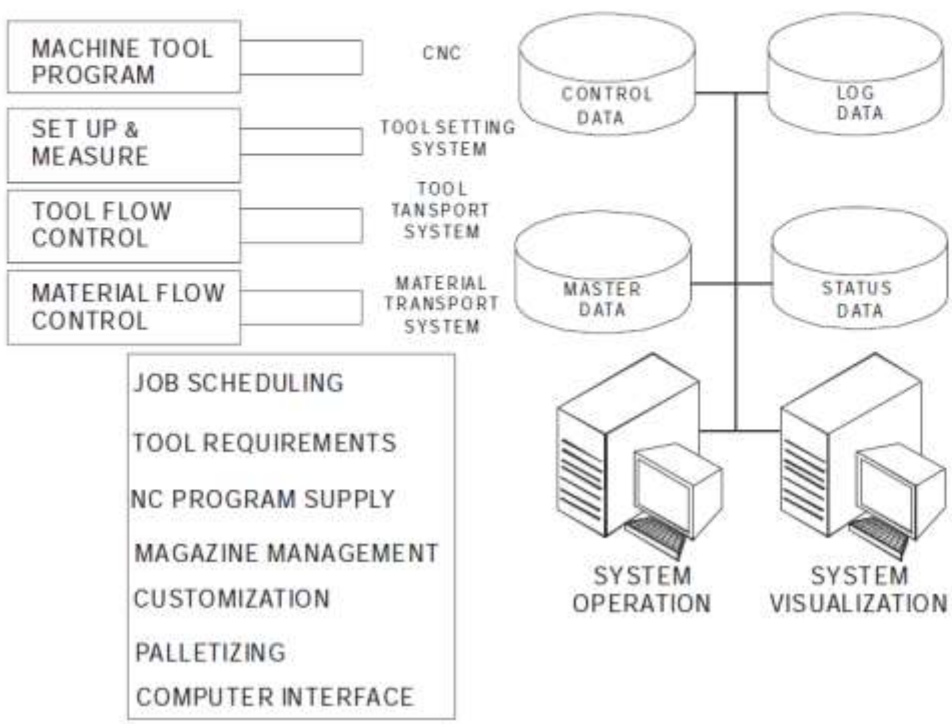


Fig. 35 Various FMS Functions

Manufacturing orders with the highest priority are the first to be taken up for manufacture. During the scheduling processes a check is carried out to establish whether the necessary NC programs, workpiece carriers and master data are available. (Fig. 36). If the operator informs the system that the missing resources can be procured in time, the order is then considered to be accepted and scheduled. This scheduling routine is repeated for as long as there is still free manufacturing capacity available. The availability check is repeated prior to start of manufacture.

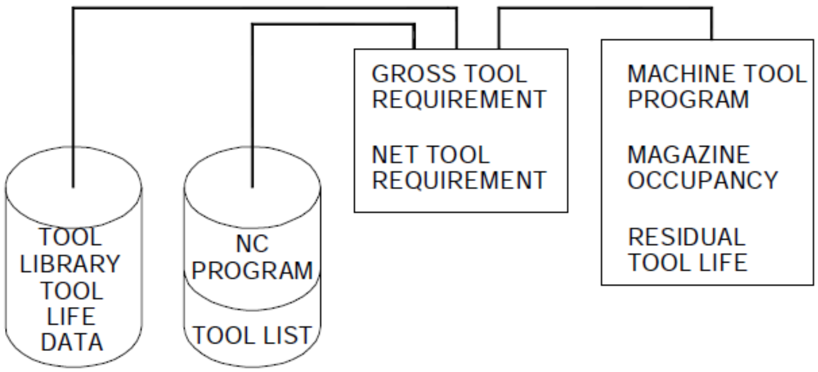


Fig. 36 Data Requirements

Tool Requirements

Tool requirements planning (Fig. 37) for scheduled manufacturing orders are carried out on two separate occasions:

- Immediately after job scheduling and
- Prior to the start of manufacturing

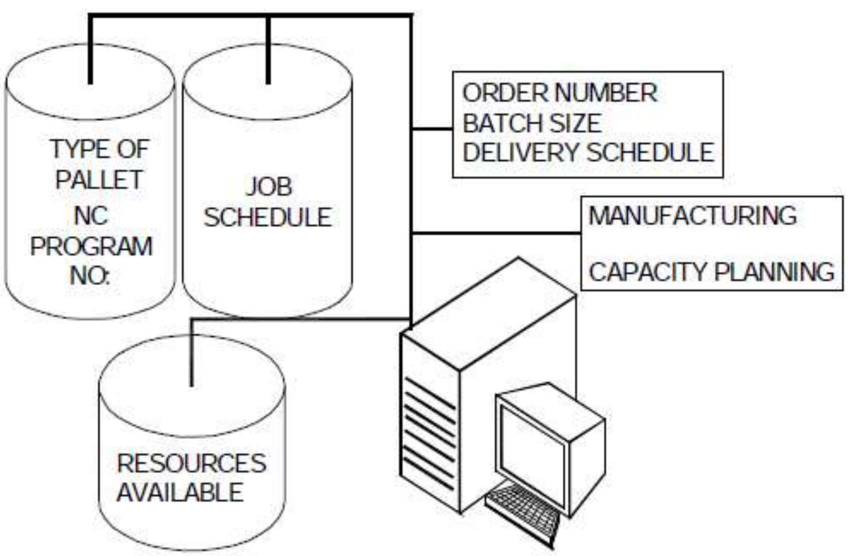


Fig. 37 Tool Data Requirements

(i) Preliminary planning phase: Tool identification numbers and all the intervention times for each tool application must be taken from the tool lists of the NC programs. The tool lives for all the tools used in the system are stored in the tool reference data management files. By linking all the relevant data it is possible to ascertain the gross tool requirements; these requirements are notified to the operator (display, printout). The operator confirms that the tools can be obtained in good time.

(ii) Final planning phase: Before manufacturing starts, a requirement analysis is performed which takes into account the residual tool lives of the tools accommodated in the machine magazine. The net tool requirements list and the list of tools due for release in the machine magazine are printed out in the form of tool loading and unloading lists. A tool setting unit may be connected to the cell computer as an option. The setting unit is provided with the reference data for the tools to be set. The actual tool data or the tool correction data determine by the unit is transferred online to the cell computer. For changing the tools, the relevant data are available for the machine tool PLC.

Material Flow Control

The material flow control facility controls and supervises the transport of the workpiece carriers with the clamped workpiece in the flexible manufacturing cell. The workpiece carriers are transported by the transport system of the cell between a source station and a destination station. Source and destination station include clamping locations, machine tools, washing and measuring machines, etc. The transport requests are specified by the station-specific programs (e.g. machine tool program, fixturing programme) to the MFC facility at the end of an operation and processed by the MFC facility according to the FIFO principle (FIRST IN FIRST OUT).

In addition to the stations, each cell normally has storage locations where the workpiece can be held if the destination station is occupied. If this happens the transport job together with the destination and the priority is preserved. The source station identifier is replaced by the storage location number. Information on the source and destination is obtained by interpreting the workpiecespecific schedule, in which among other things the sequence of operations is defined. During transport the status data of the transport system, source and destination stations, workpiece carrier and workpiece are updated by the MFC facility in real time.

Machine Tool Program

In the FMC system the machine tool program undertakes all the tasks arising at the interface to the machine tool. These tasks are online functions, so that each of the machine tools integrated into the FMC system is assigned its own machine tool program.

The machine tool programs process:

i. NC functions

• Maintaining a list of the NC programs available in the CNC

• Loading a program by preparing the CNC for loading and activating program transfer via the NC program supply module

• Erasing the CNC memory

ii. Tool data

• Reading the tool magazine and forwarding the contents to the tool requirement module

• Forwarding the tool offset data on loading the tool magazine

• Alarms and status messages which lead to the cancellation of automatic processing of the machine tool.

Alarms and status messages are logged by the basic software system. The relevant status data are simultaneously updated.

Synchronization

Synchronization must be carried out in the event of a restart for a machine tool in the FMC:

(i) Resetting the PLC

• Interrogate alarms and status

• Cancel NC programs

• Read tool magazine data

(ii) Forwarding the information to the relevant program modules

(iii) Resetting the NC program supply module.

CNC Program Supply

With the aid of this module, (Fig. 38) CNC programs are:

• transferred to the CNC of the cell,

• retransferred from a CNC (updated, optimized programs),

• read from floppy disk or via a host computer interface into the cell computer,

• deleted from the NC program library.

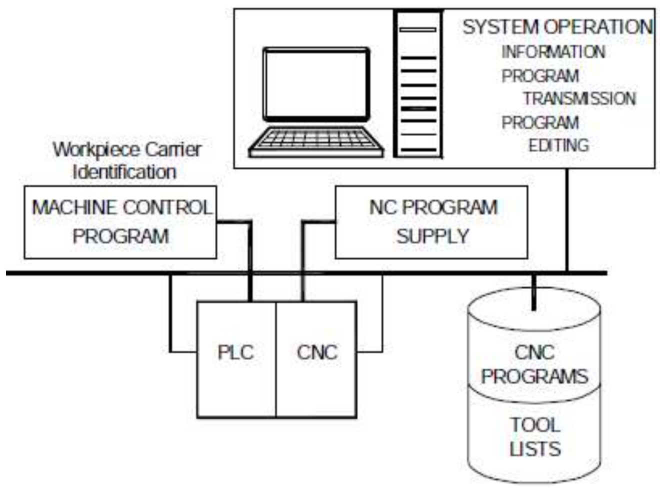


Fig. 38 CNC Program Management

The CNC programs are held ready by a machine tool program at the interface to the CNC and transferred if the CNC signals that it is ready to receive. Retransmission of updated NC programs is initiated by means of operator inputs on the cell computer. When CNC programs are transferred to the cell computer they are read into an input file, provided with the necessary prefix and management data by the operator interacting with the computer and transferred to the library with a particular CNC program number and references to subroutines and tool lists. The status of the CNC program indicates whether the program is blocked, released for production or whether it is an updated version. By entering appropriate requests on the operator console lists information relating to:

• All blocked diagrams

• All programs with update versions etc.

Tool Flow Control

Figure 39 shows a schematic diagram of tool flow control. The tool flow control facility processes the bi-directional transfer of tools between the cell magazines. For each machine tool, the tool planning function supplies the tool flow control facility with lists containing the identification numbers of the tools required and the tools those are available.

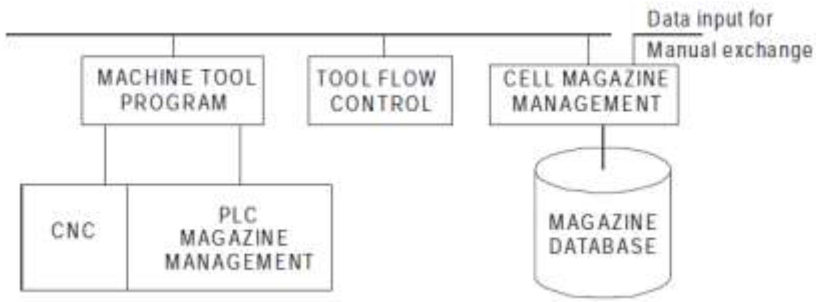


Fig. 39 Schematic Diagram of Tool Flow Control

The deciding factor is the time of requirement or the time of tool release for dismantling. Before a workpiece arrives at the machining location of the machine tool a check is carried out to establish whether:

• All the tools required are available in the machine tool magazine, or

• The tools not in the machine tool magazine are available in the cell magazine.

If the necessary tools are not available the workpiece is rejected. If the tools are in the cell magazine, a change of tools is initiated. The time of the change of tools is notified to the relevant machine by the PLC as follows: From flags set in the NC programs the machine tool PLC knows if there is enough time available for a change of tools. If a flag is set, the tool flow control facility is informed.

Tool Changing

The co-ordinates of the tool location are passed to the PLC of the handling device where they are converted into movement instructions. At the same time as the handling device is executing the movement instructions, the PLC of the machine tool positions the magazine for tool changing. Once the new tool has been loaded, the tool that is no longer required can be exchanged and transferred to the cell magazine. A free location is specified by the cell store management facility. Physical tool exchange is accompanied by a magazine management update.

4.9 *System Configuration*

Several flexible manufacturing cells can be combined to form a system under the control of a supervisory computer. In such a system, tasks are distributed among the individual cell computers and the supervisory computer. A typical arrangement is shown in Fig. 40. Machine related functions such as CNC program supply and the machine tool programs, any material flow control within the cell and the associated data storage facilities remain at cell level.

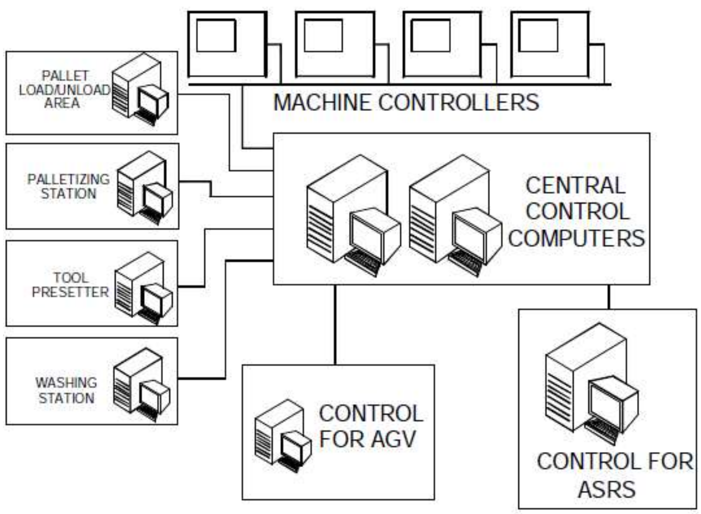


Fig.40

Execution of the higher functions of job scheduling, tool requirement management, material flow control and palletizing etc., are the responsibility of the co-ordination computer.

• Each of the cells is a self-contained functional unit

• The cells can be put into operation at different times

• The cells have a standardized interface to the supervisory computer

• The cells can be supplied by different machine manufacturers

• Incorporation of autonomous cells into the system can be done as and when needed.

Typical FMS Layout

Figure 41 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

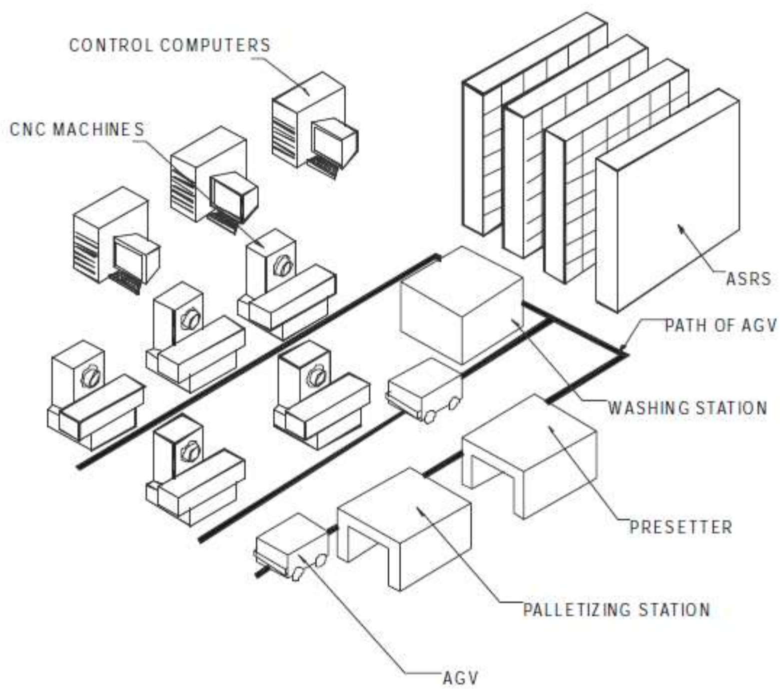


Fig. 41 A Typical FMS

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.

4.10 *Flexible Manufacturing Systems*

- Flexible Manufacturing Systems (FMS) is a strategic approach to answer the competitive global manufacturing challenge
- FMS is made possible by advanced technologies such as CAD, CAM, CAPP, CIM, GT and etc.
- In this section, we will briefly describe the basics of FMS including
- Flexibility
- Volume-variety
- Layout
- Part / tool management

4.11 *Flexibility*

- Flexibility can be defined as a collection of properties of a manufacturing system that support changes in production activities or capabilities
- A number of types of flexibility have been discussed including
- Machine flexibility: use multi-purpose CNC machines
- Routing flexibility: use CAPP
- Process flexibility: use multi-purpose CNC machines
- Product flexibility
- Production flexibility
- Expansion flexibility

Volume-Variety

- There are five types of manufacturing systems:
- Transfer line
- Stand-alone CNC machine
- Manufacturing cell
- Special manufacturing system
- Flexible manufacturing system.
- Different systems have different characteristics and hence, suit for different products and production types.
- Key characteristics of various manufacturing systems

- Transfer line
- Flexible manufacturing module
- Manufacturing cell
- Special manufacturing systems
- Flexible manufacturing systems

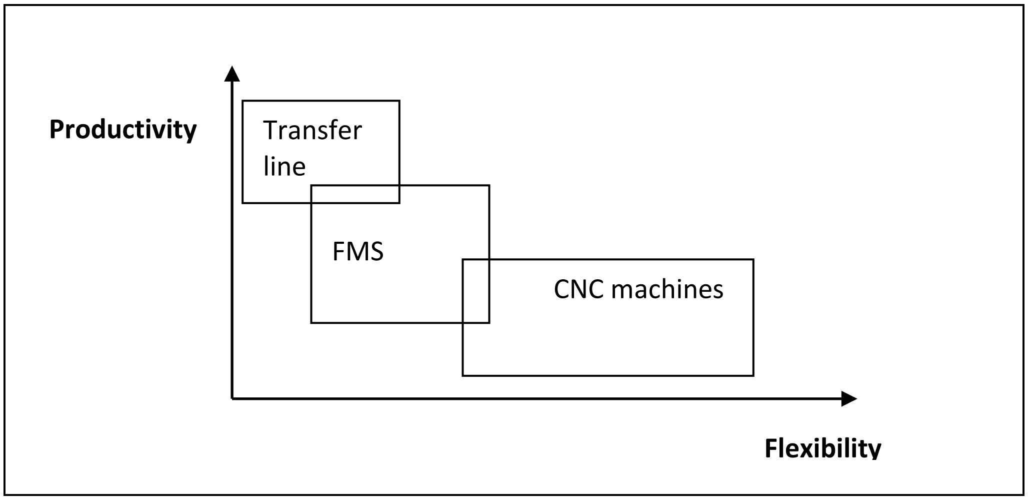


Fig. 42 The characteristics of different types of manufacturing methods

- The key characteristics of various manufacturing systems

In Manufacturing Systems:

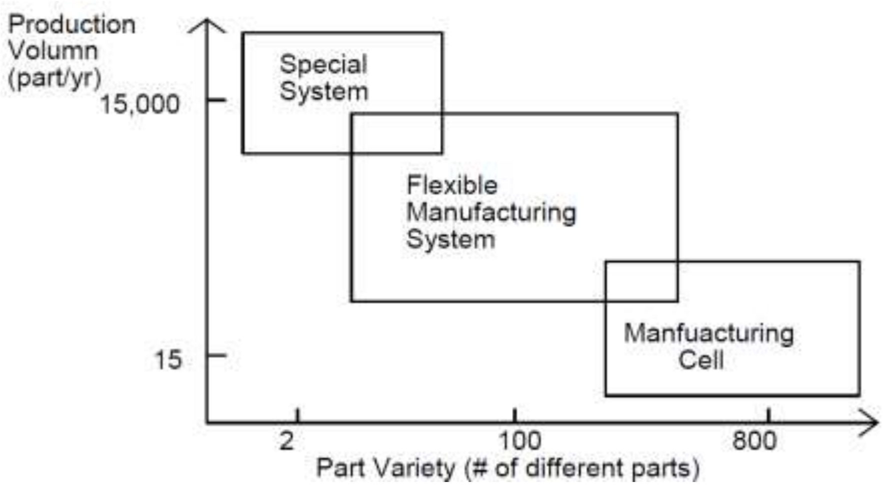


Fig. 43

Special Mfg. System: the least flexible CIM system. It is designed to produce a very limited number of different parts (2 - 8).

Mfg. Cell: the most flexible but generally has the lowest number of different parts manufactured in the cell would be between 40 - 80. Annual production rates rough from 200 - 500.

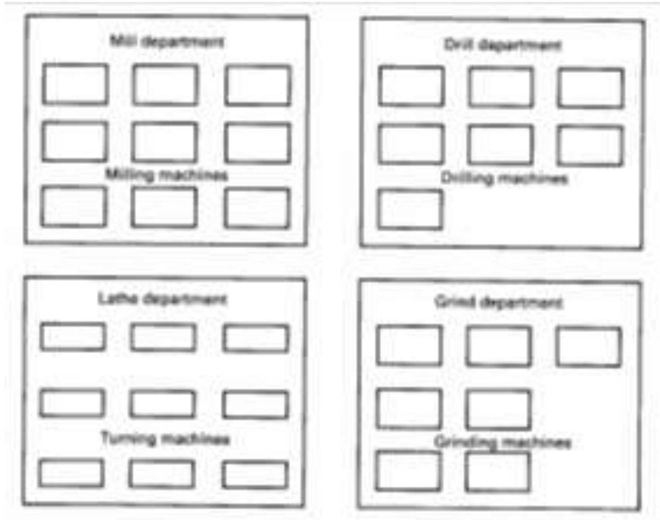
Flexible Mfg. System: A typical FMS will be used to process several part families with 4 to 100 different part numbers being the usual case.

- An FMS is an automated, mid-volume, mid-variety, central computer-controlled manufacturing system.
- The essential physical components of the FMS are:
- Independent CNC machines capable of performing multiple functions and having automated tool changer
- Automated material-handling system to move parts between machines and fixtures
- All components are computer-controlled
- Equipment such as coordinate measurement machines and part-washing devices
- An FMS consists of two subsystems:
- Physical subsystem
- Control subsystem
- Some examples are shown in the textbook

4.12 *Conventional Approaches to Manufacturing*

Conventional approaches to manufacturing have generally centered on machines laid out in logical arrangements in a manufacturing facility. These machine layouts are classified by:

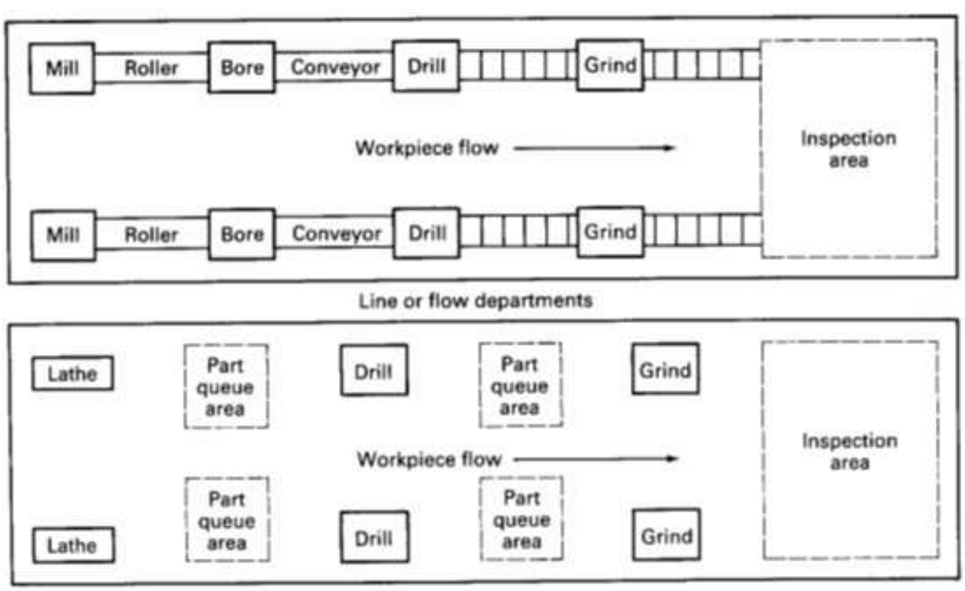
a. Function - Machines organized by function will typically perform the same function, and the location of these departments relative to each other is normally arranged so as to minimize interdepartmental material handling.Workpiece produced in functional layout departments and factories are generally manufactured in small batches up to fifty pieces (a great variety of parts).



Machine layout by function.

Fig. 44

b. Line or flow layout - the arrangement of machines in the part processing order or sequence required. A transfer line is an example of a line layout. Parts progressively move from one machine to another in a line or flow layout by means of a roller conveyor or through manual material handling. Typically, one or very few different parts are produced on a line or flow type of layout, as all parts processed require the same processing sequence of operations. All machining is performed in one department, thereby minimizing interdepartmental material handling.

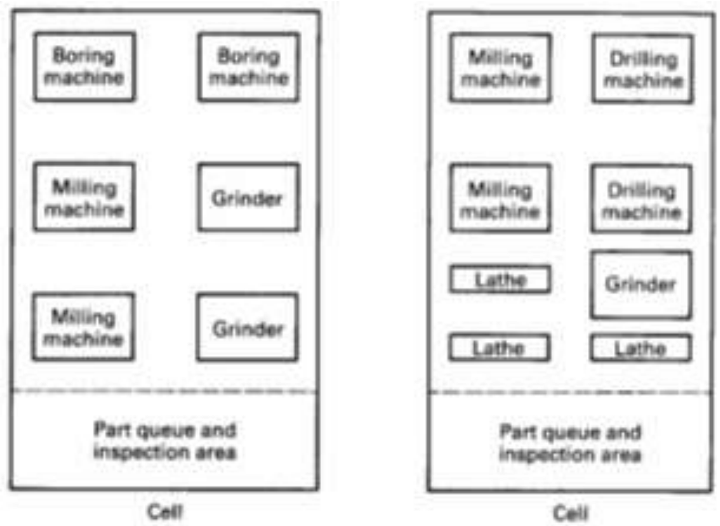


Line or flow machine layout.

Fig. 45

c. Cell - It combines the efficiencies of both layouts into a single multi-functional unit. It referred to as a group technology cell; each individual cell or department is comprised of different machines that may not be identical or even similar. Each cell is essentially a factory within a factory, and parts are grouped or arranged into families requiring the same type of processes, regardless of processing order.

Cellular layouts are highly advantageous over both function and line machine layouts because they can eliminate complex material flow patterns and consolidate material movement from machine to machine within the cell.



Machine layout by cell based on part families to be processed

Fig. 46

Manufacturing Cell

Four general categories:

i. **Traditional stand-alone NC machine tool** - is characterized as a limited-storage, automatic tool changer and is traditionally operated on a one-to-one machine to operator ratio. In many cased, stand-alone NC machine tools have been grouped together in a conventional part family manufacturing cell arrangement and operating on a one-to-one or two-to-one or three-to-one machine to operator ratio.

ii. **Single NC machine cell or mini-cell** - is characterized by an automatic work changer with permanently assigned work pallets or a conveyor-robot arm system mounted to the front of the machine, plus the availability of bulk tool storage. There are many machines with a variety of options, such as automatic probing, broken tool detection, and high-pressure coolant control. The single NC machine cell is rapidly gaining in popularity, functionality, and affordability.

iii. **Integrated multi-machine cell** - is made up of a multiplicity of metal-cutting machine tools, typically all of the same type, which have a queue of parts, either at the entry of the cell or in front of each machine. Multi-machine cells are either serviced by a material-handling robot or parts are palletized in a two- or three-machine, in-line system for progressive movement from one machining station to another.

4.13 FMS - sometimes referred to as a flexible manufacturing cell (FMC), is characterized by multiple machines, automated random movement of palletize parts to and from processing stations, and central computer control with sophisticated command-driven software. The distinguishing characteristics of this cell are the automated flow of raw material to the cell, complete machining of the part, part washing, drying, and inspection with the cell, and removal of the finished part.

I. Machine Tools & Related Equipment

- Standard CNC machine tools
- Special purpose machine tools
- Tooling for these machines
- Inspection stations or special inspection probes used with the machine tool

The Selection of Machine Tools

1. Part size
2. Part shape
3. Part variety
4. Product life cycle
5. Definition of function parts
6. Operations other than machining - assembly, inspection etc.

II. Material Handling System

A. The primary work handling system - used to move parts between machine tools in the CIMS. It should meet the following requirements.

i). Compatibility with computer control

ii). Provide random, independent movement of palletized work parts between machine tools.

iii). Permit temporary storage or banking of work parts.

iv). Allow access to the machine tools for maintenance tool changing & so on.

v). Interface with the secondary work handling system

B. The secondary work handling system - used to present parts to the individual machine tools in the CIMS.

i). Same as A (i).

ii). Same as A (iii)

iii). Interface with the primary work handling system

iv). Provide for parts orientation & location at each workstation for processing.

III. *Computer Control System* - Control functions of a firm and the supporting computing equipment

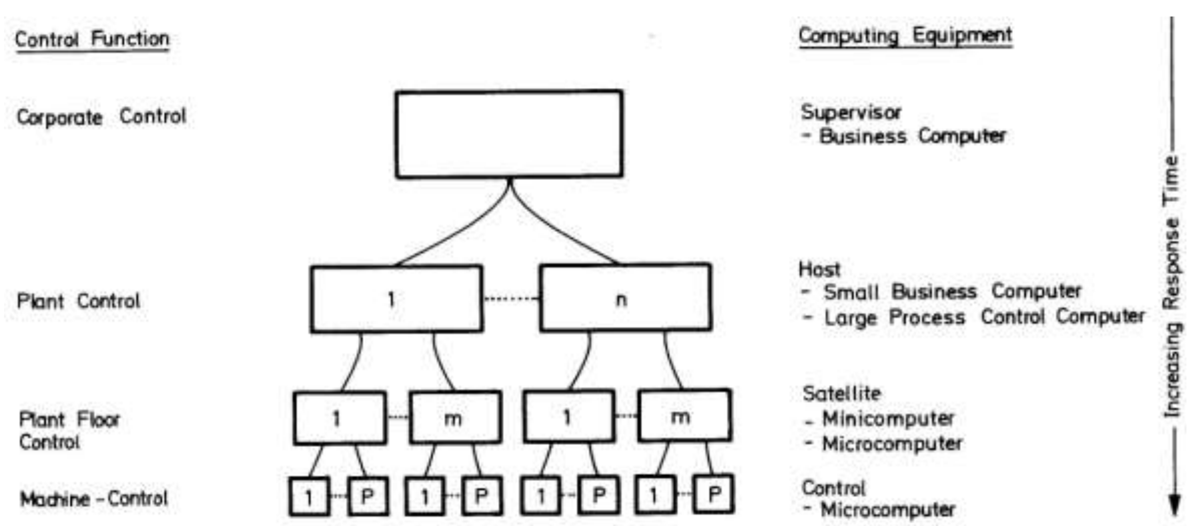


Fig. 47

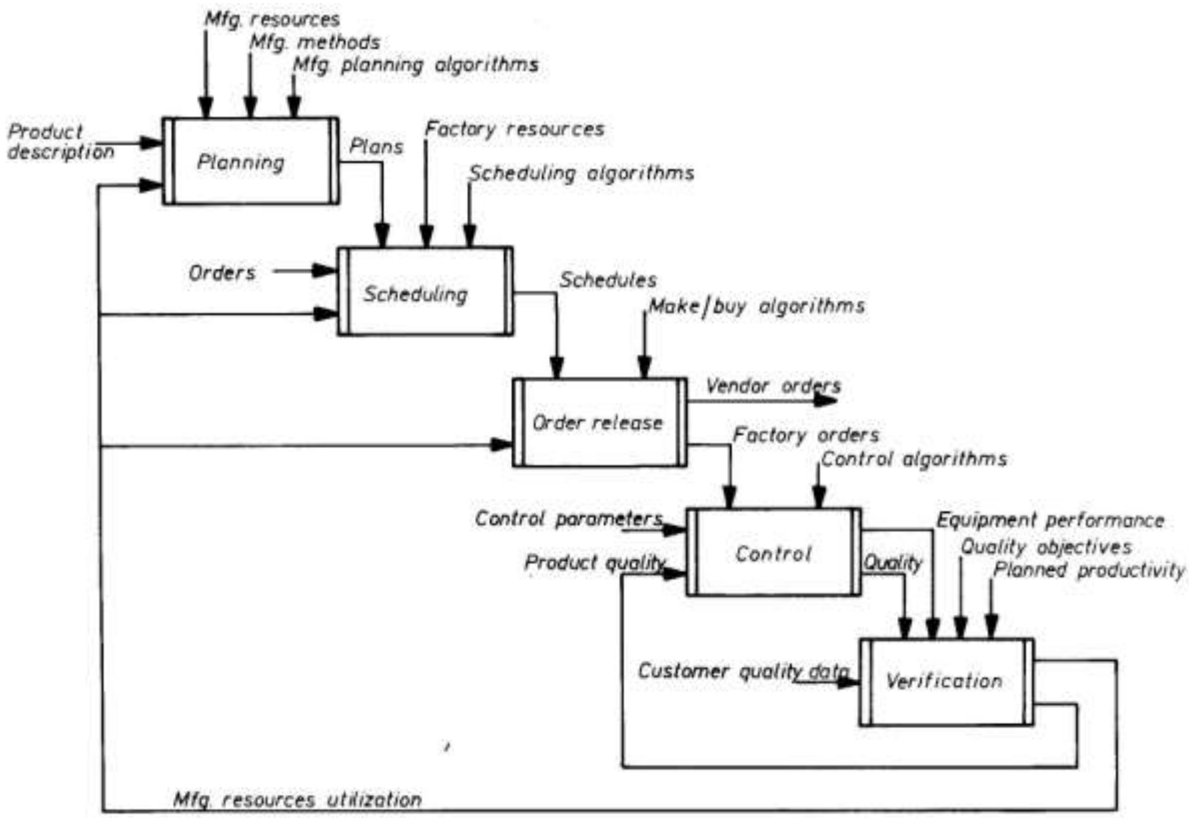


Fig. 48 *Control Loop of a Manufacturing System*

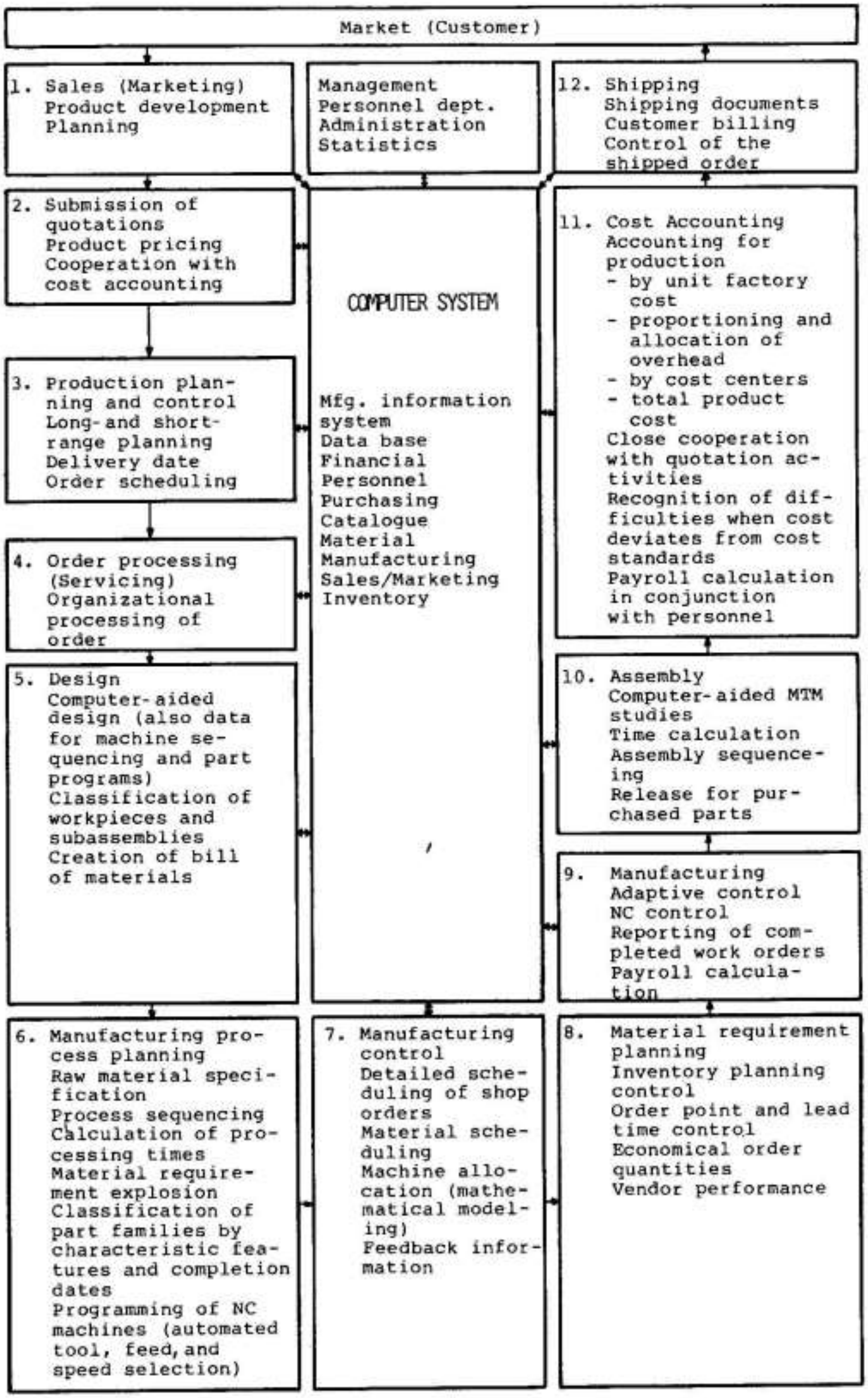

Market (Customer)
1. Sales (Marketing) Product development Planning
Management Personnel dept. Administration Statistics
12. Shipping Shipping documents Customer billing Control of the shipped order
2. Submission of quotations Product pricing Cooperation with cost accounting
COMPUTER SYSTEM
Mfg. information system Data base Financial Personnel Purchasing Catalogue Material Manufacturing Sales/Marketing Inventory
11. Cost Accounting Accounting for production - by unit factory cost - proportioning and allocation of overhead - by cost centers - total product cost Close cooperation with quotation activities Recognition of difficulties when cost deviates from cost standards Payroll calculation in conjunction with personnel
3. Production planning and control Long- and short-range planning Delivery date Order scheduling
4. Order processing (Servicing) Organizational processing of order
5. Design Computer-aided design (also data for machine sequencing and part programs) Classification of workpieces and subassemblies Creation of bill of materials
10. Assembly Computer-aided MTM studies Time calculation Assembly sequencing Release for purchased parts
9. Manufacturing Adaptive control NC control Reporting of completed work orders Payroll calculation
6. Manufacturing process planning Raw material specification Process sequencing Calculation of processing times Material requirement explosion Classification of part families by characteristic features and completion dates Programming of NC machines (automated tool, feed, and speed selection)
7. Manufacturing control Detailed scheduling of shop orders Material scheduling Machine allocation (mathematical modeling) Feedback information
8. Material requirement planning Inventory planning control Order point and lead time control Economical order quantities Vendor performance

Fig. 49

IV. Functions of the computer in a manufacturing organization

Operation problems in FMS

- The operation problems in FMS include
- Part selection and tool management
- Fixture and pallet selection
- Machine grouping and loading (part and tool assignment)
- Part selection and tool management methods
- There are several methods available.
- The mathematical programming approach (Hwang's model). Let:

  i = 1, 2, …,N = part types

  c = 1, 2, …,C = tool types

  t = tool magazine capacity

  $$b_{ic} = \begin{cases} 1 & \text{if part type } i \text{ requres tool } c \\ 0 & \text{otherwise} \end{cases}$$

  d_c = number of slots required to hold tools in the tool magazine of each machine

  $$z_i = \begin{cases} 1 & \text{if part type } i \text{ is selected in the batch} \\ 0 & \text{otherwise} \end{cases}$$

  $$y_c = \begin{cases} 1 & \text{if tool } c \text{ is loaded on a machine} \\ 0 & \text{otherwise} \end{cases}$$

  Note that z_i and y_c are decision variables. The goal is:

  $$\text{Maximize} \quad \sum_i z_i$$

  subject to: $\sum_c d_c y_c \le 1$

  $b_{ic} z_i \le y_c$, for all i, c

  z_i = 0 or 1, for all i, c

  y_c = 0 or 1, for all i, c

- After the parts and tools are selected, one must determine the tool allocation problem. There are several different policies for tool allocation
- Bulk exchange policy: change all the tools according to a preset schedule
- Tool migration policy: change the tools once the parts are processed

- Resident tooling policy: allocate the tools according to the similarity and change the tools only when they worn out. The tool allocation algorithm is the same as the machine allocation algorithm discussed in the previous section.
- Tool sharing policy: combine bulk exchange and resident tooling policies.
- Fixture and pallet selection
- Fixture is the interface between the machine and the material-handling system.
- The use of palletized parts is very important in the integration of machines, material-handling equipment and storage facilities.
- The fixture and pallet selection problem can be considered as a subset of the part selection problem. The approximate number of pallets required is:

$$\text{Number of pallets} = \frac{PR \bullet CT}{PT \bullet NP}$$

where, *PR* = parts required per shift

CT = average pallet cycle time

PT = planned production time per shift

NP = number of parts per pallet

- Machine grouping and loading
- The machine grouping and loading problem refers to grouping of machines and allocation of operations and tools required for the selected part types.
- A number of criteria have to be considered:
    - Balance the assigned machine processing times
    - Minimize the number of movements from machine to machine
    - Balance the workload per machine in the system
    - Fill the tool magazines as densely as possible
    - Maximize the number of weighted operations.

Quantitative Analysis of Flexible Manufacturing Systems

- FMS analysis techniques:
    1. Deterministic models
    2. Queuing models
    3. Discrete event simulation

4. Other approaches, including heuristics

- Deterministic models
   1. Bottleneck model - estimates of production rate, utilization, and other measures for a given product mix
   2. Extended bottleneck model - adds work-in-process feature to basic model
- For a given part mix, the total production rate is ultimately limited by the bottleneck station
- If part mix ratios can be relaxed, it may be possible to increase total FMS production rate by increasing the utilization of non-bottleneck stations
- As a first approximation, bottleneck model can be used to estimate the number of servers of each type to achieve a specified overall production rate
- The number of parts in the FMS at any one time should be greater than the number of servers (processing machines) in the system
   1. Ratio of two parts per server is probably optimum
   2. Parts must be distributed throughout the FMS, especially in front of the bottleneck station
   3. If WIP is too low, production rate is impaired
   4. IF WIP is too high, MLT increases

4.14 Group Technology and Flexible Manufacturing Systems

Overview of Group Technology (GT)

- Parts in the medium production quantity range are usually made in batches
- Disadvantages of batch production
- Downtime for changeovers
- High inventory carrying costs
- GT minimizes these disadvantages by recognizing that although the parts are different, there are groups of parts that possess similarities
- GT exploits the part similarities by utilizing similar processes and tooling to produce them
- GT can be implemented by manual or automated techniques
- When automated, the term *flexible manufacturing system* is often applied

Group Technology Defined

- An approach to manufacturing in which similar parts are identified and grouped together in order to take advantage of their similarities in design and production
- Similarities among parts permit them to be classified into part families
- In each part family, processing steps are similar
- The improvement is typically achieved by organizing the production facilities into manufacturing cells that specialize in production of certain part families

Part Family

- A group of parts that possess similarities in geometric shape and size, or in the processing steps used in their manufacture
- Part families are a central feature of group technology
- There are always differences among parts in a family
- But the similarities are close enough that the parts can be grouped into the same family

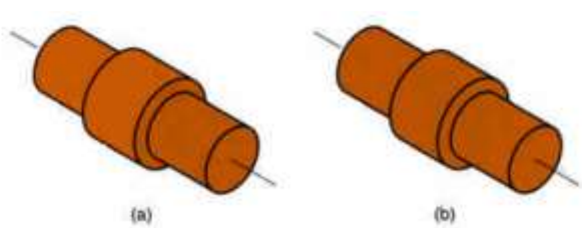


Fig. 50

Two parts that are identical in shape and size but quite different in manufacturing:

(a)1,000,000 units/yr, tolerance = ±0.010 inch, 1015 CR steel, nickel plate

(b)100/yr, tolerance = ±0.001 inch, 18-8 stainless steel

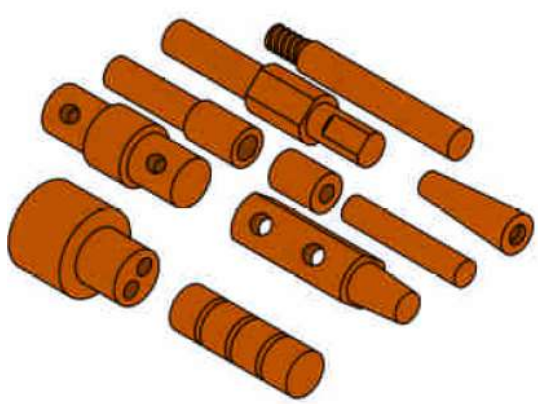


Fig. 51

Ten parts those are different in size and shape, but quite similar in terms of manufacturing

- All parts are machined from cylindrical stock by turning; some parts require drilling and/or milling

Ways to Identify Part Families

1. Visual inspection - using best judgment to group parts into appropriate families, based on the parts or photos of the parts

2. Production flow analysis - using information contained on route sheets to classify parts

3. Parts classification and coding - identifying similarities and differences among parts and relating them by means of a coding scheme

Parts Classification and Coding

- Most classification and coding systems are one of the following
- Systems based on part design attributes
- Systems based on part manufacturing attributes
- Systems based on both design and manufacturing attributes

Part Design Attributes

- Major dimensions
- Basic external shape
- Basic internal shape
- Length/diameter ratio
- Material type
- Part function
- Tolerances
- Surface finish

Part Manufacturing Attributes

- Major process
- Operation sequence
- Batch size
- Annual production
- Machine tools
- Cutting tools
- Material type

Benefits of a Well-Designed Classification and Coding System

- Facilitates formation of part families
- Permits quick retrieval of part design drawings
- Reduces design duplication
- Promotes design standardization
- Improves cost estimating and cost accounting
- Facilitates NC part programming by allowing new parts to use the same part program as existing parts in the same family
- Computer-aided process planning (CAPP) becomes feasible

Composite Part Concept

- A *composite part* for a given family is a hypothetical part that includes all of the design and manufacturing attributes of the family
- In general, an individual part in the family will have some of the features of the family, but not all of them
- A production cell for the part family would consist of those machines required to make the composite part
- Such a cell would be able to produce any family member, by omitting operations corresponding to features not possessed by that part
- Composite part concept: (a) the composite part for a family of machined rotational parts, and (b) the individual features of the composite part

Composite Part Features and Corresponding Manufacturing Operations

Design feature Corresponding operation

Design feature	Corresponding operation
1.External cylinder	Turning
2.Face of cylinder	Facing
3.Cylindrical step	Turning
4.Smooth surface	External cylindrical grinding
5.Axial hole	Drilling
6.Counterbore	Counterboring
7.Internal threads	Tapping

4.15 Machine Cell Designs (Types of GT cells)

(a) Single machine

(b) Multiple machines with manual handling

(c) Multiple machines with mechanized handling

(d) Flexible manufacturing cell

(e) Flexible manufacturing system

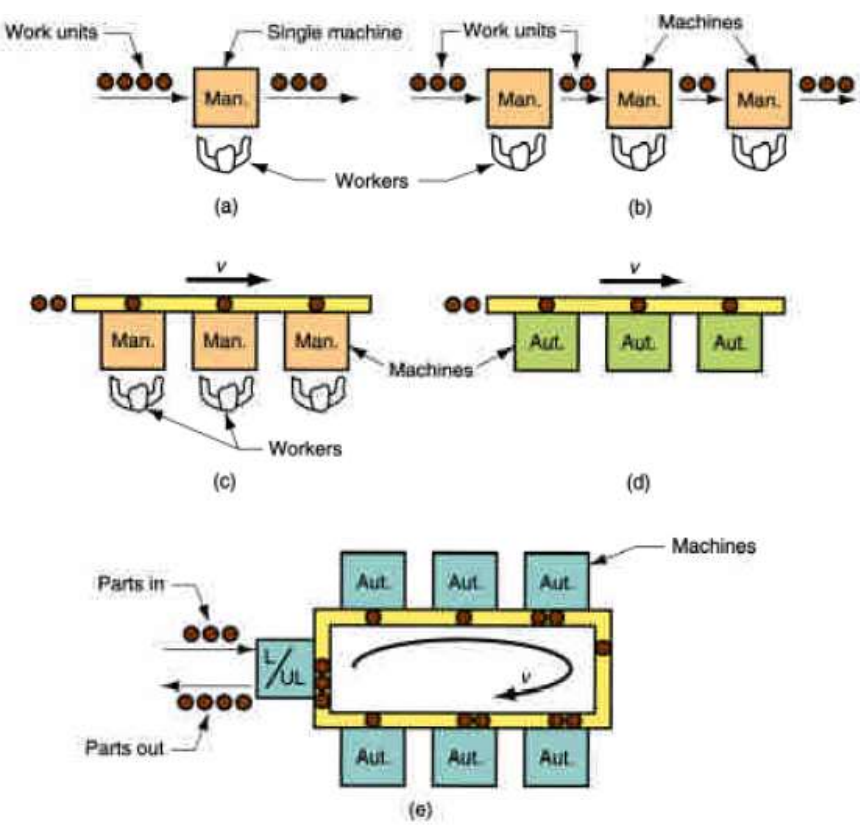


Fig. 52

Benefits of Group Technology

- Standardization of tooling, fixtures, and setups is encouraged
- Material handling is reduced
- Parts are moved within a machine cell rather than entire factory
- Process planning and production scheduling are simplified
- Work-in-process and manufacturing lead time are reduced
- Improved worker satisfaction in a GT cell
- Higher quality work

Problems in Group Technology

- Identifying the part families (the biggest problem)
- If the plant makes 10,000 different parts, reviewing all of the part drawings and grouping the parts into families is a substantial task
- Rearranging production machines in the plant into the appropriate machine cells
- It takes time to plan and accomplish this rearrangement, and the machines are not producing during the changeover

FMS Planning and Design Issues

- Part family considerations
  - Defining the part family of families to be processed
    - Based on part similarity
    - Based on product commonality
- Processing requirements
  - Determine types of processing equipment required
- Physical characteristics of workparts
  - Size and weight determine size of processing equipment and material handling equipment
- Production volume
  - Annual quantities determined number of machines required
- Types of workstations

- Variations in process routings
- Work-in-process and storage capacity
- Tooling
- Pallet fixtures

FMS Operational Issues

- Scheduling and dispatching
    - Launching parts into the system at appropriate times
- Machine loading
    - Deciding what operations and associated tooling at each workstation
- Part routing
    - Selecting routes to be followed by each part
- Part grouping
    - Which parts should be on the system at one time
- Tool management
    - When to change tools
- Pallet and fixture allocation
    - Limits on fixture types may limit part types that can be processed

Flexible Manufacturing System: Overview

- A highly automated GT machine cell, consisting of a group of processing stations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by an integrated computer system
- The FMS relies on the principles of GT
- No manufacturing system can produce an unlimited range of products
- An FMS is capable of producing a single part family or a limited range of part families

Flexibility Tests in an Automated Manufacturing System

- Automated manufacturing cell with two machine tools and robot. Is it a flexible cell?

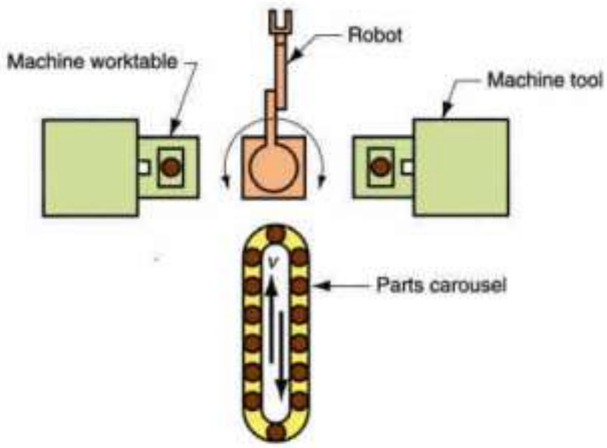


Fig. 53

- To qualify as being flexible, a manufacturing system should satisfy the following criteria ("yes" answer for each question):

1. Can it process different part styles in a non-batch mode?
2. Can it accept changes in production schedule?
3. Can it respond gracefully to equipment malfunctions and breakdowns?
4. Can it accommodate introduction of new part designs?

If the automated system does not meet these four tests, it should not be classified as a flexible manufacturing or cell.

Is the Robotic Work Cell Flexible?

1. Can it machine different part configurations in a mix rather than in batches?
2. Can production schedule and part mix be changed?
3. Can it operate if one machine breaks down?

Example: while repairs are being made on the broken machine, can its work be temporarily reassigned to the other machine?

4. As new part designs are developed, can NC part programs be written off-line and then downloaded to the system for execution?

This fourth capability also requires that the toolings in the CNC machines as well as the end effecter of the robot are suited to the new part design.

FMS Components

- Hardware components

Workstations - CNC machines in a machining type system

Material handling system - means by which parts are moved between stations

Central control computer - to coordinate the activities of the components so as to achieve a smooth overall operation of the system

- Software and control functions
- Human labor

Five Types of FMS Layouts

1. In-line
2. Loop
3. Ladder
4. Open field
5. Robot-centered cell

   ➢ The basic layout of the FMS is established by the material handling system

Three of the five FMS layout types: (a) in-line

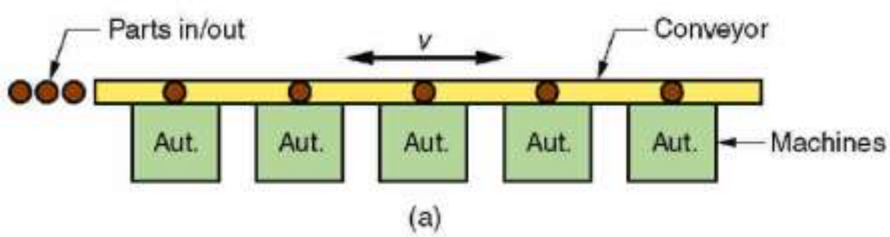


Fig. 54

Key: Aut = automated station; L/UL = load/unload station;

Insp = inspection station; AGV = automated guided vehicle;

AGVS = automated guided vehicle system

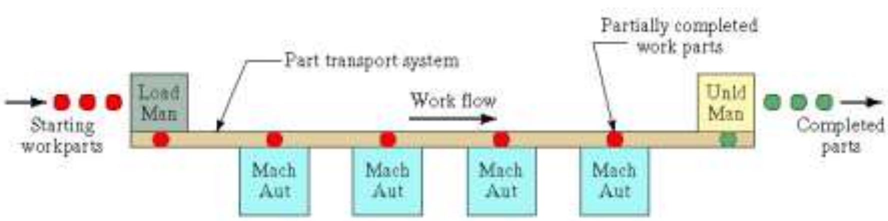


Fig. 55

- Straight line flow, well-defined processing sequence similar for all work units
- Work flow is from left to right through the same workstations
- No secondary handling system

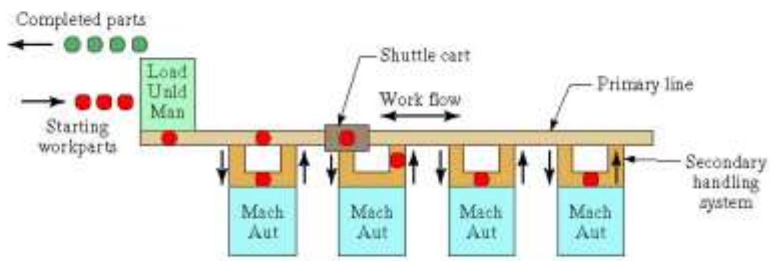


Fig. 56

- Linear transfer system with secondary parts handling system at each workstation to facilitate flow in two directions

Loop layout

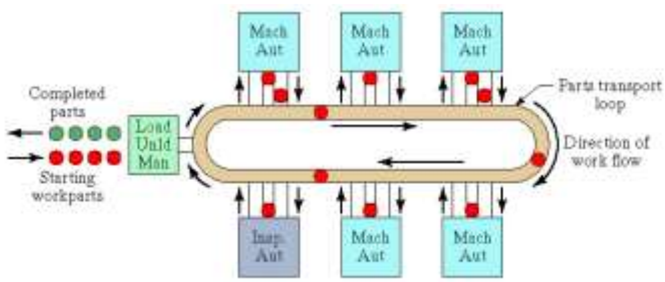


Fig. 57

- One direction flow, but variations in processing sequence possible for different part types
- Secondary handling system at each workstation

Rectangular Layout

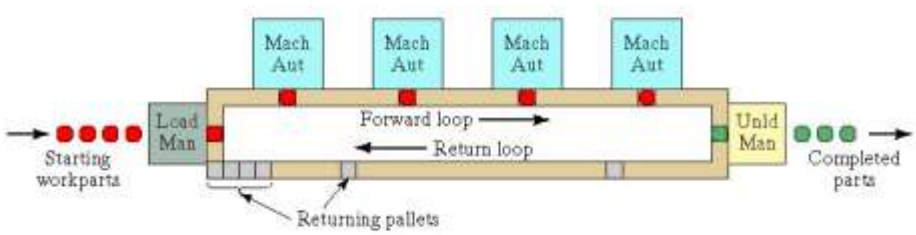


Fig. 58

- Rectangular layout allows recirculation of pallets back to the first station in the sequence after unloading at the final station

Ladder layout

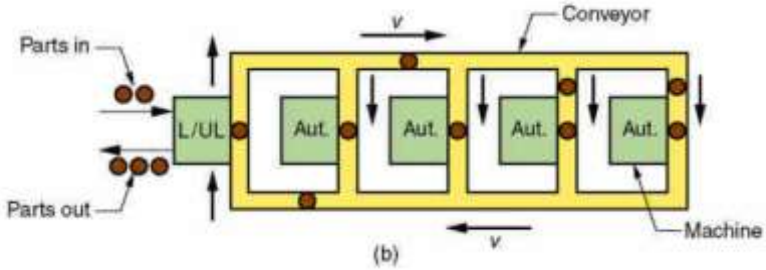


Fig. 59

Key: Aut = automated station; L/UL = load/unload station;
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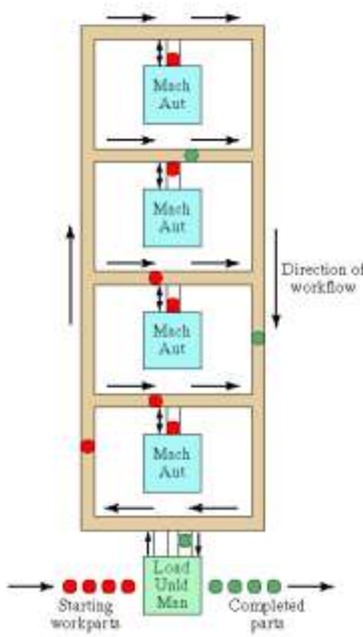

Fig. 60

- Loop with rungs to allow greater variation in processing sequence

Open field

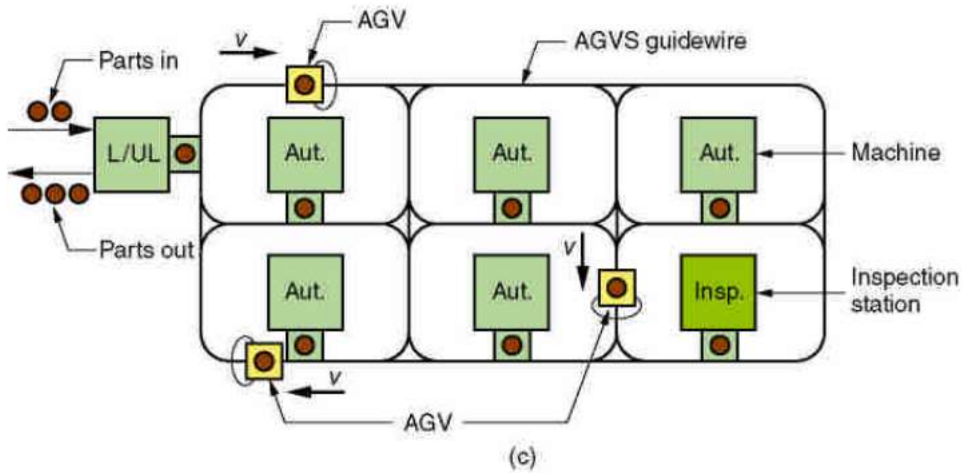

Fig. 61

•Key: Aut = automated station; L/UL = load/unload station;

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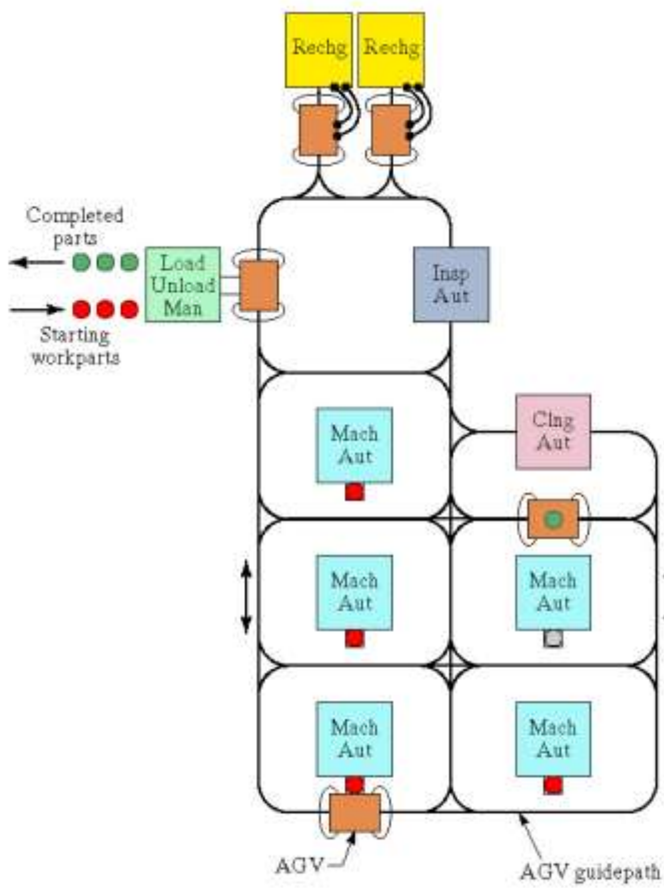

Fig. 62

- Multiple loops and ladders, suitable for large part families

Robot centered layout

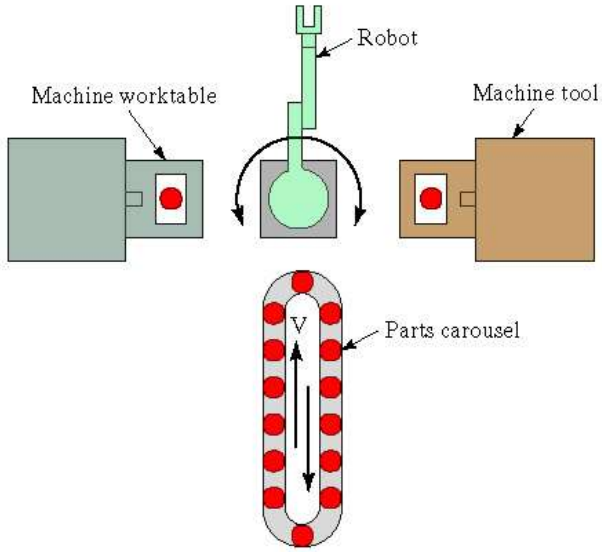

Fig. 63

- Suited to the handling of rotational parts and turning operations

Typical Computer Functions in a FMS

1. Workstation control
   - Individual stations require controls, usually computerized
2. Distribution of control instructions to workstations
   - Central intelligence required to coordinate processing at individual stations
3. Production control
   - Product mix, machine scheduling, and other planning functions
4. Traffic control
   - Management of the primary handling system to move parts between workstations
5. Shuttle control
   - Coordination of secondary handling system with primary handling system
6. Workpiece monitoring
   - Monitoring the status of each part in the system
7. Tool control
   - Tool location

        - Keeping track of each tool in the system
    - Tool life monitoring
        - Monitoring usage of each cutting tool and determining when to replace worn tools

8. Performance monitoring and reporting
    - Availability, utilization, production piece counts, etc.
9. Diagnostics
    - Diagnose malfunction causes and recommend repairs

- *NC part programming* - development of NC programs for new parts introduced into the system
- *Production control* - product mix, machine scheduling, and other planning functions
- *NC program download* - part program commands must be downloaded to individual stations
- *Machine control* - individual workstations require controls, usually CNC

More Computer Functions in a FMS

Workpart control - monitor status of each workpart in the system, status of pallet fixtures, orders on loading/unloading pallet fixtures

Tool management - tool inventory control, tool status relative to expected tool life, tool changing and resharpening, and transport to and from tool grinding

Transport control - scheduling and control of work handling system *System management* - compiles management reports on performance (utilization, piece counts, production rates, etc.)

Duties Performed by Human Labor

- ✓ Loading and unloading parts from the system
- ✓ Changing and setting cutting tools
- ✓ Maintenance and repair of equipment
- ✓ NC part programming
- ✓ Programming and operating the computer system
- ✓ Overall management of the system

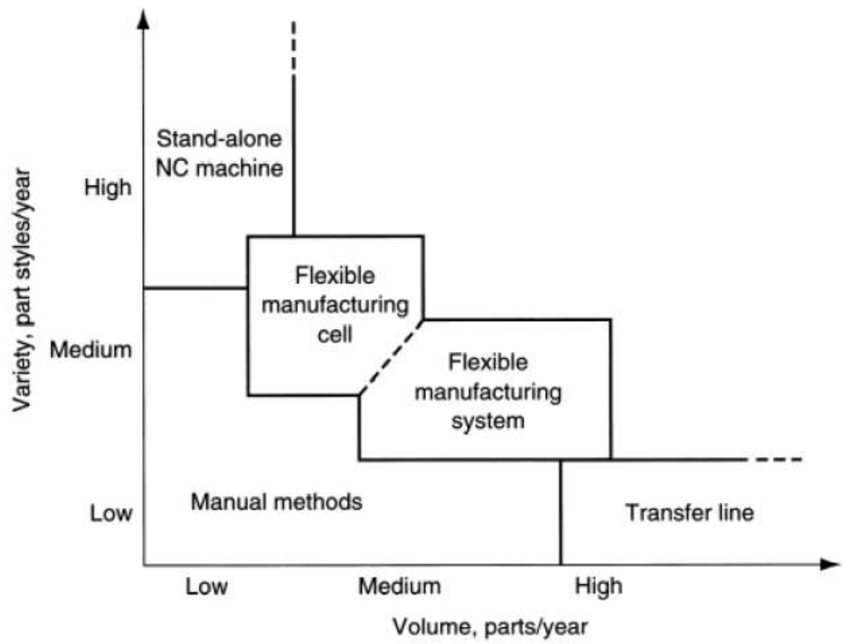

Fig. 64 *Application characteristics of flexible manufacturing systems and cells relative to other types of production systems*

Typical FMS Benefits

- Higher machine utilization than a conventional machine shop due to better work handling, off-line setups, and improved scheduling
- Reduced work-in-process due to continuous production rather than batch production
- Lower manufacturing lead times
- Greater flexibility in production scheduling

Where to Apply FMS Technology

- The plant presently either:
  - Produces parts in batches or
  - Uses manned GT cells and management wants to automate the cells
- It must be possible to group a portion of the parts made in the plant into part families

    - The part similarities allow them to be processed on the FMS workstations
- Parts and products are in the mid-volume, mid-variety production range

Flexible Manufacturing System - Defined

A highly automated GT machine cell, consisting of a group of processing stations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by an integrated computer system

- The FMS relies on the principles of GT
    - No manufacturing system can produce an unlimited range of products
    - An FMS is capable of producing a single part family or a limited range of part families

Flexibility Tests in an Automated Manufacturing System

To qualify as being flexible, a manufacturing system should satisfy the following criteria ("yes" answer for each question):

a. Can it process different part styles in a non-batch mode?
b. Can it accept changes in production schedule?
c. Can it respond gracefully to equipment malfunctions and breakdowns?
d. Can it accommodate introduction of new part designs?

1. Part variety test

   Can it machine different part configurations in a mix rather than in batches?

2. Schedule change test

   Can production schedule and part mix be changed?

3. Error recovery test
    - Can it operate if one machine breaks down?
        - Example: while repairs are being made on the broken machine, can its work be temporarily reassigned to the other machine?
4. New part test
    - As new part designs are developed, can NC part programs be written off-line and then downloaded to the system for execution?

Types of FMS

- Kinds of operations
  - Processing vs. assembly
  - Type of processing
    - If machining, rotational vs. non-rotational
- Number of machines (workstations):
  - Single machine cell (n = 1)
  - Flexible manufacturing cell (n = 2 or 3)
  - Flexible manufacturing system (n = 4 or more)

Single-Machine Manufacturing Cell

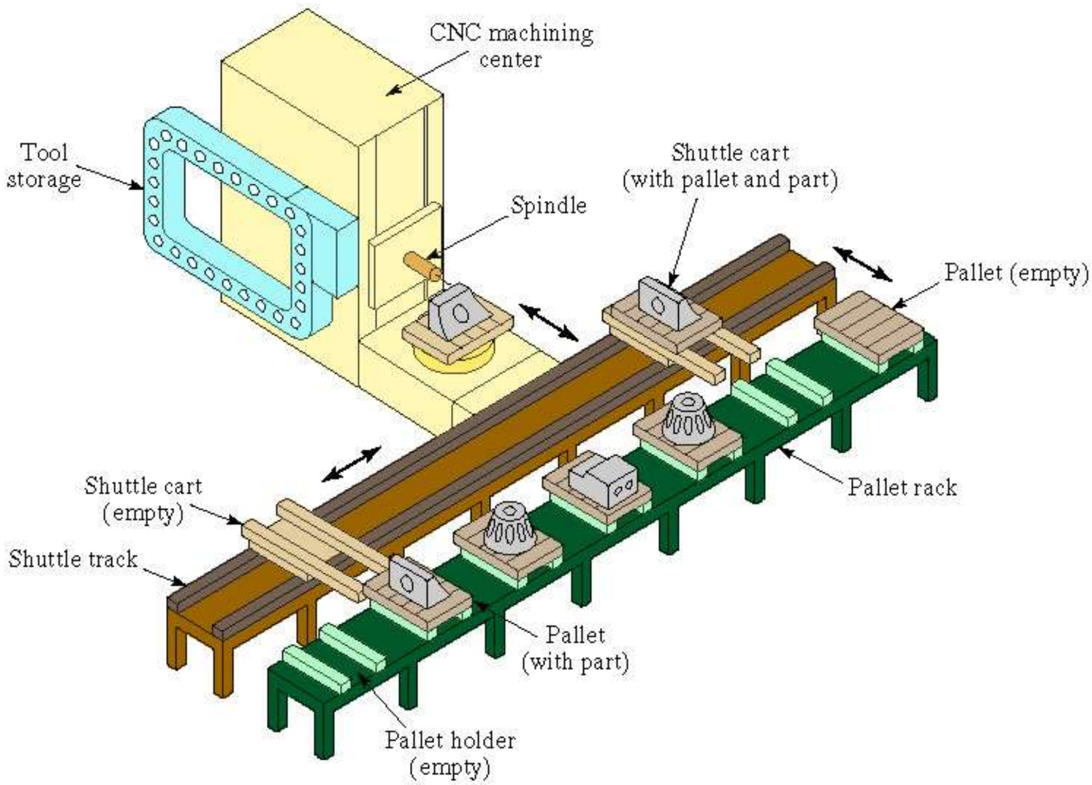

Fig. 65 A single-machine CNC machining cell (photo courtesy of Cincinnati Milacron)

Fig. 66 Flexible Manufacturing Cell

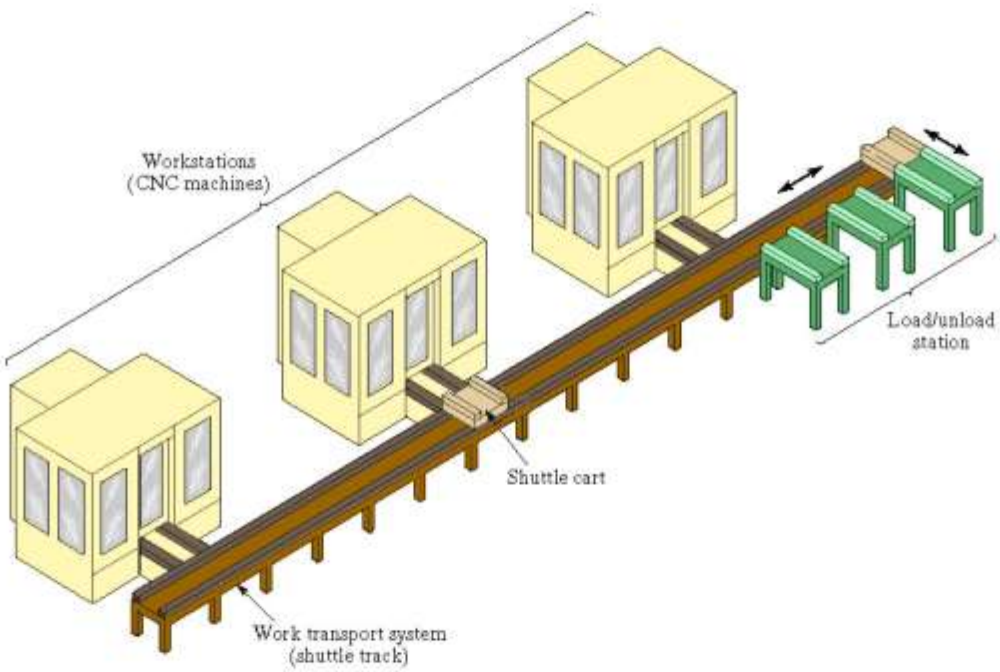

Fig. 67 A two-machine flexible manufacturing cell for machining (photo courtesy of Cincinnati Milacron)

Fig. 68 A five-machine flexible manufacturing system for machining (photo courtesy of Cincinnati Milacron)

Fig. 69

Features of the Three Categories

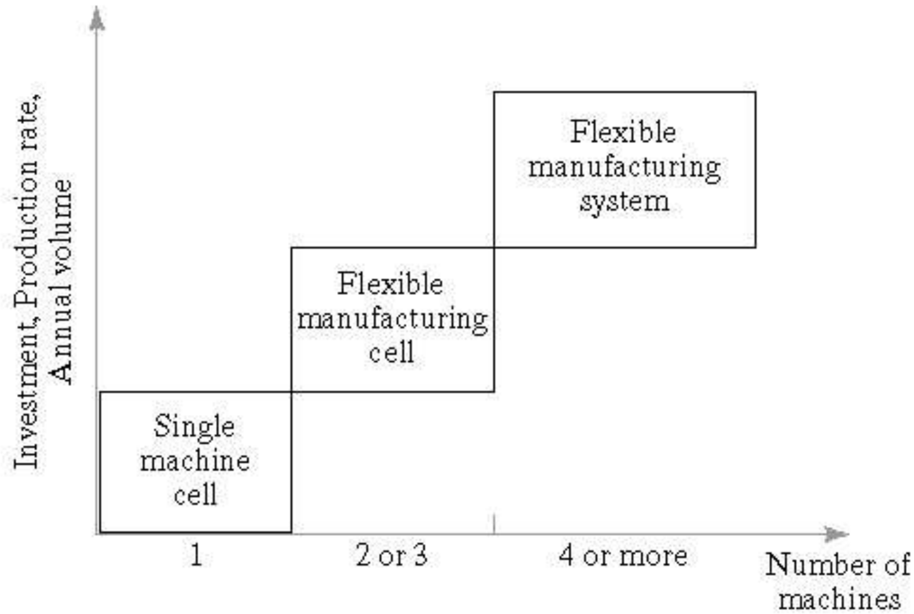

Fig. 70

FMS types: Level of Flexibility

a. Dedicated FMS

- Designed to produce a limited variety of part styles
- The complete universe of parts to be made on the system is known in advance
- Part family likely based on product commonality rather than geometric similarity

b. Random-order FMS

- Appropriate for large part families
- New part designs will be introduced
- Production schedule is subject to daily changes

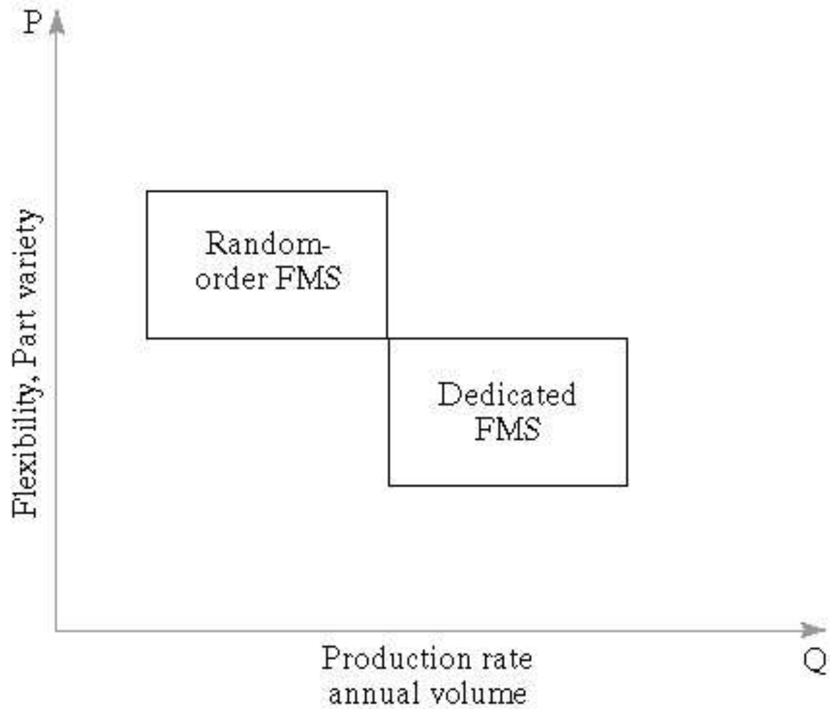

Fig. 71

FMS Components

1. Workstations
2. Material handling and storage system
3. Computer control system
4. Human labor

Workstations

- Load and unload station(s)
  - Factory interface with FMS
  - Manual or automated
  - Includes communication interface with worker to specify parts to load, fixtures needed, etc.
- CNC machine tools in a machining type system
  - CNC machining centers
  - Milling machine modules
  - Turning modules
- Assembly machines

Material Handling and Storage

- Functions:
  - Random, independent movement of parts between stations
  - Capability to handle a variety of part styles
    - Standard pallet fixture base
    - Workholding fixture can be adapted
  - Temporary storage
  - Convenient access for loading and unloading
  - Compatibility with computer control

Material Handling Equipment

- Primary handling system establishes basic FMS layout
- Secondary handling system - functions:
  - Transfers work from primary handling system to workstations
  - Position and locate part with sufficient accuracy and repeatability for the operation
  - Reorient part to present correct surface for processing
  - Buffer storage to maximize machine utilization

FMS Applications

- Machining –most common application of FMS technology
- Assembly
- Inspection
- Sheet metal processing (punching, shearing, bending, and forming)
- Forging

FMS Development in India

Because of the high cost in FMS, Indian manufacturers have not evinced much interest in the total adoption of this technology. The first unit of this type was established at the Heavy Alloy Penetrator Project (HAPP) at Trichy in South India during late 80's. This unit has all the facilities of a FMS. Part of the equipment was manufactured at HMT and the installation of the factory was done by erstwhile HMT CIM division. Subsequently a number of flexible turning cells have been set up by manufacturing industries in different parts of the country. FMS as a whole is not very popular today because of its high cost and the time taken to design and install one. However, the principles of FMS are quite relevant and are being widely followed for achieving global competitiveness.

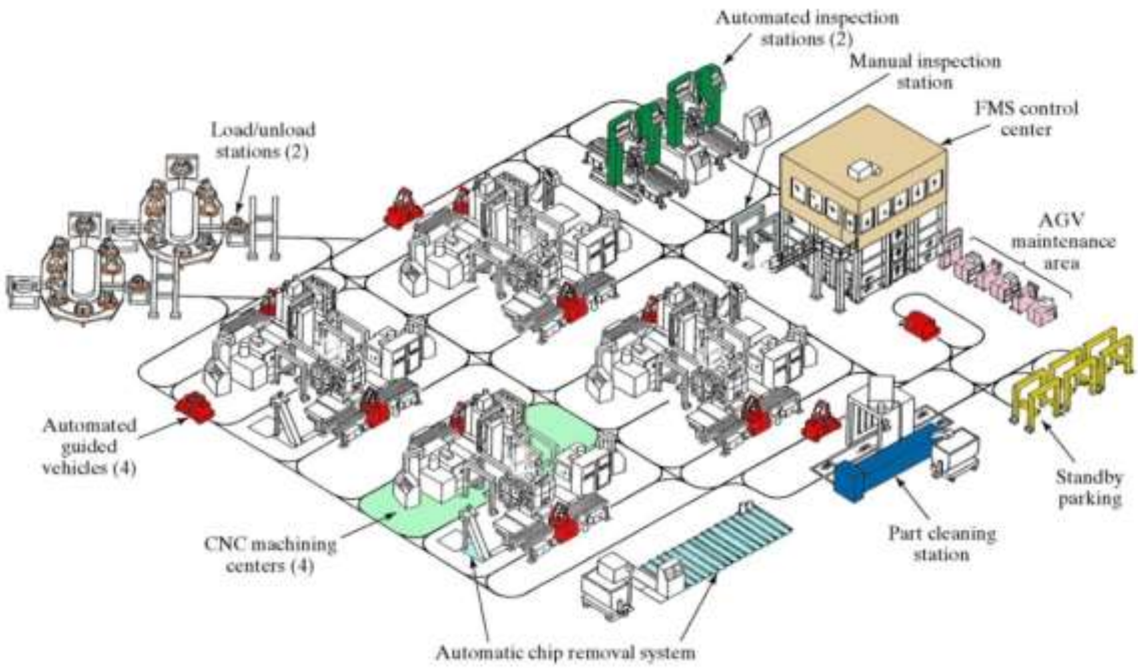

Fig. 72 FMS at Chance-Vought Aircraft (courtesy of Cincinnati Milacron)

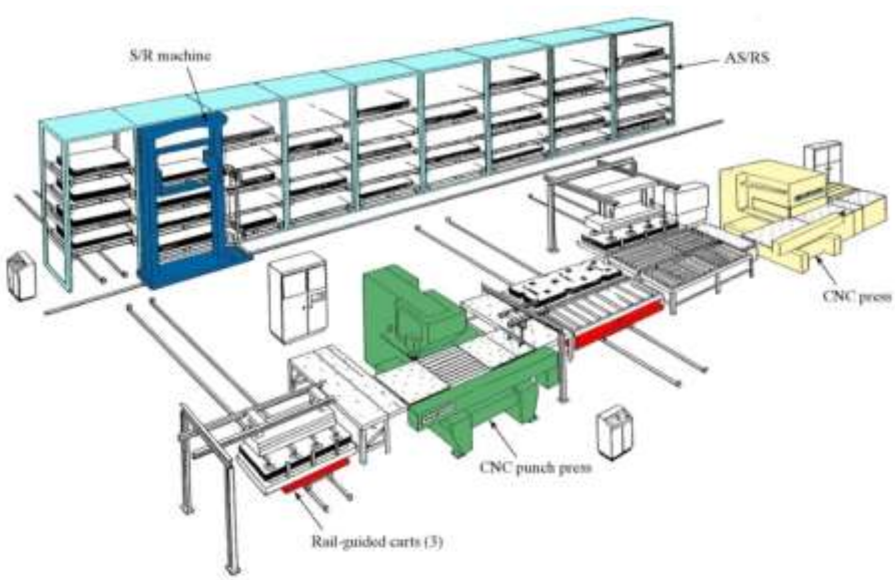

Fig. 72 FMS for Sheet Metal Fabrication

FMS Benefits

- Increased machine utilization
  - Reasons:
    - 24 hour operation likely to justify investment
    - Automatic tool changing
    - Automatic pallet changing at stations
    - Queues of parts at stations to maximize utilization
    - Dynamic scheduling of production to account for changes in demand
- Fewer machines required
- Reduction in factory floor space required
- Greater responsiveness to change
- Reduced inventory requirements
  - Different parts produced continuously rather than in batches
- Lower manufacturing lead times
- Reduced labor requirements
- Higher productivity
- Opportunity for unattended production
  - Machines run overnight ("lights out operation")

Summary:

Shop floor control: The three phases of shop floor control

1. Order release
2. Order scheduling
3. Order progress

Factory Data Collection System

- On-line versus batch systems
- Data input techniques
  - Job traveler

- Employee time sheets
- Operation tear strips
- Prepunched cards
- Providing key board based terminals
    - One centralized terminal
    - Satellite terminals
    - Workstation terminals

Automatic identification methods

- Bar codes
- Radio frequency systems
- Magnetic stripe
- Optical character recognition
- Machine vision

Automated data collection systems

- Data acquisition systems
- Multilevel scanning

Components of Flexible Manufacturing Systems(FMS)

- Workstations
- Material handling and storage
- Computer control system
- Human resources

Flexibility

Flexibility in manufacturing means the ability to deal with slightly or greatly mixed parts, to allow variation in parts assembly and variations in process sequence, change the production volume and change the design of certain product being manufactured.

Workstations

- Load/unload stations
- Machining stations
- Other processing stations

- Assembly

Material handling and storage systems

- Primary material handling
- Secondary material handling

FMS layout

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

Computer control system

- Workstation control
- Distribution of control instructions to workstations
- Production control
- Traffic control
- Shuttle control
- Workpiece monitoring
- Tool control
- Performance monitoring and reporting
- Diagnostics

Module-III

CIM Implementation: CIM and company strategy, System modeling tools-IDEF models, Activity cycle diagram, CIM open system architecture (CIMOSA), Manufacturing enterprise wheel, CIM architecture, Product data management, CIM implementation software.

Data Communication: Communication fundamentals, Local area networks, Topology, LAN implementations, Network management and installations.

5. Introduction to CIM Implementation

CIM and company strategy

Does that mean the starting point for CIM is a network to link all the existing islands of automation and software? Or is it the integration of the existing departmental functions and activities as suggested by the CIM wheel?

The answer to both the questions just posed is no. the starting point for CIM is not islands of automation or software, not is it the structure presented by the CIM wheel, rather it is a ***company's business strategy.***

System modeling tools

It is helpful if the modeling tool is of sufficient sophistication that it exists in three forms:

- As a representation of the system
- As a dynamic model
- As an executable model

IDEF and IDEF0

IDEF initially provided three modeling methods

- IDEF0 is used for describing the activities and functions of a system
- IDEF1 is used for describing the information and its relationships
- IDEF2 is used for describing the dynamics of a system

Activity cycle diagrams

This modeling approach follows the notation of IDEF0 by having activities represented as rectangles and by having the activity names specified inside the rectangle. All resources which are to be represented in the model are classified as entity classes.

CIM open system architecture (CIMOSA)

CIMOSA was produced as generic reference architecture for CIM integration as part of an ESPRIT project. The architecture is designed to yield executable models or parts of models leading to computerized implementations for managing an enterprise.

Manufacturing enterprise wheel

The new manufacturing enterprise wheel's focus is now the customer at level 1, and it identifies 15 key processes circumferentially at level 4. These are grouped under the headings of customer support, product/process and manufacturing.

Production Strategy

The production strategy used by manufacturers is based on several factors; the two most critical are customer lead time and manufacturing lead time.

Customer lead time identifies the maximum length of time that a typical customer is willing to wait for the delivery of a product after an order is placed. Manufacturing lead time identifies the maximum length of time between the receipt of an order and the delivery of a finished product.

Manufacturing lead time and customer lead time must be matched. For example, when a new car with specific options is ordered from a dealer, the customer is willing to wait only a few weeks for delivery of the vehicle. As a result, automotive manufacturers must adopt a production strategy that permits the manufacturing lead-time to match the customer's needs. The production strategies used to match the customer and manufacturer lead times are grouped into four categories:

1. Engineer to order (ETO)

2. Make to order (MTO)
3. Assemble to order (ATO)
4. Make to stock (MTS)

Engineer to Order

A manufacturer producing in this category has a product that is either in the first stage of the life-cycle curve or a complex product with a unique design produced in single-digit quantities. Examples of ETO include construction industry products (bridges, chemical plants, automotive production lines) and large products with special options that are stationary during production (commercial passenger aircraft, ships, high-voltage switchgear, steam turbines). Due to the nature of the product, the customer is willing to accept a long manufacturing lead time because the engineering design is part of the process.

Make to Order

The MTO technique assumes that all the engineering and design are complete and the production process is proven. Manufacturers use this strategy when the demand is unpredictable and when the customer lead-time permits the production process to start on receipt of an order. New residential homes are examples of this production strategy. Some outline computer companies make personal computer to customer specifications, so they followed MTO specifications.

Assemble to Order

The primary reason that manufacturers adopt the ATO strategy is that customer lead time is less than manufacturing lead time. An example from the automotive industry was used in the preceding section to describe this situation for line manufacturing systems. This strategy is used when the option mix for the products can be forecast statistically: for example, the percentage of four-door versus two-door automobiles assembled per week. In addition, the subassemblies and parts for the final product are carried in a finished components inventory, so the final assembly schedule is determined by the customer order. John Deere and General Motors are examples of companies using this production strategy.

Make to Stock

MTS is used for two reasons: (1) the customer lead time is less than the manufacturing lead time, (2) the product has a set configuration and few options so that the demand can be forecast accurately. If positive inventory levels (the store shelf is never empty) for a product is an order-winning criterion, this strategy is used. When this order-winning criterion is severe, the products are often stocked in distribution warehouses located in major population centers. This option is often the last phase of a product's life cycle and usually occurs at maximum production volume.

5.1 *Manufacturing Enterprise (Organization)*

- In most manufacturing organizations the functional blocks can be found as:
- A CIM implementation affects every part of an enterprise; as a result, every block in the organizational model is affected

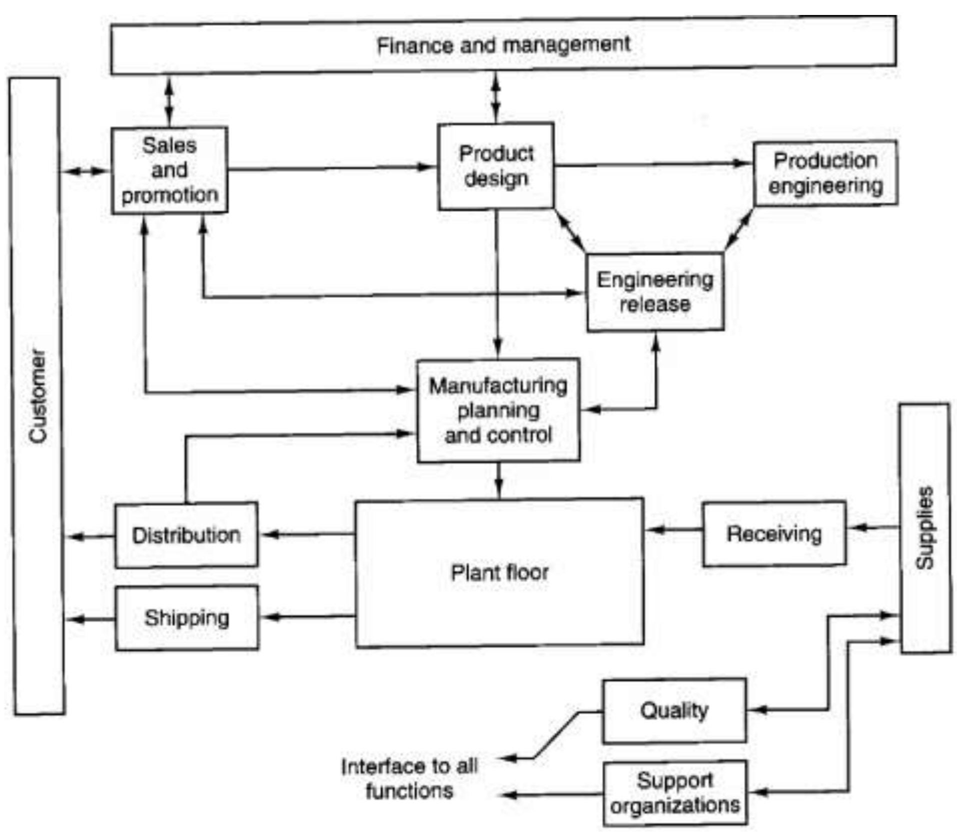

Fig. 73

Sales and Promotion

- The fundamental mission of sales and promotion (SP) is to create customers. To achieve this goal, nine internal functions are found in many companies: sales, customer service, advertising, product research and development, pricing, packaging, public relations, product distribution, and forecasting. Sales and promotion interfaces with several other areas in the business.
- The customer services interface supports three major *customer* functions: order entry, order changes, and order shipping and billing. The order change interface usually involves changes in product specifications, change in product quantity (ordered or available for shipment), and shipment dates and requirements.
- Sales and marketing provide strategic and production planning information to the *finance and management* group, product specification and customer feedback information to *product design*, and information for master production scheduling to the *manufacturing planning and control group*.

Product/Process Definition Engineering

- The unit includes *product design*, *production engineering*, and *engineering release*.
- The product design provides three primary functions: (1) product design and conceptualization, (2) material selection, and (3) design documentation.
- The production engineering area establishes three sets of standards: work, process, and quality.
- The engineering release area manages engineering change on every production part in the enterprise. Engineering release has the responsibility of securing approvals from departments across the enterprise for changes made in the product or production process.

Manufacturing Planning and Control (MPC)

- The manufacturing planning and control unit has a formal data and information interface with several other units and departments in the enterprise.

- The MPC unit has responsibility for:

1. Setting the direction for the enterprise by translating the management plan into manufacturing terms. The translation is smooth if order-winning criteria were used to develop the management plan.
2. Providing detailed planning for material flow and capacity to support the overall plan.
3. Executing these plans through detailed shop scheduling and purchasing action.

MPC Model for Information Flow

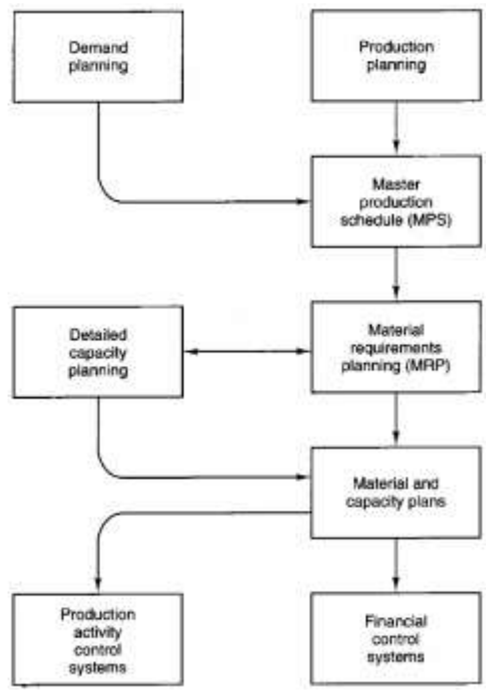

Fig. 74

Shop Floor

- Shop floor activity often includes job planning and reporting, material movement, manufacturing process, plant floor control, and quality control.
- Interfaces with the shop floor unit are illustrated.

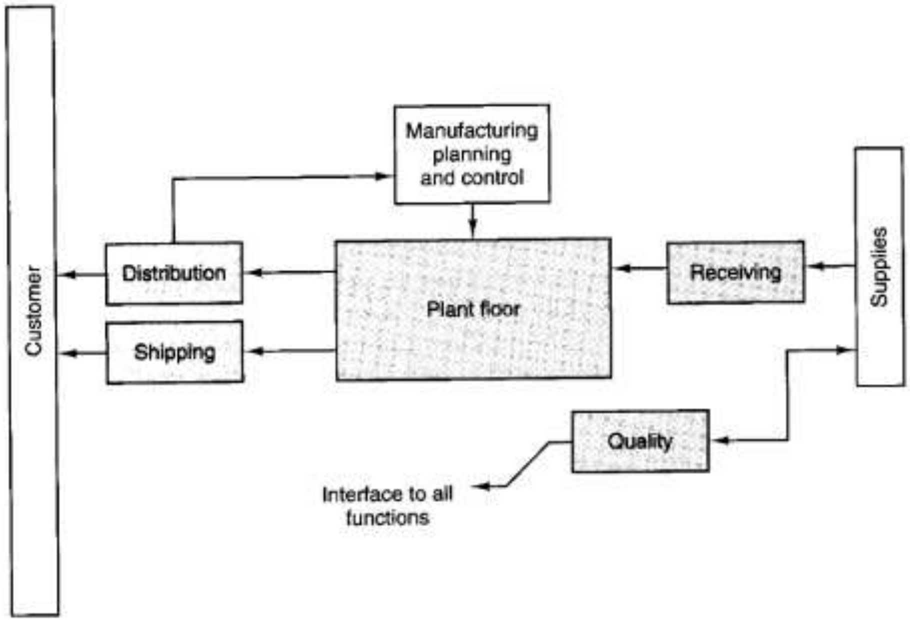

Fig. 75

Support Organization

- The support organizations, indicated vary significantly from firm to firm.
- The functions most often included are security, personnel, maintenance, human resource development, and computer services.
- Basically, the support organization is responsible for all of the functions not provided by the other model elements. Production Sequence :one possibility for the flow required to bring a product to a customer

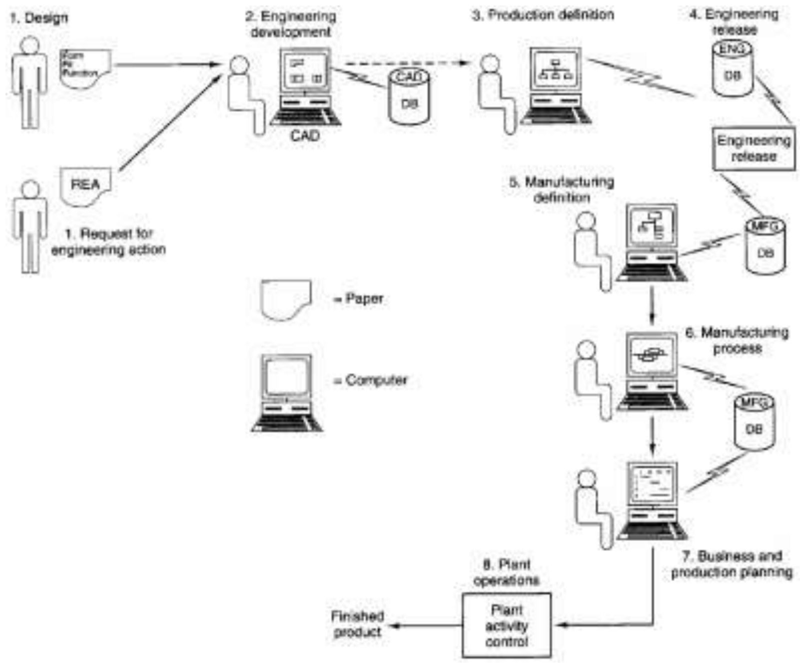

Fig. 76

5.2 Computer-integrated manufacturing (CIM) is the manufacturing approach of using computers to control the entire production process. This integration allows individual processes to exchange info with each other and initiate actions.

Through the computers integration, manufacturing can be faster and less error-prone, although the main advantage is the ability to create automated manufacturing processes.

Typically CIM relies on closed-loop control processes, based on real-time input from sensors. It is also known as flexible design and manufacturing.

CIM encompasses the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated SW packages. The data required for various functions are passed from one application SW to another in a seamless manner. For example, the product data is created during design. This data has to be transferred from the modeling SW to manufacturing SW without any loss of data.

CIM use a common DB wherever feasible and commun-tech to integrate design, manufacturing and associated business. CIM reduces the human component of manufacturing and thereby relieves the process of its slow, expensive and error-prone component.

The term "CIM" is both a method of manufacturing and the name of a computer-automated system in which individual engineering, production, marketing, and support functions of a manufacturing enterprise are organized. In a CIM system functional areas such as design, analysis, planning, purchasing, cost accounting, inventory control, and distribution are linked through the computer with factory floor functions such as materials handling and management, providing direct control and monitoring of all the operations. CIM also encompasses the whole lot of enabling technologies including total quality management, business process reengineering, concurrent engineering, workflow automation, enterprise resource planning and flexible manufacturing. A distinct feature of manufacturing today is *mass customization.* This implies that though the products are manufactured in large quantities, products must incorporate customer-specific changes to satisfy the diverse requirements of the customers. This requires extremely high flexibility in the manufacturing system. As a method of manufacturing, three components distinguish CIM from other manufacturing methodologies:

Means for data storage, retrieval, manipulation and presentation

Mechanisms for sensing state and modifying processes

Algorithms for uniting the data processing component with the sensor/modification Component.

CIM is an example of the implementation of info and common technologies in manufacturing

CIM implies that there are at least two computers exchanging info, e.g. the controller of an arm robot and a micro-controller of a Computer Numerical Control(CNC) machine. Some factors involved when considering a CIM implementation are the production volume, the experience of the company or personnel to make the integration, the level of the integration into the product itself and the integration of the production processes CIM is most useful where a high level of ICT is used in the company or facility, such as CAD/CAM systems. Manufacturing engineers are required to achieve the following objectives to be competitive in a global context

- Reduction in inventory
- Lower the cost of the product

- Reduce waste
- Improve quality
- Increase flexibility in manufacturing to achieve immediate and rapid response to:
  - Product & Production changes
  - Process & Equipment change

Change of personnel

5.3 CIM Models

Industrial enterprises throughout the world are undergoing a transformation. Globalization of economy has thrown several challenges to the manufacturing manager. The products are now designed to meet the specific market needs. The concept of maketo-stock is increasingly replaced by make-to-need. Quick response to market needs is another important requirement today. Enterprises are exploring new ways to manufacture products with better and better quality at competitive prices. Manufacturers are recognizing competitive advantages in service differentiation to the customers.

Environmental aspects and safety features are factors of major concern of product designers and manufacturing engineers. These are reflected in the current trend to reexamine the business processes and the shift to the optimization of the business processes. Industrial concepts like agile manufacturing, lean production, teamwork, and collaborative product engineering, maximum use of communication facilities like Internet, etc. are being adopted by the industries for this purpose. Topics like elimination of waste and continuous improvement of products and processes are to-day common in the agenda of manufacturing engineers.

The role of information systems and technology is very critical for implementing these concepts. Therefore the CIM architecture to day attempts to integrate business processes, people, computers, and software through an infrastructure of enabling platforms. Computer Integrated Manufacturing (CIM) is an ideal concept in which computer based manufacturing applications communicate information to coordinate design, planning and manufacturing processes. Traditional approaches to integration focus on either developing translations between two systems or a single data file that acts as a database for all integrated tools. What is needed, however, is an integration architecture, which supports each application's local data requirements. To understand each system's data requirements, there is a need to model them using a unified information model.

Manufacturing management today has to face several challenges, in order to be competitive in the world market. The manufacturing system has to be highly flexible. At the same time the delivery schedules are to be strictly adhered to. The various problems that manufacturing companies face are listed below:

(i) Manufacturing of products often requires introduction of changes in specifications as the job progresses.

(ii) Capacity management is often one of the tough problems. Manufacturing jobs are complex which make scheduling to meet delivery dates a difficult exercise. Sometimes a customer wants rescheduling which makes it necessary to reschedule many other jobs.

(iii) For efficient manufacturing management it is necessary to track at various order levels, component levels and assembly levels. Tracking is also necessary to monitor material consumption, material flow and cost.

(iv) It may be necessary to strike a balance between make to order and make to stock depending upon the market conditions. The approach to CIM model development is quite different from traditional database approach. As in a traditional database environment, a CIM environment involves many tools, which may be modeling the same entity. The data in CIM could be grouped into three: life cycle related, domain related and level of abstraction related. Within these categories, data integration or translation may be well-defined. Life cycle related applications include requirements definition, design process and implementation procedures. The domain related group includes detailed design, production planning and control, manufacturing, inspection, assembly, testing, shipping, marketing, sales and servicing and retirement of the product. The design of the manufacturing facility and the development and implementation of the corporate management structure from an entirely different group.

The need to integrate various shop floor and operation management related activities into a system has led to the development of a number of software models. Some of them may not be in active use today but are historically important in the development of CIM. These models have been developed by either joint international initiative like ESPRIT or computer companies like IBM. Some of the models are briefly described below:

(i) ESPRIT - CIM OSA Model

(ii) NIST-AMRF Hierarchical Model

(iii) Siemens Model of CIM

(iv) CIM Model of Digital Equipment Corporation

(v) IBM Model of CIM

The following sections describe these approaches in detail.

ESPRIT - CIM OSA MODEL

European Strategic Program for Research and Development in Information Technology (ESPRIT) is an industrially oriented R&D program with the aim of improving the competitiveness of the European Community industries. The ESPRIT strategy has been the creation of an environment in which multi-vendor production systems can be implemented at reasonable cost. (OSA refers to Open System Architecture). CIM- OSA was developed by AMICE (a consortium of 30 major European vendors and users of CIM systems (e.g. IBM, HP, DEC, Siemens, Fiat, and Daimler-Benz) for ESPRIT.

Within the framework of the CIM-OSA concept, it is possible to construct CIM architectures for various manufacturing industries and applications from basic building blocks according to defined guidelines. An integrating infrastructure is provided to organize and schedule the enterprise activities. Fig. 77 shows CIM-OSA integrating infrastructure. Since activities, information and control are treated as three different entities, it is possible to make changes in one entity without greatly affecting another one. The dynamic feature of the model enhances the flexibility of an enterprise to quickly adapt to changing material and information flow.

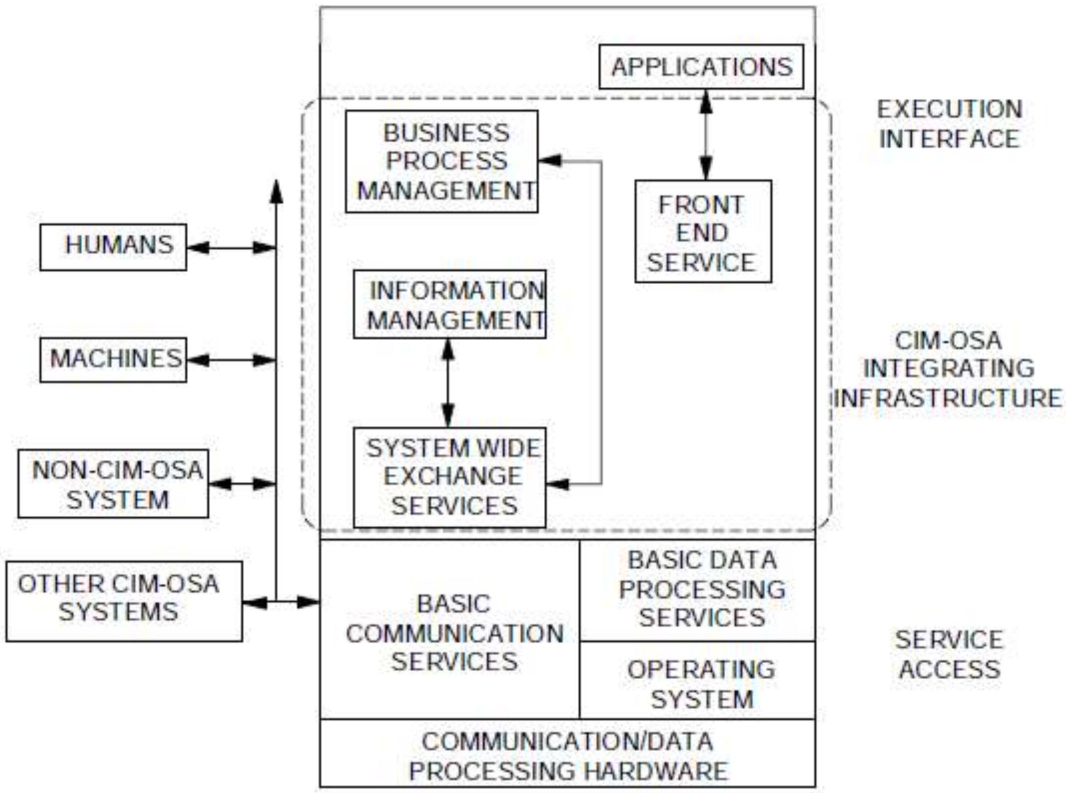

Fig. 77 CIM-OSA Integrating Infrastructure

CIM-OSA separates functions using two interrelated concepts.

• The CIMOSA Modeling Framework in which specific and generic functions are clearly separated.

• The CIMOSA Integrating Infrastructure supporting execution of generic functions and linking specific functions. It is effectively the communication system, which interconnects all of the functions in the CIM system.

CIMOSA defines four modeling views of the enterprise functions:

• The Function View describes work flows

• The Information View describes the Inputs and Outputs of Functions

• The Resource View describes the structure of resources (Humans, machines, and control and information systems)

• The Organization View defines authorities and responsibilities

An enterprise consists of engineering and operation functions. The CIM-OSA model provides a mechanism for preparing and structuring the planning and control activities of these functions and for changing structured information between them. With the help of a computer, a planner is able to consult the CIM-OSA reference architecture to construct

- an operating environment for his application (Fig. 78).

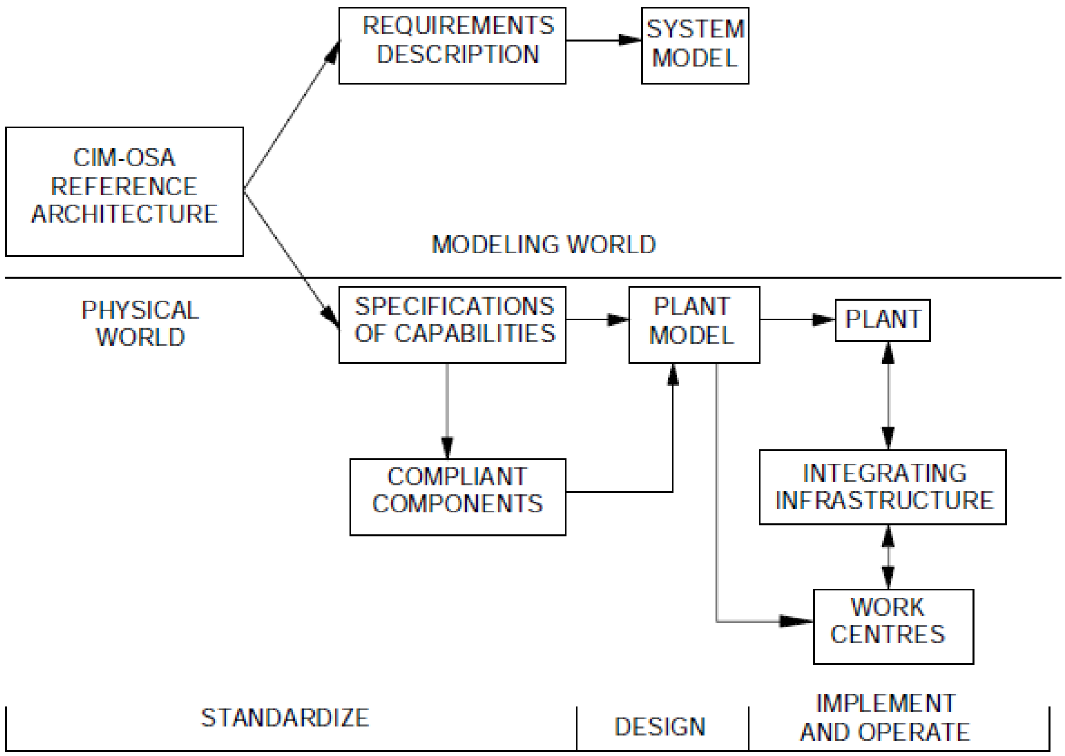

Fig. 78 Operating Environment to Apply CIM-OSA Model

The manufacturing operation can be described with the help of requirements description language to draft the enterprise model and the specification of the basic capabilities to define the compliant components. With the available CIM-OSA reference architecture, user describes the basic capabilities, which are needed for building the system. The user also specifies a set of standard services to execute the task of the enterprise using modules of the physical system. With this information, the system selects the necessary modules from the library of compliant components, which forms the basic building blocks for configuring the physical manufacturing system. The CIM-OSA model has a hierarchical structure to describe an enterprise, and the intermediate and implementation levels to define sub-functions.

CIMOSA -Computer Integrated Manufacturing Open System Architecture is the enterprise modeling framework, which aims to support the enterprise integration of machines, computers and people. Its framework is based on the system life cycle concept, and offers a modeling language, methodology and supporting technology to support these goals is a 1990s European proposal for open system architecture for CIM developed by the AMICE Consortium as a series of ESPRIT projects. The goal of CIMOSA was "to help companies to manage change and integrate their facilities and operations to face worldwide competition”

CIMOSA provides a solution for business integration with four types of products:

The CIMOSA Enterprise Modeling Framework providing a reference architecture for enterprise architecture

CIMOSA IIS, a standard for physical and application integration.

CIMOSA Systems Life Cycle is a life cycle model for CIM development and deployment.

- Inputs to standardization, basics for international standard development.

The main focus of CIMOSA has been to construct:

a framework for enterprise modelling, a reference architecture

an enterprise modeling language

an integrating infrastructure for model enactment supported by

a common terminology

CIMOSA aims at integrating enterprise operations by means of efficient information exchange within the enterprise

CIMOSA models enterprises using four perspectives:

- the *function view* describes the functional structure required to satisfy the objectives of an enterprise and related control structures;
- the *information view* describes the information required by each function;
- the *resource view* describes the resources and their relations to functional and control structures; and
- the *organization view* describes the responsibilities assigned to individuals for functional and control structures

CIM is an integration process leading to the integration of the manufacturing enterprise

Dictated by the needs of the individual enterprise this process usually starts with the need to interchange information between the some of the so called islands of automation

Flexible manufacturing cells, automatic storage and retrieval systems, CAD/CAM based design etc. are the examples of islands of automation i.e. a sort of computer based automation achieved completely in a limited sphere of activity of an enterprise

This involves data exchange among computers, NC machines, robots, gantry systems etc.

Therefore the integration process has started bottom up

The interconnection of physical systems was the first requirement to be recognized and fulfilled.

Integration of technologies brings following *benefits*:

1. Creation of a truly *interactive system* that enables manufacturing functions to communicate easily with other relevant functional units

2. Accurate data transferability among manufacturing plant or subcontracting facilities at implant or diverse locations

3. Faster responses to data-changes for manufacturing flexibility

4. Increased flexibility towards introduction of new products

5 Improved accuracy and quality in the manufacturing process (*continued)*

Improved quality of the products.

7. Control of data-flow among various units and maintenance of user-library for system-wide data.

8. Reduction of lead times which generates a competitive advantage.

9. Streamlined manufacturing flow from order to delivery.

10. Easier training and re-training facilities.

CIM is considered a natural evolution of the technology of CAD/CAM which by itself evolved by the integration of CAD and CAM

Massachusetts Institute of Technology (MIT, USA) is credited with pioneering the development in both CAD and CAM

The need to meet the design and manufacturing requirements of aerospace industries after the Second World War necessitated the development these technologies

The manufacturing technology available during late 40's and early 50's could not meet the design and manufacturing challenges arising out of the need to develop sophisticated aircraft and satellite launch vehicles

This prompted the US Air Force to approach MIT to develop suitable control systems, drives and programming techniques for machine tools using electronic control

The idea of "digital manufacturing" was prominent the 1980s, when computer-integrated manufacturing was developed and promoted by machine tool manufacturers and the Computer and Automated Systems Association and Society of Manufacturing Engineers (CASA/SME).

"CIM is the integration of total manufacturing enterprise by using integrated systems and data communication coupled with new managerial philosophies that improve organizational and personnel efficiency."

Integration of components from different suppliers: when different machines, such as CNC, conveyors and robots, are using different communications protocols

Data integrity: The higher the degree of automation, the more critical is the integrity of the data used to control the machine

While the CIM system saves on labor of operating the machines, it requires extra human labor in ensuring that there are proper safeguards for the control data signals

Process control: Computers may be used to assist the human operators of manufacturing facility, but there must always be a competent engineer to handle circumstances which could not be foreseen by SW designers

CIM makes full use of the capabilities of the digital computer to improve manufacturing. Two of them are:

i. Variable and Programmable automation

ii. Real time optimization

A computer-integrated manufacturing system is not the same as a "lights-out" factory, which would run completely independent of human intervention, although it is a big step in that direction

Part of the system involves flexible manufacturing, where the factory can be quickly modified to produce different products, or where the volume of products can be changed quickly with the aid of computers

Some or all of the following subsystems may be found in a CIM operation

- *Computer-aided techniques:*
  CAD (computer-aided design)
  CAE (computer-aided engineering)
  CAM (computer-aided manufacturing)
  CAPP (computer-aided process planning)
  CAQ (computer-aided quality assurance)
  PPC (production planning and control)
  ERP (enterprise resource planning)
  A business system integrated by a common database.

Computer-aided design (CAD) also known as computer-aided design and drafting (CADD)is the use of computer technology for the process of design and design-documentation

CAD describes the process of drafting with a computer providing the user with input-tools for the purpose of streamlining design processes; drafting, documentation

CAD output is often in the form of electronic files for print or machining operations

CAD-based SW is in direct correlation with the processes; industry-based SW typically uses vector-based(linear) environments whereas graphic-based SW utilizes raster-based one

Computer-aided engineering (CAE) is the broad usage of computer software to aid in engineering tasks

It includes computer-aided design (CAD), computer-aided analysis (CAA), computer-integrated manufacturing (CIM), computer-aided manufacturing (CAM), material requirements planning (MRP), and computer-aided planning (CAP)

Computer-aided process planning (CAPP) is the use of computer technology to aid in the process planning of a part or product, in manufacturing

CAPP is the link between CAD and CAM in that it provides for the planning of the process to be used in producing a designed part

Computer-aided manufacturing (CAM) is the use of computer SW to control machine tools and related machinery in the manufacturing of work pieces

CAM may also refer to the use of a computer to assist in all operations of a manufacturing plant, including planning, management, transportation and storage

Primary purpose is to create a faster production process and components and tooling with more precise dimensions and material consistency, which in some cases, uses only the required amount of raw material while simultaneously reducing energy consumption

Computer-aided quality assurance (CAQ) is the engineering application of computers and computer controlled machines for the definition and inspection of the quality of products

Project management software is covering many types of SW including estimation and planning, scheduling, cost control and budget management, resource allocation, collaboration SW, communication, quality management and documentation which are used to deal with the *complexity of large projects*

Enterprise resource planning (ERP) integrates internal and external management info across an entire organization, embracing finance/accounting, manufacturing, sales and service, customer relationship management

It automate this activity with an integrated SW application

Its purpose is to facilitate the flow of info between all business functions inside the boundaries of the organization and manage the connections to outside stakeholders

CIM software comprises computer programms to carry out the following functions:

- Management Information System
- Sales & Marketing & Finance
- Database Management
- Modeling and Design
- Analysis
- Simulation
- Communications
- Monitoring
- Production Control
- Manufacturing Area Control

Devices and equipment required:

- CNC, Computer numerical controlled machine tools
- DNC, Direct numerical control machine tools
- PLCs, Programmable logic controllers
- Robotics
- Computers
- Software
- Controllers
- Networks
- Interfacing
- Monitoring equipment

- Technologies:
    - FMS, (flexible manufacturing system)
    - ASRS, automated storage and retrieval system
    - AGV, automated guided vehicle
    - Robotics
    - Automated conveyance systems
- Others:
    - Lean manufacturing

5.4 Conceptual model of manufacturing

The computer has had and continues to have a dramatic impact on the development of production automation technologies. Nearly all modern production systems are implemented today using computer systems. The term computer integrated manufacturing (CIM) has been coined to denote the pervasive use of computers to design the products, plan the production, control the operations, and perform the various business related functions needed in a manufacturing firm. *CAD/CAM* (computer-aided design and computer- aided manufacturing) is another term that is used almost synonymously with CIM.

Let us attempt to define the relationship between automation and CIM by developing a conceptual model of manufacturing. In a manufacturing firm, the physical activities related to production that take place in the factory can be distinguished from the information- processing activities, such as product design and production planning, that usually occur in an office environment. The physical activities include all of the manufacturing processing, assembly, material handling, and inspections that are performed on the product.

These operations come in direct contact with the product during manufacture. They touch the product. The relationship between the physical activities and the information processing activities in our model is depicted in Figure 5. Raw materials flow in one end of the factory and finished products flow out the other end. The physical activities (processing, handling, etc.) take place inside the factory. The information-processing functions form a ring that surrounds the factory, providing the data and knowledge required to produce the product successfully. These information-processing functions include (1) certain business activities (e.g., marketing and sales, order entry, customer billing, etc.), (2) product design, (3) manufacturing planning, and (4) manufacturing control. These four functions form a cycle of events that must accompany the physical production activities but which do not directly touch the product.

Now consider the difference between automation and CIM. Automation is concerned with the physical activities in manufacturing. Automated production systems are designed to accomplish the processing, assembly, material handling, and inspecting activities with little or no human participation. By comparison, computer integrated manufacturing is (Fig 79)

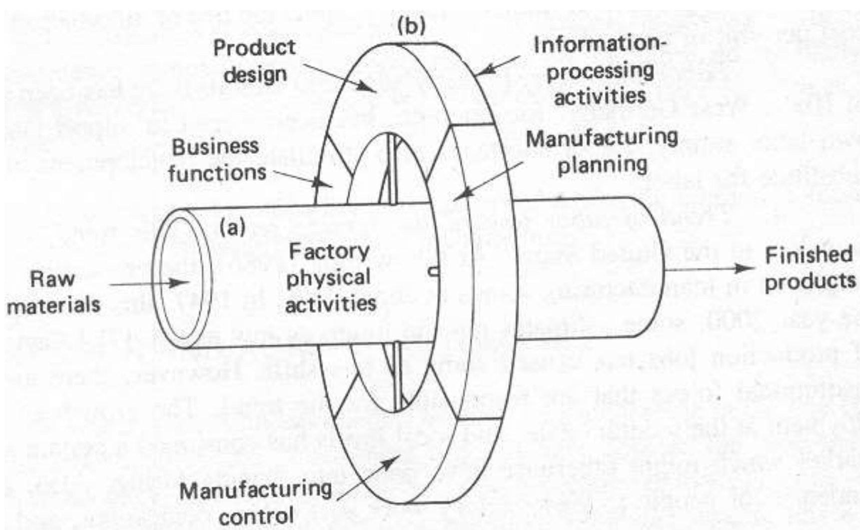

Figure 79 Model of manufacturing

In the figure 5 Model of manufacturing, showing (a] the factory as a processing pipeline where the physical manufacturing activities are performed, and (b) the information-processing activities that support manufacturing as a ring that surrounds the factory concerned more with the information-processing functions that are required to support the production operations. CIM involves the use of computer systems to perform the four types of information-processing functions. Just as automation deals with the physical activities, CIM deals with automating the information-processing activities in manufacturing.

5.5 Organization and Information Processing In Manufacturing

Manufacturing firms must organize themselves to accomplish the five functions described above. Figure 7 illustrates the cycle of information-processing activities that typically occur in a manufacturing firm which produces discrete parts and assembles them into final products for sale to its customers. The factory operations described in the preceding section are pictured in the center of the figure. The information-processing cycle, represented by the outer ring, can be described as consisting of four functions:

1. Business functions
2. Product design
3. Manufacturing planning
4. Manufacturing control

Business functions

The business functions are the principal means of communicating with the customer. They are the beginning and the end of the information-processing cycle. Included within this category are sales and marketing, sales forecasting, order entry, cost accounting, customer billing, and others. Figure 7 Information-processing cycle in a typical manufacturing firm An order to produce a product will typically originate from the sales and marketing department of the firm. The production order will be one of the following forms: (1) an order to manufacture an item to the customer's specifications, (2) a customer order to buy one or more of the manufacturer's, proprietary products, or (3) an order based on a forecast of future demand for a proprietary product.

Product design

If the product is to be manufactured to customer specifications, the design will have been provided by the customer. The manufacturer's product design department will not be involved. If the product is proprietary, the manufacturing firm is responsible for its development and design. The product design is documented by means of component drawings, specifications, and a bill of materials that defines how many of each component goes into the product.

Manufacturing planning

The information and documentation that constitute the design of the product flow into the *manufacturing planning* function. The departments in the organization that perform manufacturing planning include manufacturing engineering, industrial engineering, and production planning and control. As shown in Figure 7, the in formation-processing activities in manufacturing planning include process planning, master scheduling, requirements planning, and capacity planning. *Process planning* consists of determining the sequence of the individual processing and assembly operations needed to produce the part. The document used to specify the process sequence is called a *route sheet.* The route sheet lists the production operations and associated machine tools for each component (and subassembly) of the product. The manufacturing engineering and industrial engineering departments are responsible for planning the processes and related manufacturing details. The authorization to produce the product must be translated into the master schedule or master production schedule. The *master schedule* is a listing of the products to be made, when they are to be delivered, and in what quantities. Units of months are generally used to specify the deliveries on the master schedule. Based on this schedule, the individual components and subassemblies that make up each product must be planned. Raw materials must be requisitioned, purchased parts must be ordered from suppliers, and all of these items must be planned so that they are available when needed. This whole task is called *requirements planning* or *material requirements planning.* In addition, the master schedule must not list more quantities of products than the factory is capable of producing with its given number of machines and workers each month. The production quantity that the factory is capable of producing is referred to as the plant capacity. We will define and discuss this term later in the chapter. *Capacity planning* is concerned with planning the manpower and machine resources of the firm.

Manufacturing control

Manufacturing control is concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans. *Shop floor control* is concerned with the problem of monitoring the progress of the product as it is being processed, assembled, moved, and inspected in the factory. The sections of a traditional production planning and control department that are involved in shop floor control include scheduling, dispatching, and expediting. Production scheduling is concerned with assigning start dates and due dates to the various parts (and products) that are to be made in the factory. This requires that the parts be scheduled one by one through the various production machines listed on the route sheet for each part. Based on the production schedule, *dispatching* involves issuing the individual work orders to the machine operators to accomplish the processing of the parts. The dispatching function is performed in some plants by the shop foremen, in other plants by a person called the dispatcher. Even with the best plans and schedules, things sometimes go wrong (e.g., machine breakdowns, improper tooling, parts delayed at the vendor). The *expediter* compares the actual progress of a production order against the schedule. For orders that fall behind, the expediter attempts to take the necessary corrective action to complete the order on time.

Inventory control overlaps with shop floor control to some extent. *Inventory control* attempts to strike a proper balance between the danger of too little inventory (with possible stock-outs of materials) and the expense of having too much inventory. Shop floor control is also concerned with inventory in the sense that the materials being processed in the factory represent inventory (called work-in-process). The mission of quality *control* is to assure that the quality of the product and its components meet the standards specified by the product designer. To accomplish its mission, quality control depends on the inspection activities performed in the factory at various times throughout the manufacture of the product. Also, raw materials and components from outside sources must be inspected when they are received. Final inspection and testing of the finished product is performed to ensure functional quality and appearance.

CIM is recognized as Islands of Automation. They are

1. CAD/CAM/CAE/GT
2. Manufacturing Planning and Control.
3. Factory Automation
4. General Business Management

CASA/SME's CIM Wheel is as shown in Fig 80

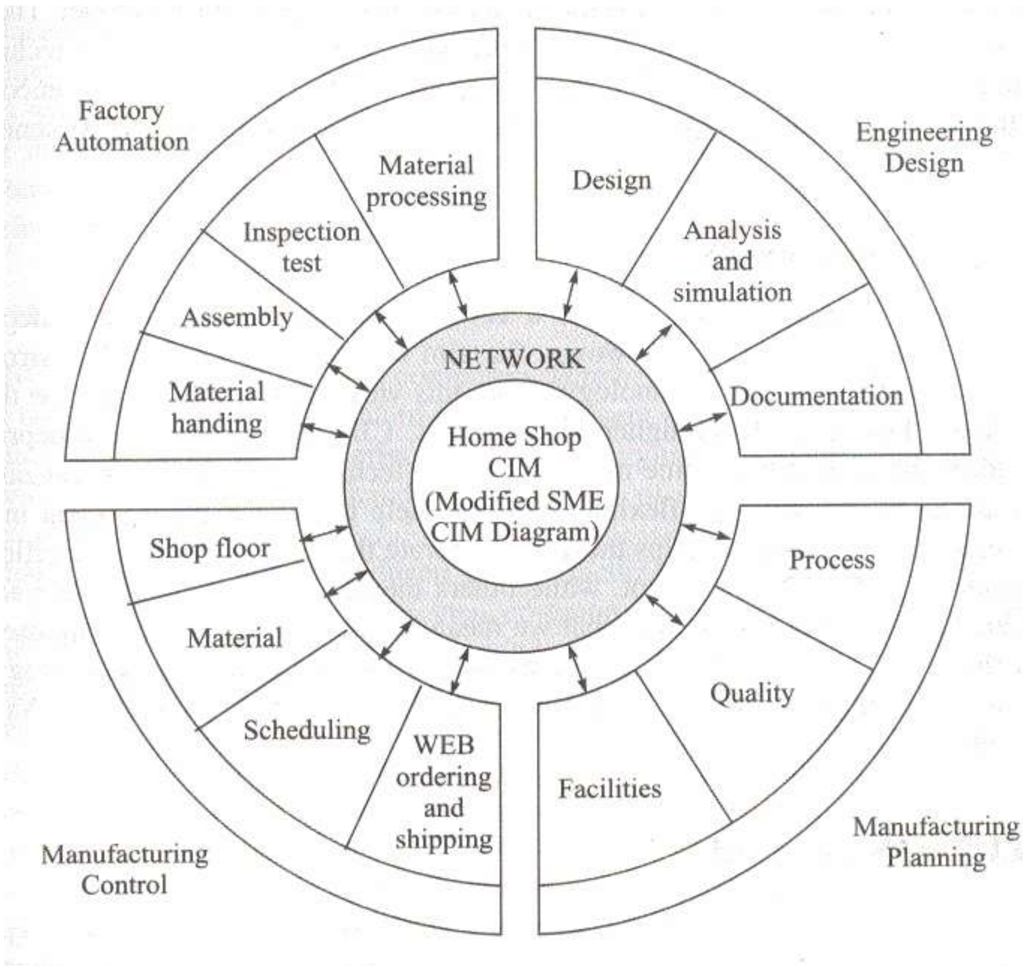

Figure 80 CASA/SME's CIM Wheel

Product data management (PDM): CIM implementation software

The four major modules typically contained within the PDM software are

- Process models
- Process project management
- Data management

- Data and information kitting

The PDM environment provides links to a number of software packages used by a company. They are

- A CAD package
- A manufacturing/production management package
- A word processing package
- Databases for various applications
- Life-cycle data

Communication fundamentals

- A frequency
- An amplitude
- A phase which continuously changes
- A bandwidth
- An introduction to baseband and broadband
- Telephone terminology
- Digital communications

Local area networks

- Signal transmission, baseband and broadband
- Interconnection media

Topology

- Star topology
- Ring topology
- Bus topology
- Tree topology

LAN implementations

- Client server architecture
- Networks and distributed systems
- Multi-tier and high speed LANs

Network management and installation

- Security and administration
- Performance

- Flexibility
- User interface
- Installation

5.6 CIM Architecture

CIM Architecture Overview

To develop a comprehensive CIM strategy and solutions, an enterprise must begin with .solid foundations such as CIM architecture. A CIM architecture is an information systems structure that enables industrial enterprises integrate information and business processes It accomplishes this first by establishing the direction integration will take; and second, by defining the interfaces between the users and the providers of this integration function. The chart illustrates how CIM architecture answers the enterprise's integration needs. As you can see here, CIM architecture provides a core of common services. These services support every other area of the enterprise—from its common support functions to its highly specialized business processes.

Three key building blocks

The information environment of an industrial enterprise is subject to frequent changes in systems configuration and technologies. A CIM architecture can offer a flexible structure that enables it to react to these changes. This structure relies on a number of modular elements that allow systems to change more easily to grow along with enterprise needs. And as you can see from the chart on the facing page, the modular elements that give a CIM architecture its flexible structure are based on three key building blocks:

• *Communications*—the communication and distribution of data.

• *Data management*—the definition, storage and use of data

• *Presentation*—the presentation of this data to people and devices throughout the enterprise

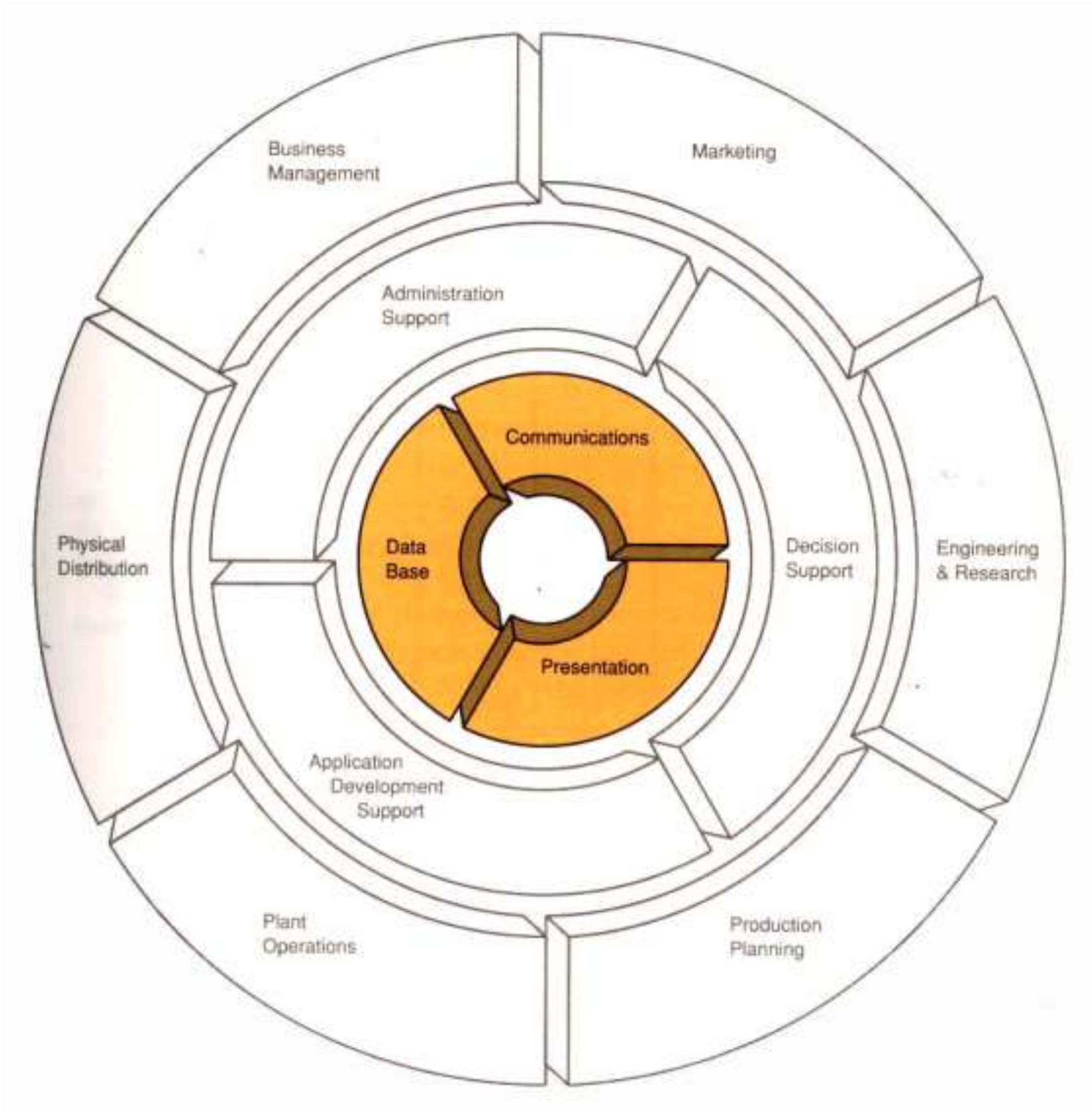

Fig 81 CIM Architecture Elements

Utilizing these building blocks, CIM architecture can provide a consistent base for integrating the enterprise's product, processes and business data. It can define the structure of the hardware, software and services required to support the enterprise's complex requirements. And it can translate this information into a form that can be used by the enterprise's people, devices and applications. In the following sections we will examine the advantages each of these building blocks brings to the CIM environment.

5.7 Communications in the CIM environment

Communications or the delivery of enterprise data to people, systems and devices is a critical aspect of CIM architecture. This is because today's industrial environment brings together a wide range of computer systems, technologies, system architectures, operating systems and applications. This range makes it increasingly difficult for people and machines to communicate with each other especially when they describe and format data differently. IBM has long recognized this need to communicate data across multiple environments. Our first response was developing Systems Network Architecture (SNA) in the 1970's. SNA supports communication among different IBM systems, and over the years ft has become the standard for host communications in many industrial companies. However, in the CIM environment communications must be even more integrated. It must expand beyond individual areas, throughout the entire enterprise, and beyond—to customers...to vendors...and to sub-contractors.

Communications in the CIM environment will involve a wide range of data transfer, from large batches of engineering or planning data to single-bit messages from a plant floor device. Many connectivity types and proto cols must be supported to enable the enterprise's people, systems and devices to communicate. This is especially true in cases where response time is critical, such as during process alerts.

6. Introduction to Data Communication and Networking

Data is defined as the raw, unorganized information that is available on each component of a CIM system like a PC, Robot, and Workstation or CNC machine. Normally, each component wants access to all the necessary data to make decisions. This means each component in a CIM system, can take advantage of all the available information to achieve higher reliability, more optimal processing or manufacturing and higher throughput.

Networks allow channels of communications to exist among various sections of a manufacturing system. Real-time modifications to business plans can be effected via communications through the network. Networks are essential to move information faster across various users or various segments of CIM. For example, while the design is being completed, if the manufacturing engineer has access to the design data of the component, the engineer can plan fixture design and start creating the program for manufacture. The process-planning engineer can select a suitable machine tool to machine the component. These are typical cases where time can be saved. Networks are today integral parts of CIM systems, which have made data sharing easy, peripheral changing or interfacing easy and information sharing possible.

6.1 Principles of Networking

Advances in technology have been adding more processing power into smaller computers. The trend has been to move away from massive, centralized computers, which handle every task to networks of smaller desktop computers, each closely tailored to a particular application. From the manufacturing standpoint, this eliminates the possibility of shutting down the entire plant if a large central computer fails. It is easier to replace a defective PC. More desktop computers can be added to the network depending on the need. Thus, the network is scalable. Networking also allows incremental growth of the overall system with minimal investment and disruption.

Networking is a convenient technique for tying together the various “islands of automation” which were discussed in Chapter 1 and in the process makes integration possible through high-speed data exchange between different automated segments.

Networking of computers was initially adopted successfully by service sectors like banking, airline and train reservation etc. and later was introduced in manufacturing industries. Today, many designs involve collaborative efforts of hundreds of engineers.

Networked systems facilitate quick information exchange and effectively cut down development lead-time. Some examples are:

(i) Design and development of VLSI and UVLSI chips like microprocessors.

(ii) Design and manufacture of aircrafts and automobiles.

Communication networks can be classified into four categories depending upon the physical separation of the communicating devices:

(i) Miniature (< 50 m): Such networks are concerned with the interconnection of multiple computational elements.

(ii) Small (< 500 m): These are concerned with the interconnection of multiple computational units.

(iii) Medium (< 1 km usually): These networks are concerned with the interconnection of multiple computational units (office workstations, CAD systems, shop floor computers and data collection terminals, CNC systems, Robots etc.). These are connected through a Local Area Network (LAN), or Intranet. LAN may cover distances more than one 1 km too.

(iv) Large (> 1 km): Large networks involve connection of remote mainframes, networking of a minicomputer system to a remote mainframe or terminals etc. It can be citywide (Metropolitan Area Network-MAN) or countrywide or Worldwide-WAN). With Internet becoming more and more popular, the intranet-internet- extranet technologies have found favour with manufacturing companies.

6.2 Network Techniques

Network technology can be broadly classified into two categories. They are Local area network (LAN) or Wide area networks (WAN). LANs are intended to serve a number of users who are physically located close together. WANs are more akin to telephone network, tying different people in different buildings, cities or even countries. A message is routed through several interim points before reaching its final destination; a WAN may also incorporate the ability to automatically change to an alternate message routing path if the computer at one location fails. A LAN (local area network) has 2 to 10 times more traffic on it than a wide area network (WAN). Each individual point within a network that can communicate through the network is called a node. Each node is assigned a unique address. This way, a destination address can be put into each message and it can be sent to correct recipient.

Local Area Network (LAN)

A network is a linking of a group of computers to communicate with each other and share software and hardware resources via the cables and interfaces that connect the computers and peripherals. Application softwares used in a network allow several users access the same program and data at the same time. As the name implies, a Local

Area Network or LAN is a system that covers short distances. Usually LAN is limited to a single department or a single building or a single campus. Typical data transmission speeds are one to 100 megabits per second.

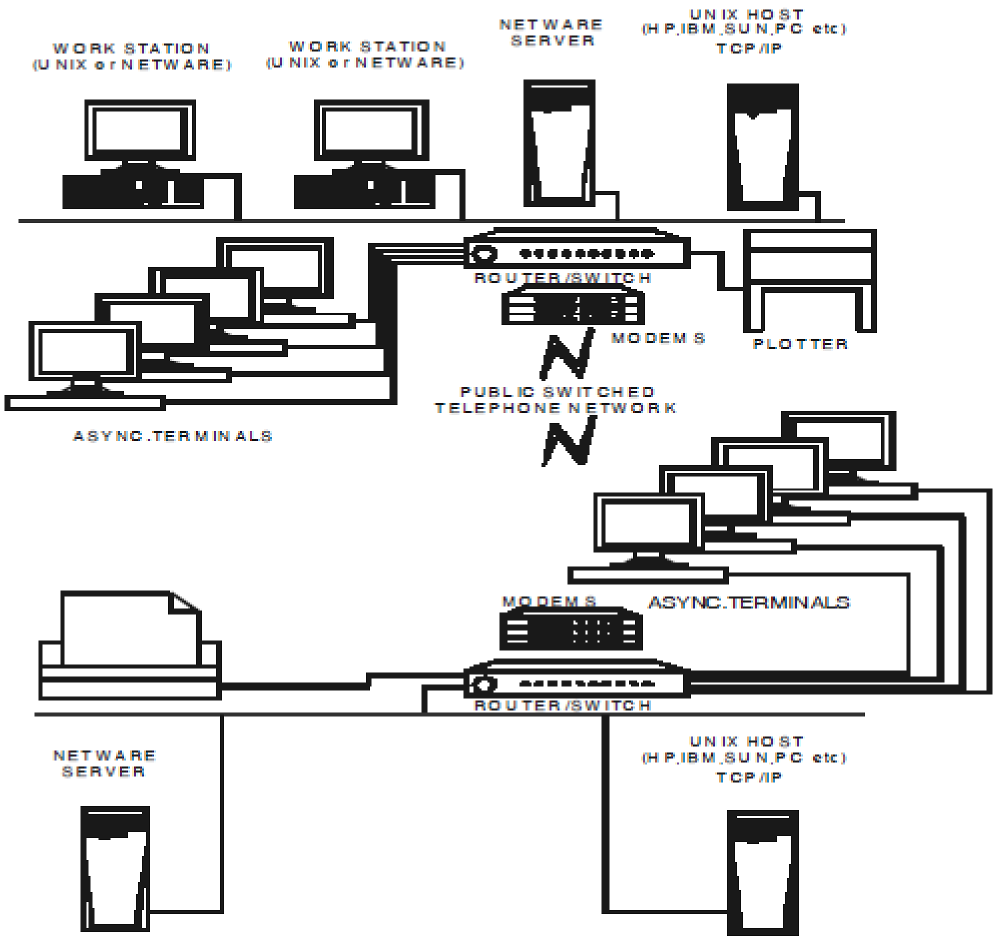

Fig. 82 A Typical Local Area Network

Fig. 82 shows a typical network, in which two LAN's are shown, each networking a number of computers connected to its file server. A network connects together a number of workstations, as shown in the figure. Another way of interconnection is through a router to which a number of asynchronous terminals are connected. Remote access to another LAN can be affected through a Router-Modem-Public Switched Telephone Network- Modem-Router scheme. A router is intermediate equipment, which transfers data between two networks that use the same protocols. Modem is an equipment that connects a computer to a telephone line (usually voice grade). Modems also connect a large local network to a network provider over a leased line which is a dedicated communication line leased from the Department of Telecommunications (DOT) by one or more user organizations. Leased lines provide faster communication capability than dial-up lines. Common resources of the network include a bank of printers and plotters and facilities for disc mirroring and disc duplexing.

Local area networks (LANs) fall into different sizes. Their topology, access method, medium, and market are different throughout. It is a private data communications system covering a limited geographical area, which is typically about a kilometre long. A LAN lets a factory network communicate with computers vertically and horizontally. It allows sharing of input and output devices and databases. The LAN allows access to remote mainframes. Many LAN topologies are available today.

A LAN is capable of data transfer rates of 1-10 Mbits/sec in computer-to-computer communications. It also handles requirements of dissimilar devices found in various applications, involving human, machines, and databases. A LAN can integrate the hardware and data on shop floor. An advantage of a LAN is that it allows electronic communications to maintain, optimize, and use external database resources and process controls with less than 10 seconds response. It does appropriate filtering of messages so that bad messages cannot get through, and it allows downloading of program and data into production equipment like programmable controllers, numerical controllers, and microprocessors to facilitate flexible manufacturing. LANs allow machines and managers and supervisors to monitor the entire process by “zooming” onto any particular segment in as great detail as necessary. The LAN can monitor quality and make corrections, or, stop process to allow humans to make corrections, before the quality or yield of system goes down below acceptable levels.

A basic requirement of a LAN is that it must have a flexible architecture to permit PC’s and other computers located where they are needed. It must also be possible to remove a computer without causing disruption. Reliability is another important aspect. Since the manufacturing activities depend upon the working of LAN, the LAN system must be highly reliable. The most widely used LAN system is Ethernet.

PC's attached to a LAN can use the processing capabilities of other intelligent devices in the network as in a host-to-terminal network.

Components of a Small Local Area Network

A LAN in a CIM setup is a system comprising the following basic components:

(i) Computers: (PC's, Design Workstations, CNC Systems, robots, PLC's etc.)

(ii) Network Cable: A transmission cable is attached to each device (computer/ peripheral) to enable the transmission of messages from one device to another.

The details of cables commonly used are given in Table 1.

Table 1 Cables used in Networking

Type	*Data Transmission Rate*	*Distance*	*Remarks*
Twisted pair	1 M bit/sec	Short distance100 m	Least Expensive base band, single channel
Coaxial Cable -base band -broad band	 10 M bit/sec 5 M bit/sec	 up to 4 km up to 50 km	 Multi Channel Capability
Fibre Optics	100 M bits or more		Multi Channel Large Capacity Expensive

The simplest form of Ethernet uses a passive bus operated at 10 Mbps. The bus is formed from a 50-Ohm co-axial cable, which connects all the computers in the LAN. A single LAN may have up to a maximum of 1024 attached systems, although in practice most LANs have far fewer. One or more pieces of coaxial cable are joined end to end to create the bus, known as an "Ethernet Cable Segment". Each segment is terminated at both ends by 50-Ohm resistors (to prevent reflections from the discontinuity at the end of the cable) and is also normally earthed at one end (for electrical safety). The computers are attached to the cable using transceivers or network interface cards. The two major means of electrically carrying data on a LAN are as follows: BASE BAND allows devices to send digital data at a set speed. All nodes in the LAN are exposed to data, but a node will ignore a message if it is intended for another node.

BROAD BAND is similar to cable television. A number of very high frequency signals are placed in line and data is sent using these signals as “carriers,” in the same way as television uses several channels. Several “networks” can, in essence, share the same cable, because it is possible to filter out all but desired “carriers”.

(iii) Network Interface Card (NIC): This is communication hardware in the form of an add-on card for sending and receiving messages. This is also called network adapter. NIC is plugged into one of the slots of the PC expansion slots and the transmission cable is attached to the connector provided on the card. A detailed description of network cards is given in section 15.7.

(iv) Network Server: Network Server is the computer used to manage shared resources. Server is a combination of hardware and software. The file server performs the following tasks:

• Manages the shared hard disc
• Makes sure that multiple requests do not conflict each other
• Protects data
• Prevents unauthorized access to databases and application programs
• Maintains a list of privileges and authorizations

(v) Central Mass Storage: The hard disc of the file server should have sufficient capacity (usually in term of several Gigabytes) to meet the storage requirements of the users of the network.

Network Wiring Methods

There are two basic ways by which three or more nodes can be incorporated in a network. These are point-to-point and multi-drop. (Refer Fig. 83)

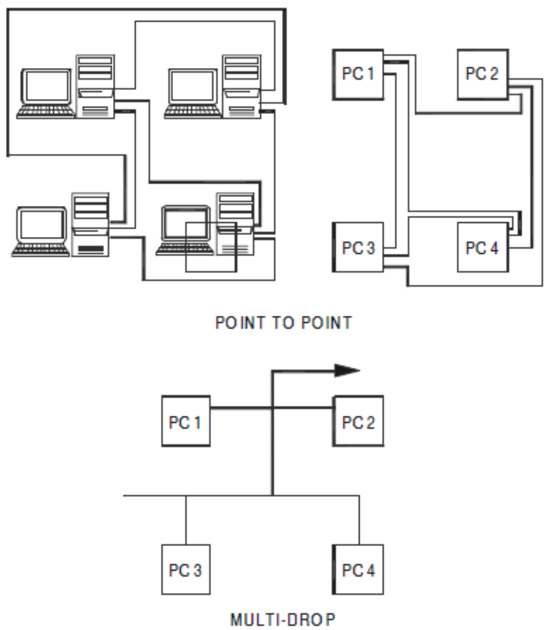

Fig. 83 Network Wiring Methods

6.3 Network Topologies

There are several commonly used network topologies, or ways of routing the interconnections. (Refer Fig. 84)

(i) Star Network: This means running a separate cable or line between server and each node. This is useful when a master slave relationship exists between the server and the nodes. For sending data and files from one node to another a request should be made to the server, which establishes a dedicated path between the nodes. The data can be transmitted through this path.

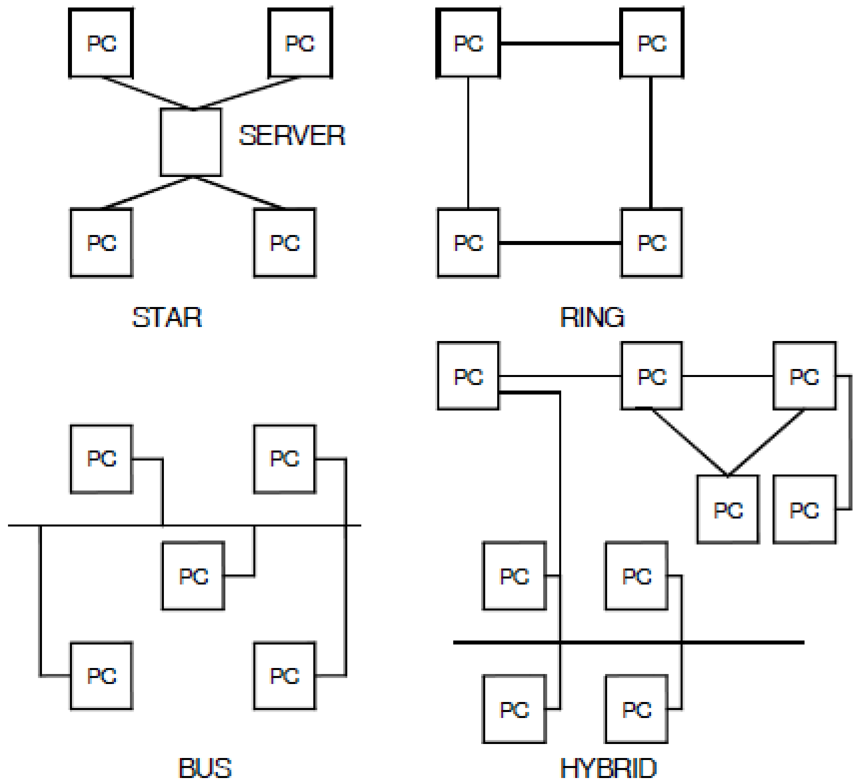

Fig. 84 Network Topologies

(ii) Ring Network: This involves connecting all nodes in series. The cable will normally loop back to form a full circle. This is some times used when nodes are widely separated, as each node can act as a repeater (amplifier) for message destined for downstream nodes. The data will have to pass through other nodes before reaching the server. The data is sent in the form of a packet which contains both source and destination addresses of the data. As the packet circulates through the ring the destination station copies the data into its buffer and the packet continues to circulate until it goes back to source workstation as an acknowledgement.

(iii) Bus Networks: This type on interconnection allows all nodes to share the same cable. Any message that travels on the cable is “seen” by every node on the cable. This topology uses both base band and broadband transmission.

(iv) Hybrid Networks: This includes features of more than one topology to achieve the optimal trade-off of reliability, performance, flexibility and cost.

6.4 Computer Integrated Manufacturing and Enterprise Integration

An introduction to Computer Integrated Manufacturing (CIM)

- According to SME, CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personal efficiency.
- CIM is made possible by the computer technology today and has many advantages over the traditional manufacturing systems.
- A step forward is enterprise integration.

The idea in enterprise-wide integration is to integrate people, technology, business processes, customers and suppliers located at dispersed geographic locations.

- There are three essential tools for enterprise integration:
- Network communication
- Database management systems
- Group-ware.
- In this section, we will briefly introduce these tools, following by a discussion on the framework of CIM.

Network communication

- Terminology used in network communication
- Hertz (Hz): number of cycles per second
- Baud: number of signals per second
- Data rate: number of bits sent per second (bps)
- Channel: a logic communication path
- Bandwidth: the band of frequency used by a communication path
- Channel capacity: number of bits that can be transmitted per second
- Interoperability: two systems work with each other through interface
- Local area network: LAN is used to interconnect local computers at 100 Mbps
- Wide area network: WAN is used to connect remote computers at 1.5 Mbps
- Metropolitan area network: MAN is large LANs that connects LANs
- The communication network is the backbone of enterprise integration

- In general, there are three levels of communication in a company, and each require a different type of network:
- Device level at the shop floor – sub-network connects individual devices such as machine tools and robots
- Plant level – local area network (LAN) connects manufacturing cells and departments
- Enterprise level – wide area network (WAN) or Metropolitan area network (MAN) links various plants / sites and interconnect corporations through data exchange protocols.
- Network topology: the general physical layout of the network is called network topology. As shown in Figure 7.9, there are four types of network topology:
- Star
- Ring
- Bus
- Tree

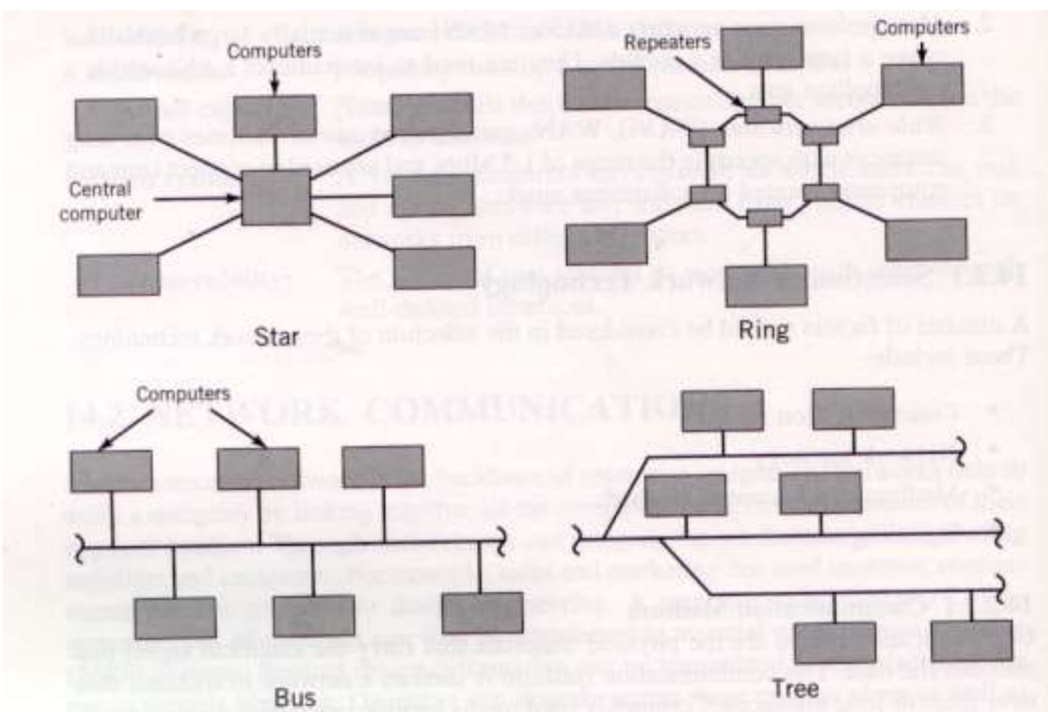

Fig. 85 Illustration of network topology

- The network access control: there are several commonly used method for network access control
- Carrier Sense Multiple Access with Collision Detection (CSMA/CD) or Ethernet (IEEE 802.3 standard). Physically, two ethernet coaxial cables are connected together using a repeater (an amplifier). Through the cables, the ethernet cards can send and receive packets.
- Token ring (IEEE 802.5 standard) and Token bus (IEEE 802.4 standard) are designed to resolve the communication crash problem. They use multiple coaxial cables to connect the computers into a ring. So when a communication path is busy the other one can take over.
- The network protocol
- The interpretation of the transmitted data among a network is done based on network protocol.
- A protocol is a set of rules of information exchange between two devices
- According to ISO/OSI (open system interconnection), protocols can be divided into seven layers:
    - The physical layer: specifies the hardware
    - The data link layer: handles the data transformation such as synchronization, error control and flow control
    - The network layer: decides the paths of the information in the network
    - The transport layer: establishes the connection, initiate the data transfer and manage the data transfer
    - The session layer: controls communication
    - The presentation layer: coding and decoding
    - The application layer: user interface
- Based on ISO/OSI, several different protocols have been developed. For example, the Manufacturing Automation Protocol (MAP) is developed by General Motors Co. The most commonly used protocol is however, the Transmission Control Protocol / Internet Protocol (TCP/IP) developed by US Dept. of Defense. TCP/IP suit now consists of several protocols including Telnet, FTP, Network file systems (NFS), and simple mail transfer protocol (SMTP).

- Network hardware. In addition to the computers, various hardware devices are needed in network connections. These include:
- Reapeater: circuit used to connect the devices with same protocols
- Bridge: circuit used to connect two similar or dissimilar LANs
- Routers: a combination of both repeater and bridge
- Gateway: a special purpose computer that does the protocol conversions.
- Network performances. The network performances can be measured by the following criteria: network availability and response time.
- Network availability can be determined based on the reliability theory. If there are *n* components connected in series and the their probability of being available is a_i, i = 1, 2…, *n*, then the system availability is:

$$A = \prod_{i=1}^{n} a_i$$

On the other hand, suppose the *n* components are connected in parallel, the system availability is:

$$A = 1 - \prod_{i=1}^{n} a_i$$

- the response time is determined by the summation of service time and waiting.

6.5 Plant floor communications

Let's examine one area where communications can be extremely challenging the plant floor. This is due to the wide range of manufacturing and computer equipment that has been used to manage the various production tasks over the decades.

IBM solution for communicating across these systems is the IBM Plant Floor Series, a set of software products. One of these products, Distributed Automation Edition (DAE), is a systems enabler designed to provide communications functions that can be utilized by plant floor applications. These functions include:

• Defining and managing networks

• Making logical device assignments

• Managing a program library

• Queuing and routing messages

• Establishing alert procedures
• Monitoring work-cell status

These functions enable Distributed Automation Edition to assist manufacturing engineers as they select or develop application programs to control work-cell operations and provide communications capabilities between area- and plant-level systems.

DAE supports several communications protocols to meet the needs of a variety of enterprises. For example, it supports SNA for connections to plant host systems and the IBM PC-Network as well as the IBM Token- Ring protocol and Manufacturing Automated Protocol (MAP) for plant floor communications. MAP is the evolving plant floor communications industry standard, adopted by the International Standards Organization (ISO) for communications among systems provided by different vendors.

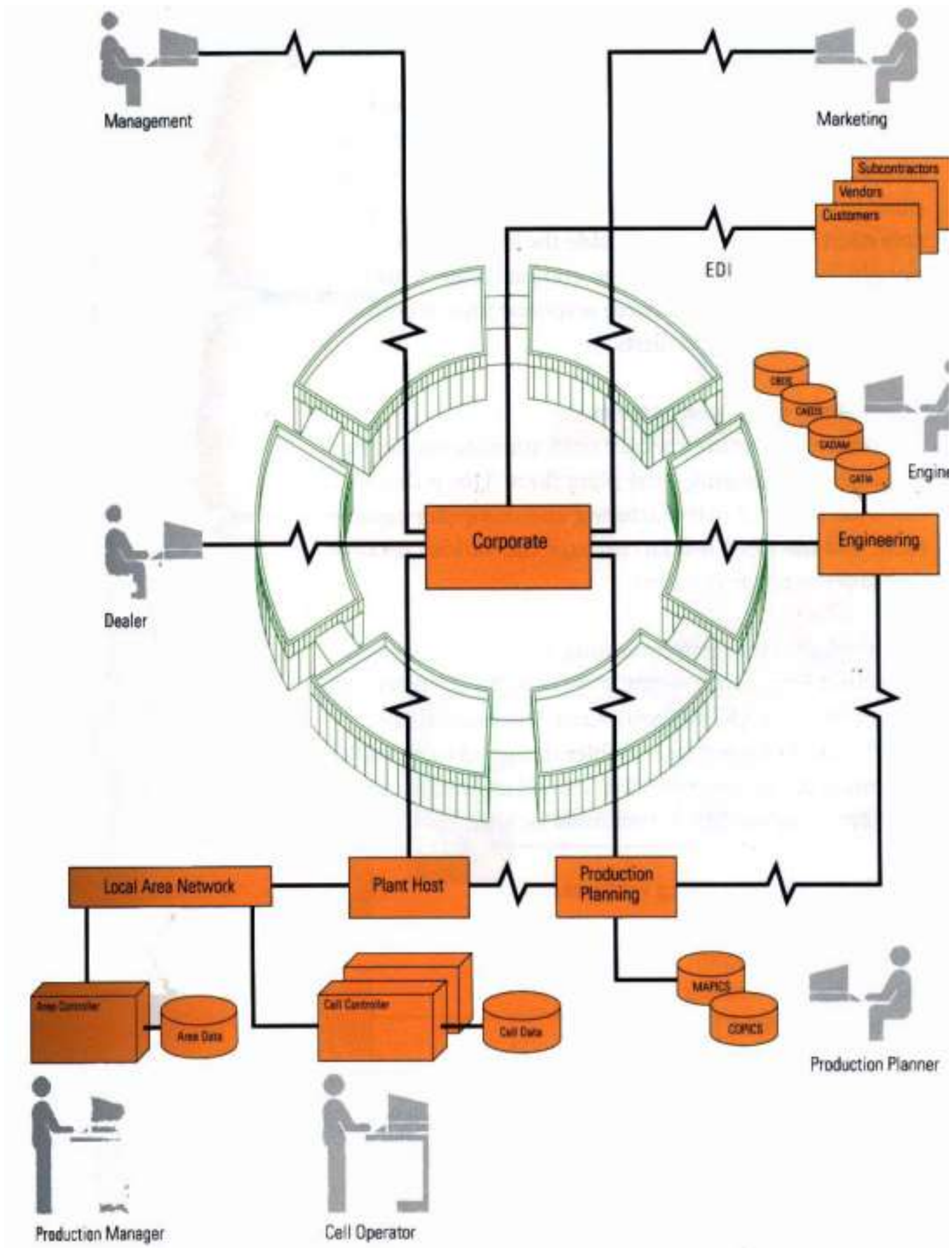

Fig 86: Communications in the CIM environment

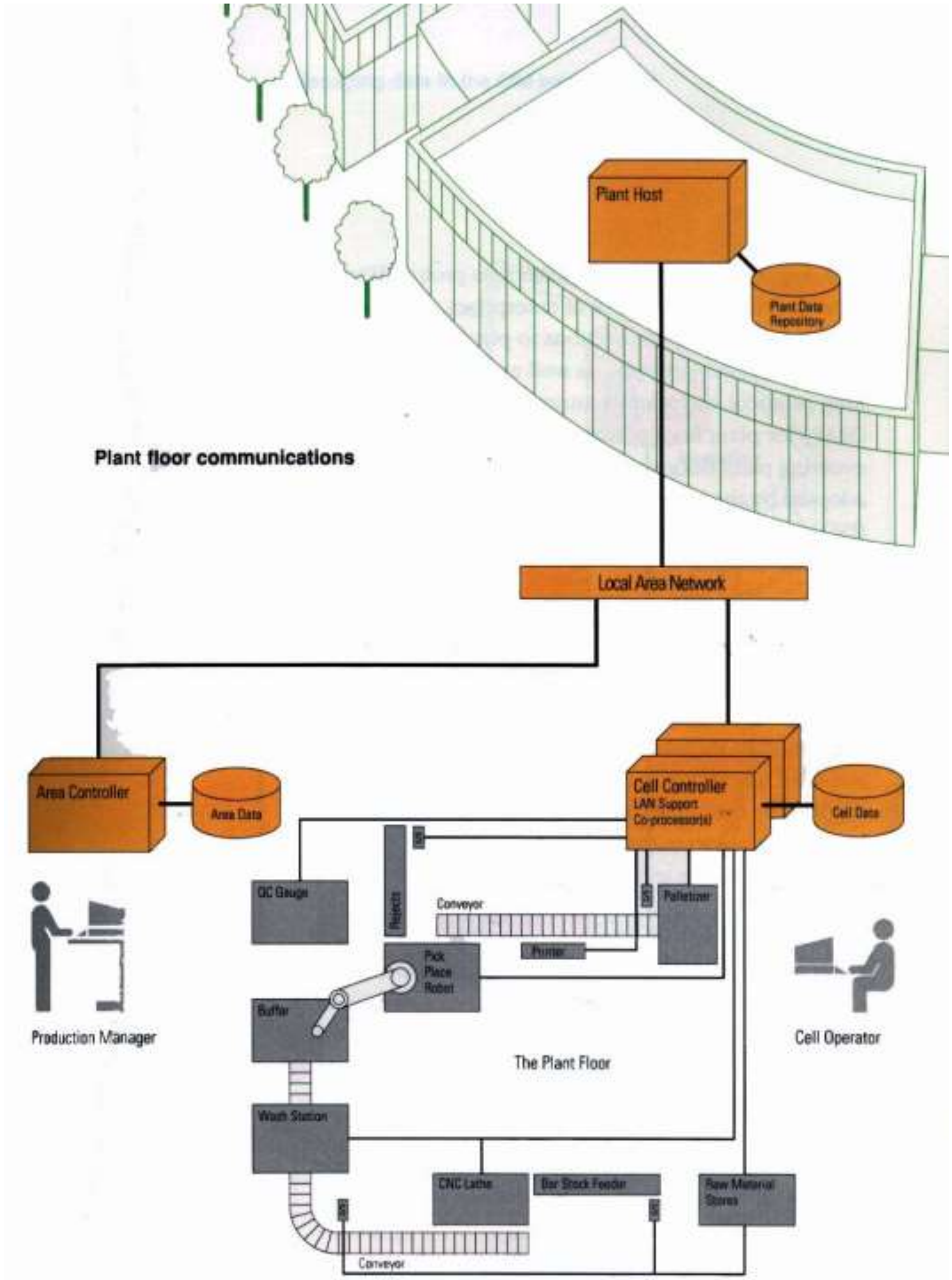

Fig 87: Plant Floor Communications

6.6 Managing data in the CIM environment

The second building block of CIM architecture is data management. This includes how data is defined, how different data elements are related, where data is stored, and who has access to that data. Data management is particularly critical in today's industrial environment, since there are so many different data bases, formats, and storage and access techniques.

Standards are evolving. For example, Structured Query Language (SQL) provides a consistent way for relational data base applications and users to acce5s a data base. Unfortunately, there is a significant amount of data that exists today in other data base technologies that is not accessible by current standards that where data management within a CIM architecture can help.

Data management defines and records the location of the data created and used by the enterprise's business functions. Data management also means enabling users to get the data they need—with out having to know where this data is located. Relationships among several data elements must be known if data is to be shared by users and applications. In addition, other data attributes are important when sharing data. These include the type of data (text, graphics, image), its business status (working. review, completed), and the source of this data (person, application, or machine). In a CIM architecture, data management can be accomplished through three individual storage functions:

- The data repository
- The enterprise data store
- The local data files

Some of the key data management functions—the repository, for example—are already being implemented by the Consolidated Design File (CDF) established through the IBM Data Communication Service (DCS).

The Consolidated Design File operates on a relational data base and is built on SQL. One example of its use is as an engineering data base to integrate CAD/CAM applications with the business needs of the engineering management function. In this environment, IBM's DCS/ CDF provides the following repository functions:

- Transforming data to a user-selected format

• Storing CAD/CAM data

• Adding attributes to CAD/CAM data

• Enabling users to query data and attributes

DCS/CDF also provides communications functions in order to transfer data between the repository and CAD/CAM applications.

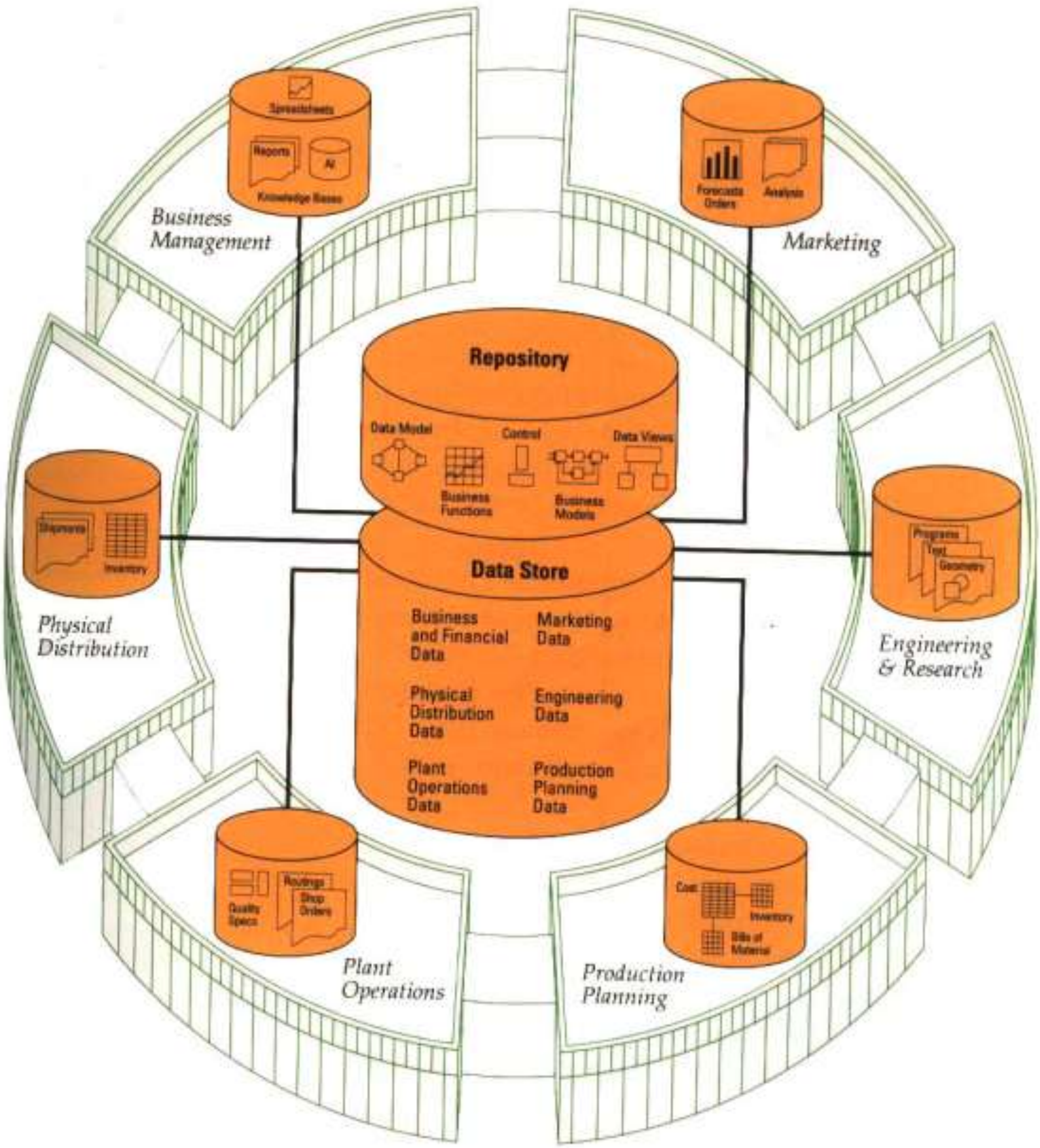

Fig 88 Managing Data in CIM Environment

6.7 Presentation in the CIM environment

Presentation in the CIM environment means providing data to and accepting data from people and devices. Of course, this data must assume appropriate data definitions and screen formats to be usable.

Because today's industrial enterprise contains such a wide array of devices and information needs, it must have a consistent way to distribute and present information to people at terminals or workstations, machine tools, robots, sensors, bar code readers, automated guided vehicles, and parts storage and retrieval systems. The range of this information covers everything from simple messages between people to large data arrays for engineering design applications. It may originate from a CIM user in one functional area of the enterprise and be delivered to a CIM user or device in another area. In today's environment, presentation occurs on displays that utilize different technologies. Some are non-programmable terminals, some are programmable workstations, and are uniquely implemented for each application. As a result, the same information is often treated differently by individual applications.

For example, the same manufactured part may be referred to as a part number in a bill of material application in Production Planning...as a drawing in Engineering's CAD application...and as a routing in a paperless shop order application from Plant Operations. As data is shared across the enterprise, it must be transformed into definitions and formats that support the needs of each individual user and application. And applications must be able to access shared data, collect the required information, and then format that information for delivery.

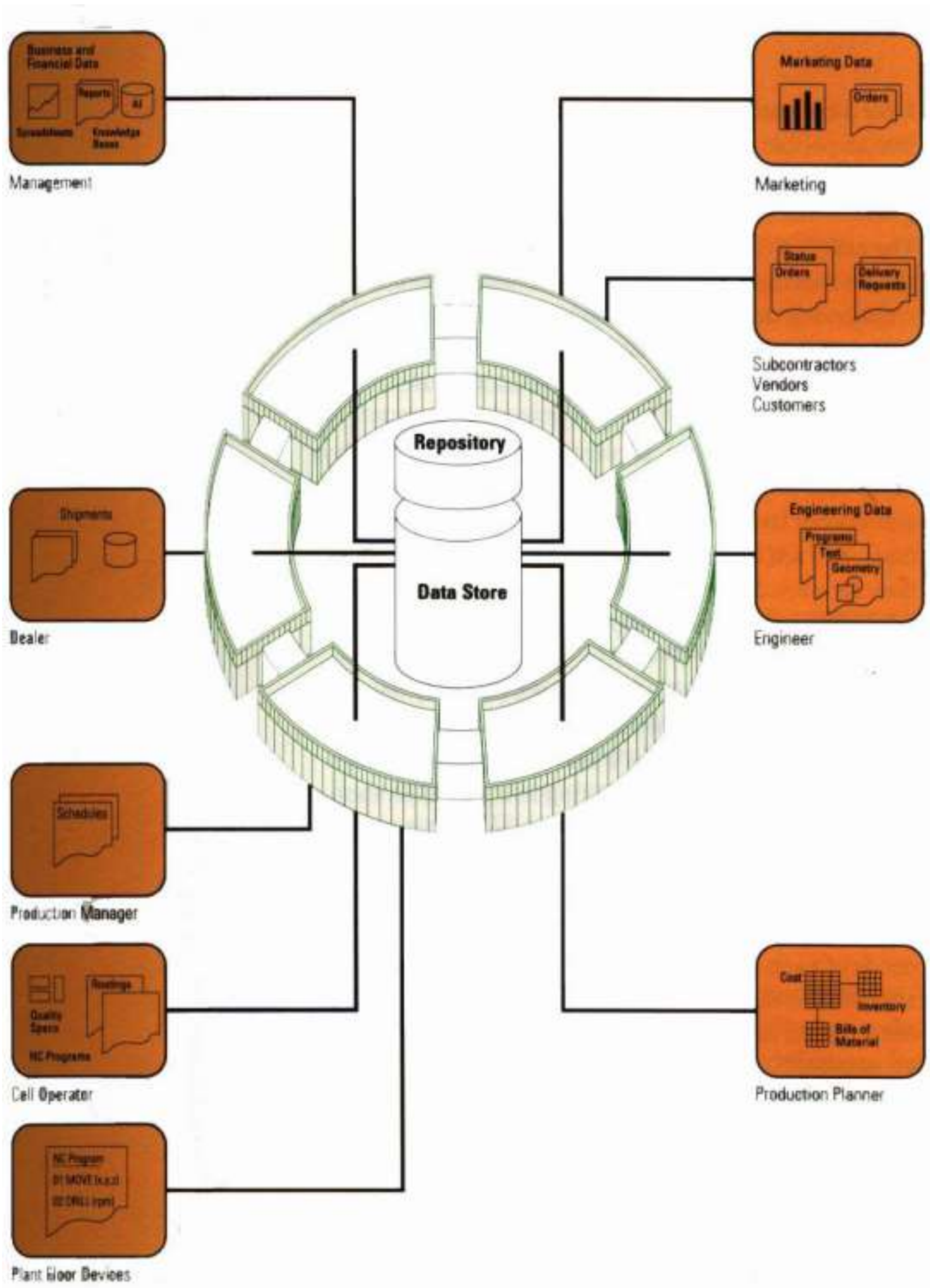

Fig 89 Presentation in the CIM Environment

Networking Overview:

Computer network A collection of computing devices that are connected in various ways in order to communicate and share resources

Usually, the connections between computers in a network are made using physical wires or cables

However, some connections are **wireless**, using radio waves or infrared signals

The generic term **node** or **host** refers to any device on a network

Data transfer rate The speed with which data is moved from one place on a network to another

Data transfer rate is a key issue in computer networks

Computer networks have opened up an entire frontier in the world of computing called the **client/server model**

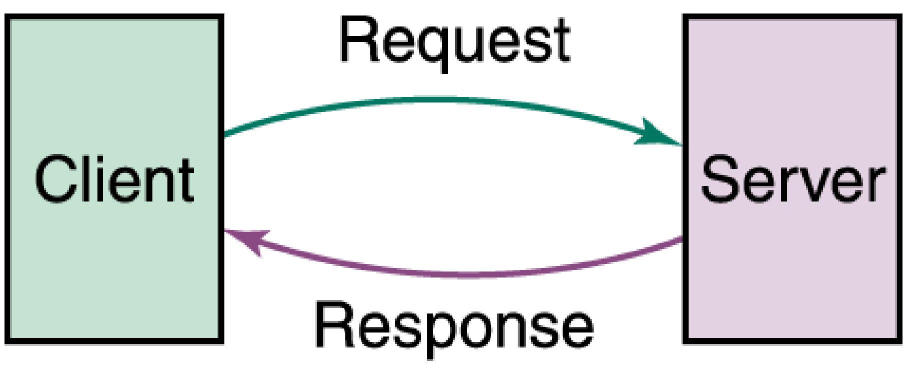

Fig 90 Client/Server interaction

File server A computer that stores and manages files for multiple users on a network

Web server A computer dedicated to responding to requests (from the browser client) for web pages

Types of Networks

Local-area network (LAN) A network that connects a relatively small number of machines in a relatively close geographical area

Various configurations, called topologies, have been used to administer LANs

- **Ring topology** A configuration that connects all nodes in a closed loop on which messages travel in one direction
- **Star topology** A configuration that centers around one node to which all others are connected and through which all messages are sent
- **Bus topology** All nodes are connected to a single communication line that carries messages in both directions

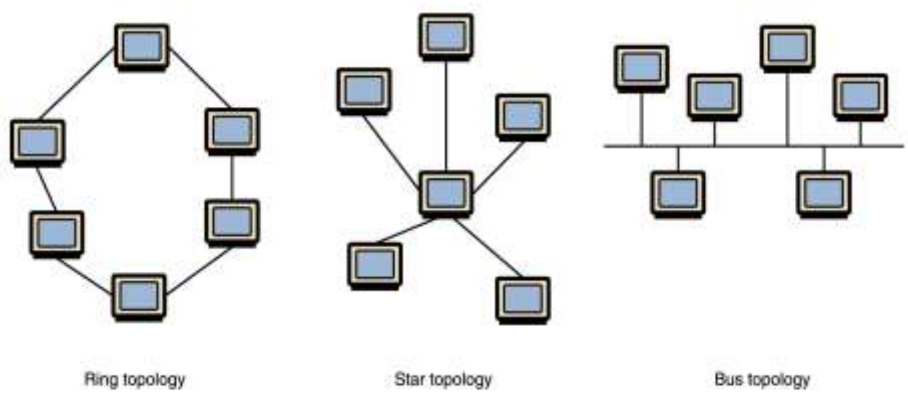

Fig 91 Various network topologies

- A bus technology called **Ethernet** has become the industry standard for local-area networks
- **Wide-area network (WAN)** A network that connects two or more local-area networks over a potentially large geographic distance

Often one particular node on a LAN is set up to serve as a **gateway**to handle all communication going between that LAN and other networks

Communication between networks is called internetworking

The **Internet,** as we know it today, is essentially the ultimate wide-area network, spanning the entire globe

- M**etropolitan-area network (MAN)** The communication infrastructures that have been developed in and around large cities

Who owns the Internet?

No single person or company owns the Internet or even controls it entirely. As a wide-area network, it is made up of many smaller networks. These smaller networks are often owned and managed by a person or organization. The Internet, then, is really defined by how connections can be made between these networks.

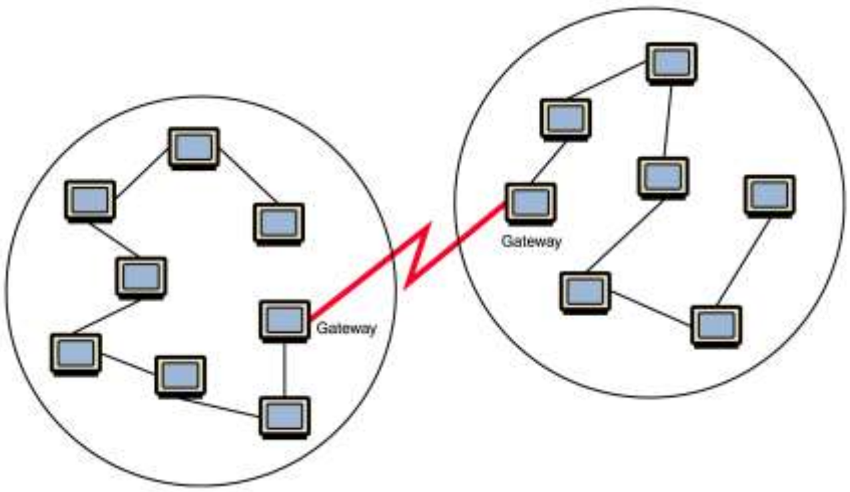

Fig 92 Local-area networks connected across a distance to create a wide-area network

Internet Connections

- **Internet backbone** A set of high-speed networks that carry Internet traffic

These networks are provided by companies such as AT&T, GTE, and IBM

- **Internet service provider (ISP)** A company that provides other companies or individuals with access to the Internet

- There are various technologies available that you can use to connect a home computer to the Internet
  - A **phone modem** converts computer data into an analog audio signal for transfer over a telephone line, and then a modem at the destination converts it back again into data
  - A **digital subscriber line (DSL)** uses regular copper phone lines to transfer digital data to and from the phone company's central office

– A **cable modem**usesthe same line that your cable TV signals come in on to transfer the data back and forth

- **Broadband** A connection in which transfer speeds are faster than 128 bits per second
  – DSL connections and cable modems are broadband connections
  – The speed for **downloads** (getting data from the Internet to your home computer) may not be the same as **uploads** (sending data from your home computer to the Internet)

Packet Switching

- To improve the efficiency of transferring information over a shared communication line, messages are divided into fixed-sized, numbered **packets**
- Network devices called routers are used to direct packets between networks

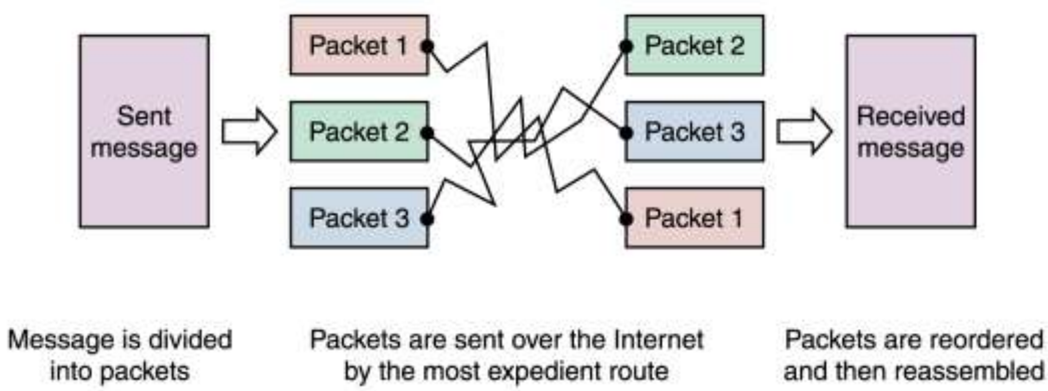

Fig 93 Messages sent by packet switching

Open Systems

- **Proprietary system** A system that uses technologies kept private by a particular commercial vendor

One system couldn't communicate with another, leading to the need for

- **Interoperability** The ability of software and hardware on multiple machines and from multiple commercial vendors to communicate *Leading to*
- **Open systems** Systems based on a common model of network architecture and a suite of protocols used in its implementation

- The International Organization for Standardization (ISO) established the **Open Systems Interconnection (OSI) Reference Model**
- Each layer deals with a particular aspect of network communication

7	Application layer
6	Presentation layer
5	Session layer
4	Transport layer
3	Network layer
2	Data Link layer
1	Physical layer

Fig 94 The layers of the OSI Reference Model

Network Protocols

- Network protocols are layered such that each one relies on the protocols that underlie it
- Sometimes referred to as a **protocol stack**

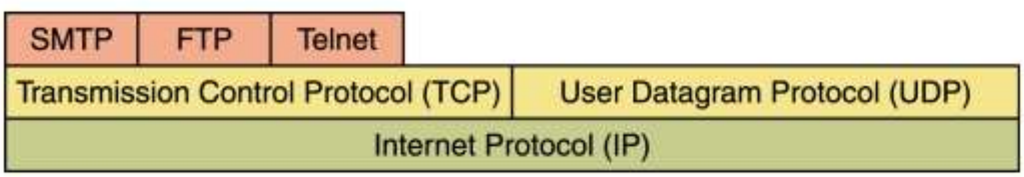

Fig 95 Layering of key network protocols

TCP/IP

- TCP stands for **Transmission Control Protocol**

  TCP software breaks messages into packets, hands them off to the IP software for delivery, and then orders and reassembles the packets at their destination

- IP stands for **Internet Protocol**

  IP software deals with the routing of packets through the maze of interconnected networks to their final destination

- UDP stands for **User Datagram Protocol**
  - It is an alternative to TCP
  - The main difference is that TCP is highly reliable, at the cost of decreased performance, while UDP is less reliable, but generally faster

High-Level Protocols

- Other protocols build on the foundation established by the TCP/IP protocol suite
  - Simple Mail Transfer Protocol (SMTP)
  - File Transfer Protocol (FTP)
  - Telnet
  - Hyper Text Transfer Protocol (http)

MIME Types

- Related to the idea of network protocols and standardization is the concept of a file's MIME type
  - MIME stands for **Multipurpose Internet Mail Extension**
  - Based on a document's MIME type, an application program can decide how to deal with the data it is given

Protocol	Port
Echo	7
File Transfer Protocol (FTP)	21
Telnet	23
Simple Mail Transfer Protocol (SMTP)	25
Domain Name Service (DNS)	53
Gopher	70
Finger	79
Hyper Text Transfer Protocol (HTTP)	80
Post Office Protocol (POP3)	110
Network News Transfer Protocol (NNTP)	119
Internet Relay Chat (IRC)	6667

Fig 96 Some protocols and the ports they use

Firewalls

- **Firewall** A machine and its software that serve as a special gateway to a network, protecting it from inappropriate access
  - Filters the network traffic that comes in, checking the validity of the messages as much as possible and perhaps denying some messages altogether
  - Enforces an organization's **access control policy**

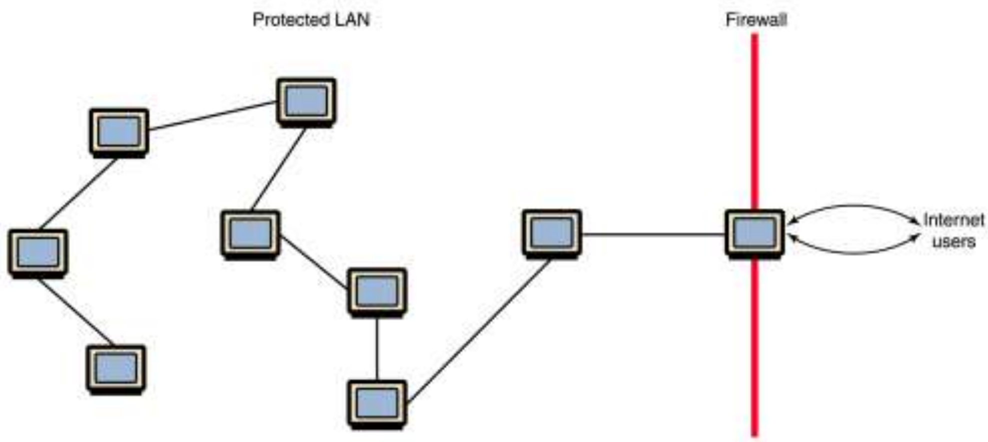

Fig 97 A firewall protecting a LAN

Network Addresses

- **Hostname** A unique identification that specifies a particular computer on the Internet

For example

matisse.csc.villanova.edu

condor.develocorp.com

- Network software translates a hostname into its corresponding IP address

For example

205.39.145.18

- An **IP address** can be split into
  - **network address**, which specifies a specific network

– **host number**, which specifies a particular machine in that network

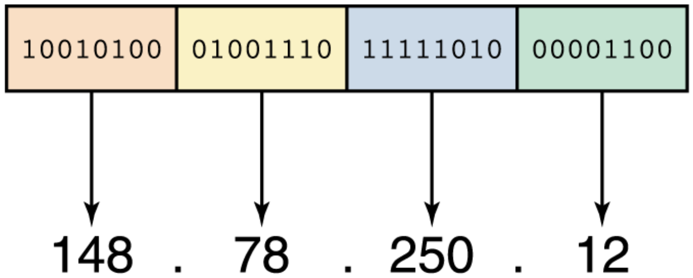

Fig 98 An IP address is stored in four bytes

Domain Name System

- A hostname consists of the computer name followed by **the domain name**
- csc.villanova.edu is the domain name
  - A domain name is separated into two or more sections that specify the organization, and possibly a subset of an organization, of which the computer is a part
  - Two organizations can have a computer named the same thing because the domain name makes it clear which one is being referred to
- The very last section of the domain is called its **top-level domain (TLD)** name

Top-Level Domain	General Purpose	New TLDs	General Purpose
.com	U.S. Commercial	.biz	Business
.net	Network	.info	Information
.org	Nonprofit organization	.pro	Professional
.edu	U.S. Educational	.museum	Museums
.int	International	.aero	Aerospace industry
.mil	U.S. Military	.coop	Cooperative
.gov	U.S. Government		

Fig 99 Top-level domains, including some relatively new ones

- Organizations based in countries other than the United States use a top-level domain that corresponds to their two-letter country codes

Country Code TLD	Country
.au	Australia
.br	Brazil
.ca	Canada
.gr	Greece
.in	India
.ru	Russian Federation
.uk	United Kingdom

Fig 100 Some of the top-level domain names based on country codes

- The **domain name system** (DNS) is chiefly used to translate hostnames into numeric IP addresses
  - DNS is an example of a distributed database
  - If that server can resolve the hostname, it does so
  - If not, that server asks another domain name server

Module-IV

CIM System: Open System Open systems inter connection, Manufacturing automations protocol and technical office protocol (MAP /TOP).

Database for CIM: Development of databases, Database terminology, Architecture of database systems, Data modeling and data associations, Relational data bases, Database operators, Advantages of data base.

7. Introduction to Networking Standards and their Development

The International Standardization Organization (ISO) developed a model for data communications. This is known as ISO-Open System interconnection (OSI) model. This model is shown in Fig. 103. This standard defines a series of seven layers in which communication processing takes place.

These protocol layers are:

Physical layer Data link layer

Network layer Transport layer

Session layer Presentation layer

Application layer

Each layer contains a specific set of functions. It is organized such that any given layer may be implemented in a number of ways and remains compatible with layers above and below it. There have been also standard protocols and techniques established for implementing individual layers. An example of these is the Institute of Electrical and Electronics Engineers (IEEE) 802 LAN standards, which define certain ways of implementing Layers 1 and 2.

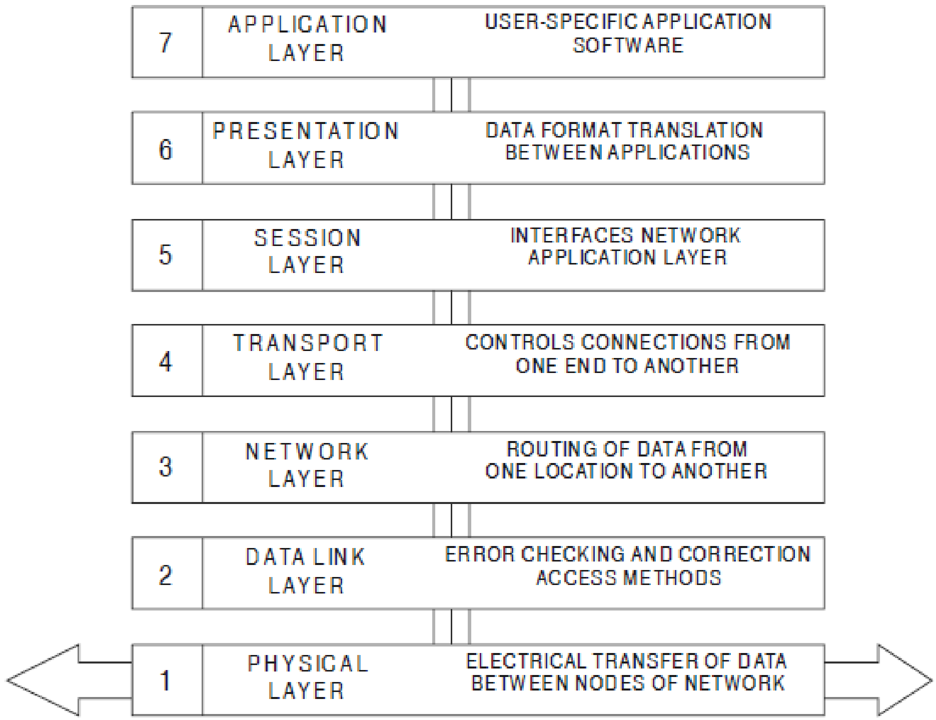

Fig. 101 OSI Model for Network Communications

The National Bureau of Standards (NBS), the European Computer Manufacturers Association (ECMA), and the Consultative Committee on International Telephony and Telegraphy (CCITT) and American Standards Institute (ANSI) are establishing middle and higher-level protocols. The seven layers of the ISO-OSI model are described below:

Physical Layer

Level one is the physical layer. It defines the physical connection between the computer and the network communication system. This connection includes cables, connectors, and modulation equipment and specifies the frequencies and voltages of connectors. The bandwidth of the cable transmission and the physical layout (topology) are defined in this layer.

Traffic control is necessary within any given channel, and various techniques exist for handling this control.

NETWORK TRAFFIC CONTROL: It is necessary to regulate the transmission of information in a network. A frequently used technique for controlling traffic on a network is CSMA/CD (Carrier Sense Multiple Access/Collision Detect). When a node has message to send, it listens on the line to see if any other message is in the process of being sent. If not, it broadcasts its message on the line. The receiving node acknowledges it. There is a chance that two nodes will begin transmitting at the same time. The collision detect action determines when this happens by measuring a higher energy level in the line. Both nodes involved in the collision wait for a random period of time (each different) and try again.

Another popular network control method is called token passing. Here, the right to transmit data is called a token, and this token is passed from one node to another node in an organized fashion. Whichever node has the token has right to transmit data for a preset maximum amount of time. It must then next pass the token to the next node in sequence. If a node is sending and maximum time passes before all data is sent, that node must be stop sending and pass the token. It may resume when it gets the token back again. An advantage of this method is that one can compute the maximum amount of time any given node will have to wait before receiving the token and being able tosend messages. Two major token-passing schemes are token ring and token bus. Token ring uses nodes connected in a ring structure whereas token bus utilizes a bus network.

Data Link Layer

Level 2 defines how the data is to be packaged when it is sent between physical connections. This layer defines the network access control mechanisms. The formats used in network message units are also defined here. LANs do not send messages as a continuous stream. Instead, messages are broken up into message units called packets. Each packet carries the addresses of its source and destination along with suitable error detection mechanisms. An established protocol is higher level Data Line Control (HDLC). Another is Bisynchronous Communication (BSC). These are two standardized ways of transmitting data.

Network Layer

This layer defines switching and routing information between networks and how packets of data are exchanged between different LANs. An example is the X.25 standard, which defines standards for packet switching networks.

Transport Layer

The transport layer defines network addressing and the way in which connections between networks can be linked or unlinked. The transport layer guarantees the message delivery with no omissions or duplications.

Session Layer

The primary function of this layer is to define an application interface to the transport layer. This layer maps names to network addresses so that applications can use names to communicate with devices. Layers 3, 4 and 5 combine to form a sub-net level containing the software, which controls the network hardware. Though cables are attached to every device in a network, actual communication involves only two devices—the sender and the receiver. The subnet level establishes and manages a temporary link called virtual connection between the sender and the receiver. At levels 4 and 5, the major concern is about how applications in different LANs communicate. Consider two computers on a LAN, each running different programs. (See Fig. 102) Program A on computer 1 needs to exchange data with program C on computer` 2; program B on computer one needs to talk with program D on computer 2. Level 4 of OSI establishes virtual channels, effectively isolating each pair of communicating programs from other sets of programs talking over the network.

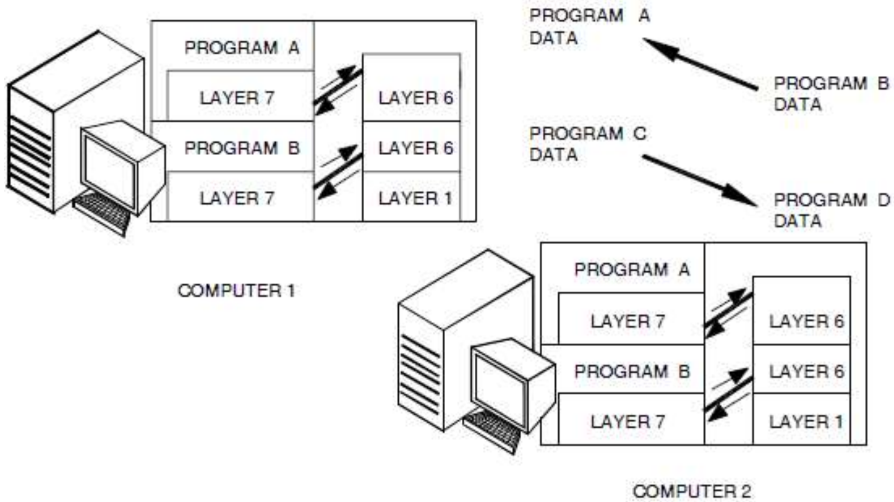

Fig. 102 Communication between Different Applications

Presentation Layer

This layer defines the translation formats and syntax from an application to the network and the manner in which software applications enter the network.

Application Layer

This layer contains several programs that define the network applications that support file serving. The developments in computer communication during the last two years have significantly simplified the communication protocols.

Examples of Network Standards

Several computer manufacturers and organizations have developed systems for network communications.

DECNET

DECNET is a trademark of former Digital Equipment Corporation. This is a good example of a network following Level 2 through 8 of the ISO OSI standard. DECNET allows change of files between computers. It allows a terminal attached to computer A to interact with computer B in another location. In advanced applications, it even supports distributed databases. It is a software protocol, where a number of different electrical and line protocols may be used to support it. For example DECNET is used in a hybrid, point-to-point network. It may also use Ethernet as an electrical protocol.

System Network Architecture

IBM's System Network Architecture (SNA) is a network management scheme used primarily for peer-to-peer communications between computers. It has become a de-facto standard for interconnection of large mainframes, due to popularity of IBM and IBM compatible hardware. Gateway devices are available from several manufacturers to interface between SNA and various LANs. SNA to non-IBM computer interfaces are also available. Several other vendors also supply SNA interfaces.

7.1 Manufacturing Automation Protocol (MAP)

MAP is a hardware/software protocol developed jointly by a group of industries and vendors of computers and PLCs. It follows the ISO OSI model. MAP was developed as a result of the plans of General Motors to automate its factories. MAP uses a broad band LAN, with a token ring protocol for traffic control. Since it is broadband, all devices in the LAN like computers, CNC machines, robots, and PLC's etc. share the same cable, but different groups of devices can be placed on separate "channels" on the line. Additionally, closed circuit TV (video) channel can also be accommodated on same cable. MAP physical level is based on the IEEE 802.4 token-bus standard. At the data link level, it uses the IEEE 802.2 logical control standard. MAP also uses 8473 network layer protocol for connectionless-mode network service.

7.2 Technical Office Protocol (TOP)

TOP is another widely used protocol, developed by Boeing Computer Services. It is similar to MAP in several respects. TOP is the initiative of a group of computer system purchasers. The members of TOP group include Boeing, General Motors, Du Pont, McDonnel Douglas, Ford Motors, Procter and Gamble and Eastman Kodak. In a multi-vendor computing environment, common communication methods are required for integration and automation of processes. TOP addresses the problem of providing multi-vendor compatibility and communications in the technical office functions. Thus, TOP is an application-oriented implementation of the OSI protocols. TOP, like MAP is based on the seven-layer OSI model. But, unlike MAP, TOP does not have to address the needs of a harsh shop floor environment. Applications, which it is designed to integrate, are electronic mail, word processing, document exchange, file transfer, graphics interchange, database management, batch processing, and videotext and business analysis. TOP provides peer-level, process-to-process, and terminal-access communications for computers ranging from personal computers to workstations and mainframes. TOP also interconnects office tasks with the factory floor via its interface with MAP. Table 2 shows a comparison of MAP and TOP. A complete TOP system will include one or more building blocks covering layers one to four and at least one building block for layers 5 to 7.

Table 2 Comparison of MAP and TOP Protocols

LAYER	MAP	TOP
LAYER 7 - APPLICATION	ISO FTAM 8571	ISO FTAM 8571
LAYER 6 - PRESENTATION	NULL	NULL
LAYER 5 - SESSION	ISO 8327	ISO 8327
LAYER 4 - TRANSPORT	ISO 8073 / CLASS 4	ISO 8073 CLASS 4
LAYER 3 - NETWORK	ISO 8473	ISO 802.2
LAYER 2 - DATA LINK	IEEE 802.2	ISO 802.2
LAYER 1 - PHYSICAL	IEEE 802.3	ISO 802.4

7.3 Networking in a Manufacturing Company

A manufacturing company carries out a number of operations using computers. These include:

- Master production scheduling and planning
- Pay roll and human resources management
- Purchasing and receiving
- Order entry and invoicing
- Shop management
- Warehouse management
- Tool crib management
- Time keeping

• Quality control
• Shipping
• Materials handling
• Inventory control
• Processing operations
• Marketing

There are software solutions to carry out the above and many others (not listed here) tasks. These are implemented in different types of computers. In addition, several devices like bar code readers and RFID tags will be used for data collection and input. All these are to be connected in a LAN for effective operation. Fig. 103 shows a typical factory LAN and the various equipment connected to the LAN.

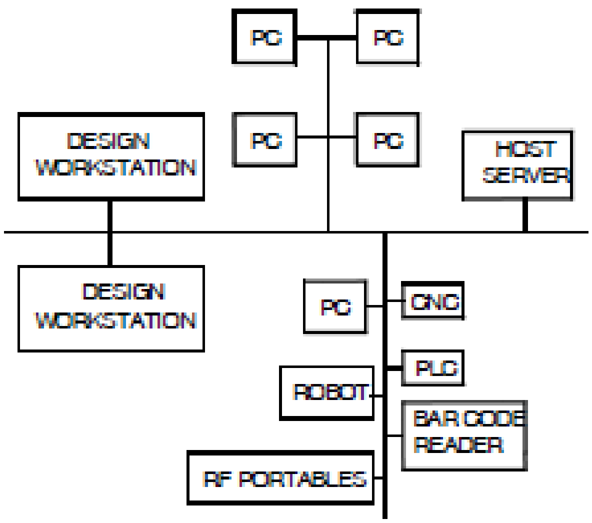

Fig. 103 A Typical Factory LAN

7.4 Internet

Internet is the mother of all networks and is a gigantic network of networks that connects presently several million people and millions of computer sites. These computer sites are spread all over the world at various government locations, corporate offices, colleges and universities and research institutions. All those people and millions like them who are linked up to the Internet can talk to each other by way of exchanging electronic messages in real time.

There are literally hundreds of databases that let people access information ranging from CAD data, manufacturing data, medical information, economic data, GIS and engineering tables. This superhighway of information makes available millions and millions of computer files filled with sound and video clips. Literally anybody can take these and people can exchange notes, reviews and views with each other via USENET newsgroups and bulletin boards.

7.5 File Transfer Protocol (FTP)

FTP stands for File Transfer Protocol. It is both a program and the method used to transfer files between computers on the Internet. Anonymous FTP is a type of FTP that lets the user transfer any of more than 2 million files from several thousand computers on the Internet to the personal computer or computer account. By using FTP, the Internet becomes like a huge disc drive attached to the computer. FTP sites contain books, journals, software, games, images, sound, multimedia, courseware, datasets and other information available for the user to transfer. There are a variety of FTP programs, but most of them work in the same way.

7.6 Client/Server

The purpose of having computers communicate with each other in a client/server mode is that they can both share the work. In the early years of computer development, mainframes sent information out to dumb terminals, and the mainframe had to do all the work. This also allows the user, for example, to take advantage of always-improving client software, which a user can install in the PC, while the software on the server machine may remain the same.

7.7 World Wide Web (WWW)

World Wide Web is an innovative hypertext front-end program based on client/ server architecture that allows the user to access information on the Internet as if it were a part of a seamless web. The goal of WWW is to make all online knowledge part of one interconnected web of documents and services, and allow the user to follow facts and texts wherever they might lead. For systems with “character only” displays such as

UNIX, DOS and VMS one has to use line browser software in which one moves through the web by typing line numbers. On systems like Windows, X-windows, and Macs these are client programs that allow the user to make links by clicking and pointing.

7.8 Intranet

INTRANET can be defined as a manufacturing organization's use of world wide web and related Internet technology to accomplish its primary objectives, viz., helping in production of superior quality goods with substantial decrease in operating costs, or achieving total customer satisfaction, maintaining healthy employer—employee relationship etc. An Intranet is designed to distribute corporate information within an organization to organization's own people. Using Intranet, web and related technology can be put to maximum use to further the purpose of the organization. People may include both employees and valuable customers of that organization. In the broadest sense, both internet and intranet use the same technology. However, Intranet is an organizational network, whereas Internet is a global one, which embraces thousands of servers providing wide range of information. Intranet has access to Internet but not vice versa. Intranets are internal networks that the employees' can access for information by simple browsing as on the World Wide Web. It acts as a reservoir of company information. It is a very effective platform for the employees to discuss projects and share ideas. Intranet enhances project management and reporting systems and improves workflow and increases productivity. Another very significant advantage of intranet is that it permits employees share information with colleagues spread over various locations simultaneously.

7.9 Enterprise Wide Network

A manufacturing enterprise can function very efficiently if various segments of the enterprise are connected in the form of an enterprise wide network. Within the industry the various users can be connected in the form of a local area network. The manufacturing engineering, business management, purchase, sales etc., can be connected through client/ server mode on a TCP/IP backbone. Fig. 106 shows a typical enterprise wide network. It can be seen that various business partners like dealers, customers and suppliers can be connected to the network making the flow of information smooth and efficient. The network can also connect service technicians who may be located at different parts of the country or even different parts of the world. The network also facilitates the professionals to log on to the network from their homes. Similarly sales people can have instant access to the company through the network irrespective of their physical location. The information flow can be through electronic mail or through suitable workflow automation software. Workflow automation is discussed in the next section. Through the network the company can reach many professionals and expert services which are located anywhere in the world.

When the different plants of a company and its associated groups are geographically distributed they can be linked together by VSAT. A VSAT is a Very Small Aperture Terminal, which can communicate with another VSAT through the satellite. Communicating through VSAT is very cost effective and efficient. Fig. 104 shows a typical VSAT based communication system. A VSAT system consists of a satellite hub (eight to nine metre antenna, along with network management switching equipment etc.) and several 1.8m VSAT terminals located at various customer premises. All communication between VSATs takes place via the hub, using a geostationary satellite hovering in a stationary orbit. Customers can share facilities of a hub operated by a service provider in their own hub if there are a large number of locations. Typical speed of communication from hub to VSAT direction is 512 kbps and VSAT to hub is 64/128/256 kbps.

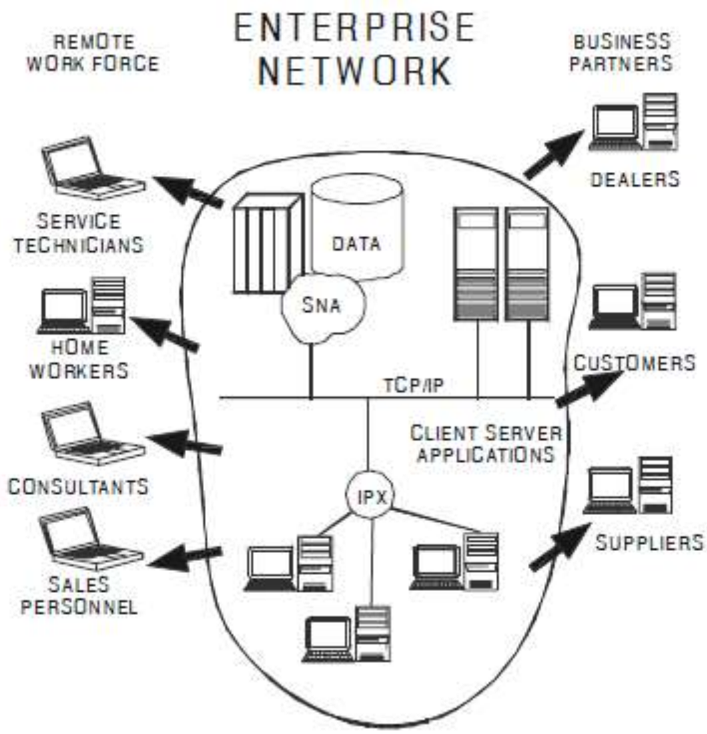

Fig. 104 Enterprise-wide Network

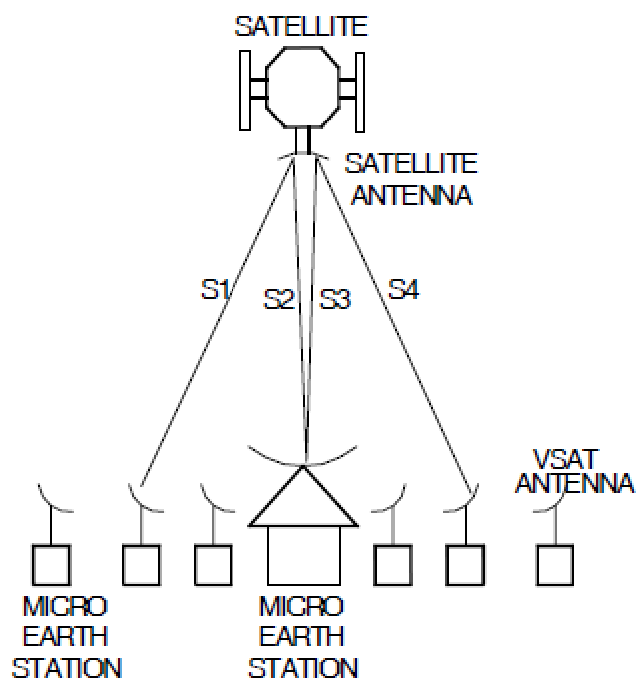

Fig. 105 VSAT-based Communication System

8. Introduction to Database in CIM

Computer Integrated Manufacturing integrates all the functions related to the manufacture. The following are the major functions among them:

i. Computer aided engineering covering design, analysis, simulation and optimization.

ii. Computer aided manufacturing

iii. Operations Management

iv. Logistics, Supply Chain Management, Warehousing and other functions.

In the ideal case, all these and their related functions use the same database as shown in Fig. 106. In essence, the successful implementation of CIM lies in the efficient way relevant data is shared among the different segments of CIM.

The information required for manufacturing is complex covering a wide range of disciplines and serving a multitude of inter-related yet vastly differing needs. The CIM database comprises basically four classes of data:

i. Product Data: Data about parts to be manufactured. It includes text and geometry data.

ii. Manufacturing Data: The information as to how the parts are to be manufactured is available in production data.

iii. Operational Data: Closely related to manufacturing data but describes the things specific to production, such as lot size, schedule, assembly sequence, qualification scheme etc.

iv. Resource Data: This is closely related to operational data but describes the resources involved in operations, such as materials, machines, human resources and money.

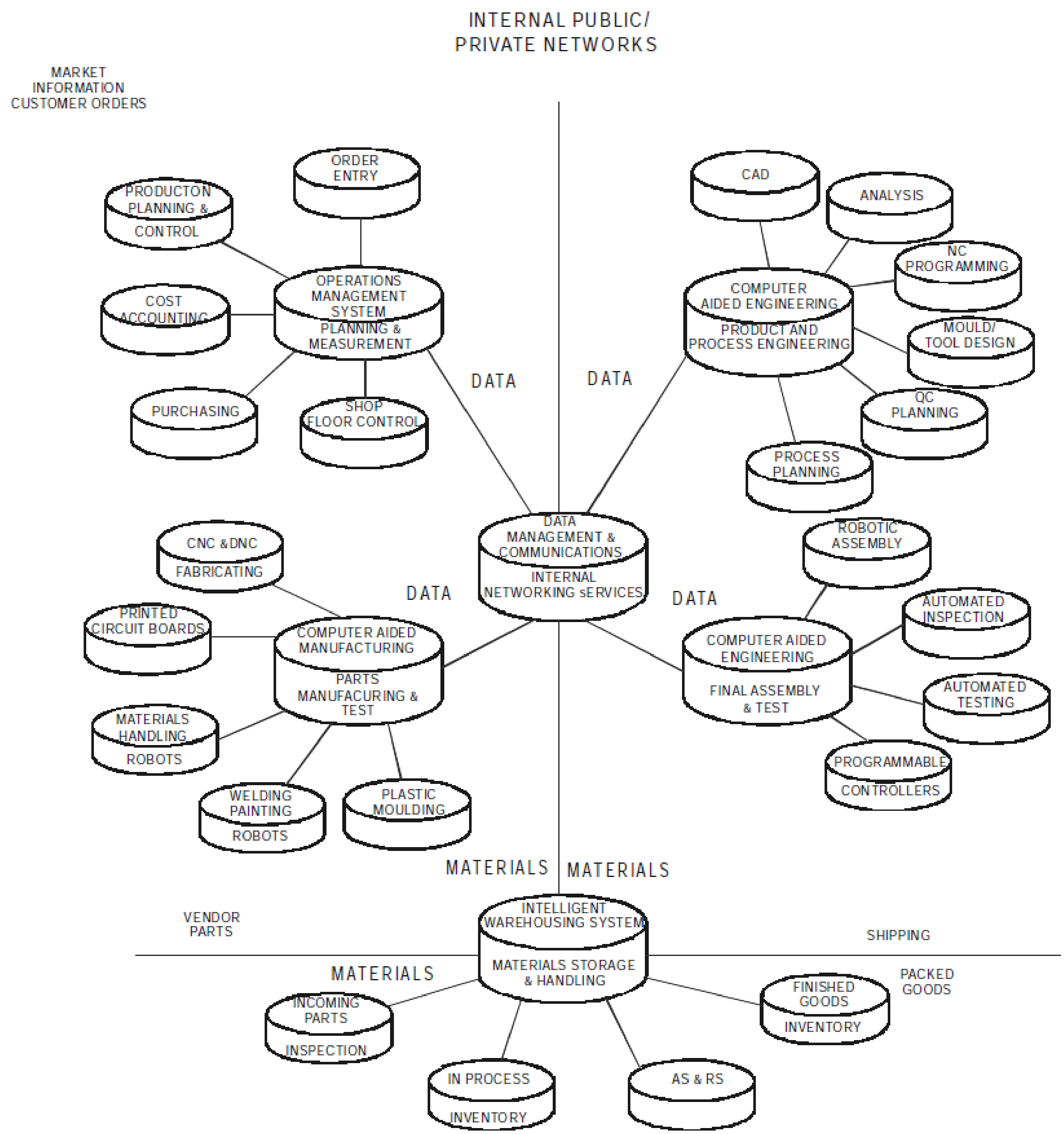

Fig. 106 CIM Data Base

Product Design and Manufacturing process increasingly requires access to substantial technical information in various stages like design, analysis and manufacturing as well as smooth co-ordination among the many functions constituting an enterprise. Manufacturing organizations may waste a considerable portion of their resources due to delayed or error prone communication from one segment to another. It would therefore be desirable to have one single central database that would contain all information.

8.1 Database Requirements of CIM

A major challenge facing the implementation of CIM is to establish the type of data needed to bridge the mechanical design and manufacturing functions. Following is the list of varied tasks one might expect to accomplish in a CIM environment.

i. Designing assemblies and performing tolerance analysis on those assemblies.

ii. Preparing production drawings of assemblies, individual parts, tooling, fixtures and other manufacturing facilities.

iii. Creating analytical models of parts for structural, kinematical and thermal analysis (FEM, MeM etc).

iv. Calculating weights, volumes, centres of gravity and other mass properties and costs of manufacturing (cost estimation).

v. Classifying existing parts according to shape, function, and the process by which they are manufactured and retrieving these parts from the parts library on demand (Group technology and coding).

vi. Preparing part lists and bill of materials (BOM).

vii. Preparing process plans for individual part manufacture and assembly (Variant or Generative).

viii. Programming CNC machines for processing complete parts (CAM).

ix. Designing work cells and programming the movement of components in those cells using work handling devices like robots, conveyors, AGV's/ RGV's, etc. (Cellular manufacture).

x. Controlling engineering changes and maintaining associativity between design and manufacturing (PDM, VPDM, concurrent associativity etc).

xi. Preparing programs to handle components or manipulate production equipment (like welding torches or robots).

xii. Preparing inspection programs including programs for CNC co-ordinate measuring machines [CNC CMM's].

The exchange of graphic information has been advanced with increasing acceptance of Initial Graphics Exchange Specification (IGES) and STEP.

Data Base

A data base can be defined as a collection of data in a single location designed to be used by different programmers for a variety of applications. The term database denotes a common base of data collection designed to be used by different programmers. More specifically it is a collection of logically related data stored together in a set of files intended to serve one or more applications in an optimal fashion. Data are stored such that they are independent of the data. A database must also have a predetermined structure and organization suitable for access, interpretation, or processing either manually or automatically. A database not only stores the data but also provides several ways to view the data depending upon the needs of the user. There are several classifications of data.

i. Physical data: These are data stored in the computer’s storage device. The volume of data required by a manufacturing company is so large that secondary storage devices such as hard discs, tapes, CD-ROMs, and other digital storage devices of several gigabyte capacities will be used.

ii. Logical data: This indicates how a user views the physical data. The distinction between the physical data and the corresponding logical view is that the user conceptualizes certain meaningful relationships among the physical data elements. For example, we may have a set of items and quantities recorded in files. The logical view or interpretation of these sets of data can be that the items represent components available in stores and that the quantities recorded correspond to their inventory.

iii. Data independence: Database management systems (DBMS) are used by the users to manage the physical data. DBMS makes a distinction between the two namely, the user and the physical data. Changes in the organization of physical data and or in the storage device parameters are absorbed by DBMS and therefore do not affect the user or more accurately, the application program. This flexibility is absent in the traditional file systems.

8.2 Objectives of Database

A database serves the following objectives:

• Reduce or eliminate redundant data

• Integrate existing data

• Provide security

• Share data among users

• Incorporate changes quickly and effectively

• Exercise effective control over data

• Simplify the method of using data

• Reduce the cost of storage and retrieval of data

• Improve accuracy and integrity of data

8.3 Issues of Concern in Database

There are, of course, some issues to be considered while implementing a database. These include:

• High investment in hardware and software

• Need to use larger and faster hardware

• Necessity to have highly trained manpower

• Redundancy to take care of eventualities like crash of the database server.

• Need to ensure integrity and reliability of data

8.4 Database Management

The manufacturing database and its management are major issues in CIM. The issues are complex but they are beginning to be addressed in a number of ways, including schemes for organizing data, standards for product data exchange and standards for communication protocols. The standards for product data exchange are discussed in chapter 17 and communication protocols have been discussed elsewhere. This chapter hence is devoted to the organization of data. A major problem to be solved to implement CIM has always been that of distributing information among different computer based systems. As indicated in earlier chapters CIM is typically integration of islands of computer aided functions running on different computers using different databases.

Joining those islands into an effective CIM enterprise requires proper methods of processing information. Information, if it is to be useful, must be appropriate, machine-interpretable, and available when and where it is needed.

Features of a Database Management System

A database management system consists of a collection of interrelated data and a set of programs to access that data. Database management involves:

- Organize a database.
- Add new data to the database.
- Sort the data in some meaningful order.
- Search the database for types of information.
- Print the data into formatted reports.
- Edit the data.
- Delete the data.

Database Administrator

The person responsible for managing the database is often referred to as database administrator. His functions include:

- Creating the primary database structure
- Backing up and restoring data in case of crash
- Modifying the structure
- Transfer data to external files
- Allocate and control user access rights
- Monitoring performance

Comparison of Database and Traditional File Systems

File system represents a tight coupling between physical data and user's program. They lack almost all the flexibilities offered by DBMS. Most of the indispensable facilities of DBMS of are, therefore forced to be absorbed by user's program. In other words besides the logic of the application the user has to provide logic for constructing the logical view of data, has to interpret the operations on the logical view and translate them in to the primitive file operations, and has to be responsible for maintaining the files that store the physical data. The tight coupling and interdependence of between a user's application and the physical data would not allow sharing of the same data by other applications that may need to view and manipulate them differently. This then forces the data to be duplicated among various applications. File systems lack dynamism in the sense that the application programs are designed, coded, debugged, and catalogued ahead of time for the preconceived requests and applications.

The following list summarizes the problems of file systems that can be overcome by DBMS.

i. Data dependence
ii. Rigidity
iii. Static nature
iv. Lack of integration
v. Data duplication
vi. Inconsistency
vii. Difficulty in sharing information
viii. Inefficiency
ix. Inability to handle adhoc requests.

8.5 Database Models

There are three ways in which data can be organized: hierarchical, network or relational.

Hierarchical Database

Fig 107 shows a typical hierarchical file structure. The nodes in level 2 are the children of node at level 1. The nodes at level 2 in turn become parents of nodes in level 3 and so on.

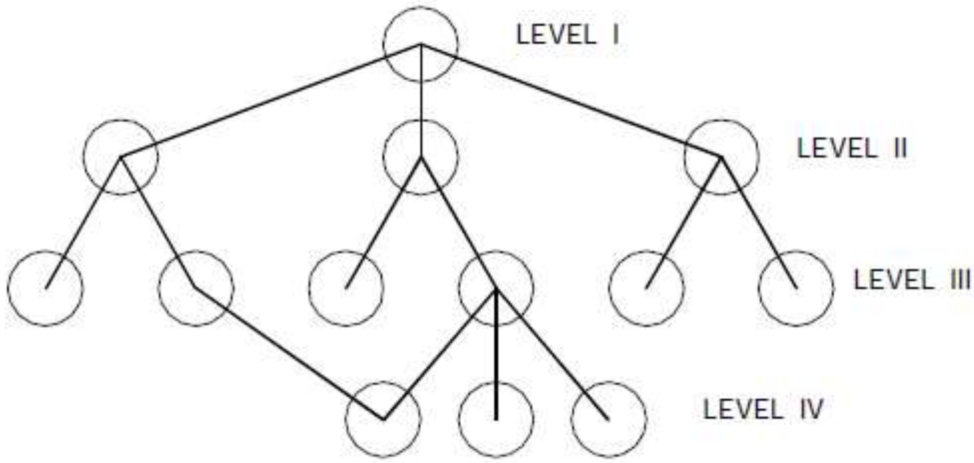

Fig. 107 Typical Hierarchical File Structure

In a hierarchical model, data files are arranged in a tree like structure which facilitates searches along branch lines; records are subordinated to other records at a higher level. Starting at the root of the tree, each file has a one-to-many relationship to its branches. A parent file can have several children. A good example of such an organization might be a parts list, in which each product is composed of assemblies which are in turn composed of sub assemblies and/or component parts. As an example of hierarchical database structure, the parts list of lathe assembly is shown in Fig 108. Examples of hierarchical database management systems are IMS and SYSTEM 2000.

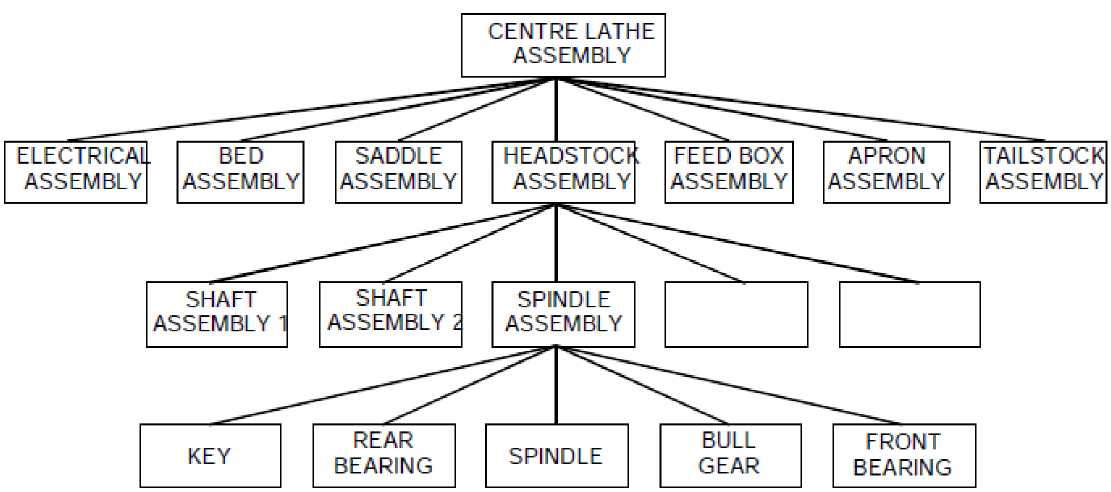

Fig. 108 Parts of a Lathe Assembly

Network Database

The network database is a combination of several hierarchies in which child files can have more than one parent file, thereby establishing a many-to- many relationship among data. A hierarchical model is actually a subset of a network model. Examples of network database languages are TOTAL and IDMS.

In both hierarchical and network databases data relationships are predefined and embedded in the structure of the database. Access to data is processed by associated application programs. A limitation of both hierarchical and network systems is the restriction they place on data access. They both require that the rules of data access be defined when the data structure is defined. The access rules are difficult to modify after the database has been implemented. They are suited for batch operations that are highly structured and repetitive involving high transaction rates.

Relational Database Management Systems (RDBMS)

Data is organized in the form of a table for a large variety of manufacturing applications. An example of such a set of data is given in Table 3.

Table 3 Dimensions for Deep Groove Ball Bearings

No.	*D*	*D1*	*D*	*D2*	*B*	*r*	*r1*
6403	17	26	62	53	17	2	1
6404	20	20	72	63	19	2	1
6405	25	36	0.00	69	21	2	1
6403	17	26	62	53	17	2	1

There is a correspondence between the concept of a table and the mathematical concept of a relation. In a RDBMS (Relational Database Management System) an entity is an object that is distinguishable from other objects. An entity set is a set of entities of the same type and is represented by a set of attributes. For each attribute there is a set of permitted values for domains. An entity relationship model (E-R Model) is based on the perception of the real world which consists of a set of entities and relationships among them.

Process planning is a good example of such an interactive need to evaluate many data relationships in order to arrive at a logical sequence of properly defined manufacturing steps. The relational database eliminates the need to follow predefined access paths to reach target data, and makes data access more flexible. The database user gains quicker access to information since the database provides direct access to all data. The access is independent of the way it is stored. The RDBMS is also flexible. Hence relational database facilitates unanticipated queries and makes it well suited to the manufacturing environment. Several vendors now offer relational database management systems, suitable for CIM applications.

Features of RDBMS include:

• Adhoc or unanticipated queries. This is typical in a manufacturing environment.

• Relational database is dynamic. The relationships change and are extended frequently in a manufacturing database.

• Suitable where enterprise information has to be available to a large number of users for decision making.

• Desirable where application specifications, development and maintenance costs are to be kept at the minimum level.

• Compatible with distributed databases.

Some of the important features of RDBMS are given below:

i. Guaranteed logical accessibility.

ii. Dynamic on-line catalogue.

iii. Comprehensive data sublanguage.

iv. Views that could be modified depending on need.

v. High-level insert updates and delete.

vi. Physical data independence.

vii. Logical data independence.

viii. Integrity independence.

ix. Distribution independence.

DBMS Architecture

Fig. 109 shows a typical RDBMS architecture. In this architecture, multiple models are derived from a single conceptual data model. It has more abstraction capability. This is also referred to as the syntactic or operational data model meaning that it is more syntactically driven and is a vehicle of user's manipulations.

There are several levels of abstraction in data modeling. These influence the RDBMS architecture. The architecture of Fig. 8.4 has multiple levels, which is a price to be paid for flexibility.

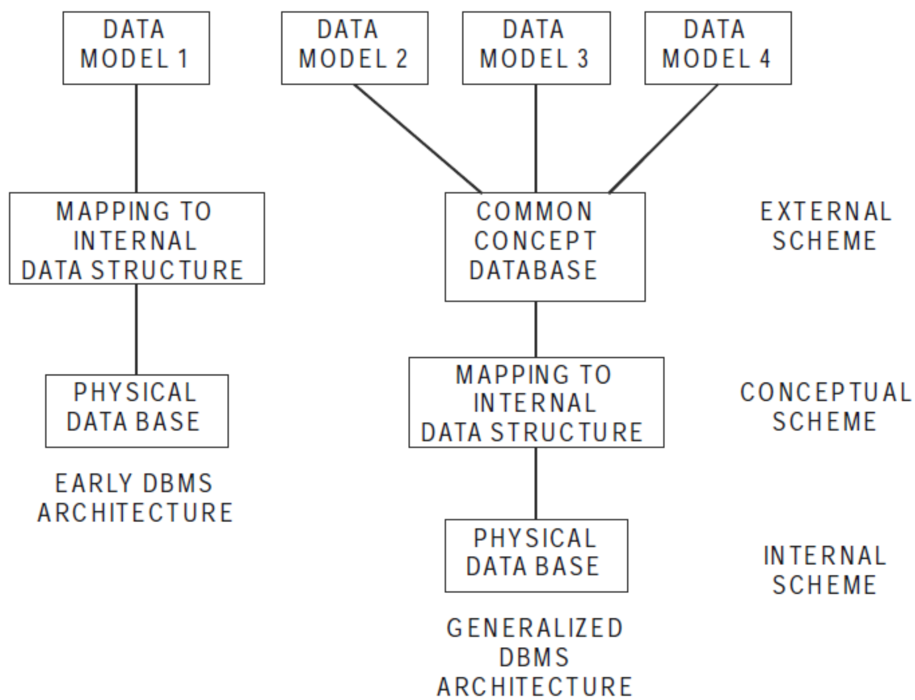

Fig. 109 RDBMS Architecture

8.6 Query Language

It was mentioned earlier that queries are used to access databases. A query language is one with which a user requests information from a database. Two categories of query languages are:

(i) Procedural

(ii) Non-procedural

There are a number of commercial query languages available today. They can be classified as:

SQL - Structured Query Language

QUEL - Query Language

QBE - Query by Example

The structured query language approach is widely used. The following section presents a brief overview of SQL.

Structured Query Language [SQL]

The advent and successful implementation of relational databases has brought with it need for a data base language that is user friendly enough for the common user while being convenient and comfortable for the programmer and applications builder. The structured query language now called SQL [pronounced “sequel”], has emerged to fill this need. The user can easily learn and understand SQL. It can be embedded in a procedural language such as C, COBOL, or PL/l. SQL helps user and programmer to understand the requirements of each other. This fact is very important in making the transition from paper files to computerized database systems smooth.

SQL is acronym for Structured Query Language. It is often referred to frequently by its former name, Sequel.

The basic structure of an SQL expression consists of three clauses: select, from and where. The static clause corresponds to the projection operation of the relational algebra. It is used to list the attributes desired in the result of a query.

The italic clause is a list of relations to be scanned in the execution of the expression. The italic clause corresponds to the selection predicate involving attributes of the relations that appear in the ‘from’ clause.

A typical SQL query has the form

Select A1, A2 ... An

From rl, r2 ... rm

Where P.

The A’s represent attributes, the r’s represent relations, and the P is a predicate.

SQL forms certain product of the relations named in the ‘from’ clause, performs a relational algebra selection using the where clause predicate.

8.7 Product Data Management (PDM)

Databases are one component needed to deliver instant, accurate data. Engineering information systems are the other. An engineering data management system should automatically notify members of the design team with updates and circulate latest change orders. In order to derive maximum benefit from CAD it must be possible to deliver CAD data efficiently and seamlessly to all downstream applications related to engineering planning. Product data management is a technology developed to meet this need. PDM systems work on network layouts called client-server architectures. The server is also called a vault, even though the information may be distributed over several workstations. The vault acts as the heart of an engineering network. The vault or the server has the capabilities to handle efficiently large amounts of complex information. Product development engineers access the vault through their desktop computers called clients.

This client-server idea works efficiently because it runs on two separate, synchronized databases. One database stores product information such as CAD drawings, part specifications, analysis data, and manufacturing product information. The other database, called a meta database is a relational database that stores information about the data. For example given a drawing number this gives information about the attributes of the drawing i.e. where a drawing is stored and when it was last updated etc. The client software lets the clients talk to the server, allowing design engineers, manufacturing engineers, and manager's access to the information stored.

The features of a PDM system include:

• Electronically track, access, sort and retrieve design data enabling the engineers to work on the most recently updated designs.

• Integrating the design environment by providing facilities for viewing drawings created in different CAD systems like AutoCAD, PRO/E, Unigraphics, CADDS 5, I-DEAS, Solid Edge, Solid Works etc.

• Providing a CAD view-and-mark up package to view complete designs on the screens of the clients so that planning engineers can satisfy themselves that designs are complete before they are released to manufacturing planning.

• Retrieving drawings and designs based on limited information so that design engineers can retrieve already available designs, thereby saving valuable time in product development.

• Capturing design revision information from a variety of documents like drawings, part lists, bill-of-materials (BOM).

• Providing data security through multi-tier access control.

• Creating comprehensive back-up and recovery procedures.

• Automatic disk clean-up of old drawing versions and batch back-up.

• Generating audit trails such as who designed the part, who modified the part, who approved the design etc.

• Providing graphical user interface tool kits so as to enable the design team to create new applications.

In short PDM is an excellent tool for concurrent engineering. PDM systems efficiently manages design reviews by getting the right documents and the drawings to the right people in the quickly. Some of the functions of PDM are discussed in the subsequent sections.

Design Review Function

To set up the design review function the project administrator defines each design project, assign the members to the team, describe the actual process and define the workflow. For example, in the case of an electric motor design project the tasks to be included may be conceptual design, stress and field analysis, detailed drawings and a description of manufacturing and assembly process. One task, for example, the design analysis will be carried out by a group of three and approved by one. The design may have to be accepted by all the members of the group. The design review system gives considerable flexibility for the persons in charge of the project.

Change Management

The project administrator develops the process that handles engineering change orders. A significant change management feature is the protection of engineering changes-in-progress from implemented too soon or by accident. This also eliminates paper work.

Where-Used Reports

This is another function of PDM. The software answers the question, “Which assembly uses component A?”. PDM produces a report which shows component-by-component breakdown of the complete assembly with the “where-used” components highlighted.

Configuration Management

The configuration management function is also called product-structure management. This shows how the parts in an assembly relate to one another. This provides an opportunity for the product administrators to create standards for handling bill-of-material part relationships and for defining product life-cycle data requirements. For example, the graphic display from a configuration management application will show the hierarchy of automobile body parts, starting with body, doors, wheels and tyres. This will be further broken down to the last nut and bolt. Each component will be described in several ways to show the use and assembly inter-relationships.

Advantages of PDM

PDM offers several benefits for the speedy execution of product development projects:

- PDM helps engineers to access design drawings in minutes.
- Managers know how many drawings were released for fabrication.
- Manufacturing engineers know exactly when to start fabrication.
- Two designers cannot simultaneously edit the same drawing.
- Two drawings cannot have the same drawing numbers.
- All information from drawing-release statistics to revision details pass to the primary project management system that tracks overall project status for all the company activities.
- The PDM system keeps a complete history of the modifications, when the modifications took place and keeps all previous versions of data for a period defined by the company.
- Subcontractors can be given direct access to PDM database. Controls ensure that no subcontractor can access data associated with the sub-sets of projects he is not involved with.

Database management overview

- Basic terminology
  - Date item: the smallest unit of data
  - Data record: a collection of data items
  - File: a collection of similar date records
  - Data base: a collection of files as an organized assembly of information that users can access for various purposes.
  - Data model: a logic representation of a collection of data elements. It is the building block for databases.
- In modern engineering, a great deal amount of information is required for any task to be accomplished. Imaging that a manufacturing company producing simple gears. The following data must be available:
  - Work material
  - Dimensions, surface finish and tolerance
  - Machines to be used in manufacturing
  - Tools

  Therefore, it is very important to have a proper database management system.
- Data model. There are two types data models:
  - Record based models, which can further decomposed as network model, hierarchical model, and relational model.
  - Object-oriented models
- In recent years, object-oriented models become dominant. The object-oriented model is based on following important concept.
  - Object: any physical or imagery entities may be referred to as an object
  - Attribute and methods: objects are characterized by attributes, which may include its intrinsic properties or its relationship with other objects. A method is an operation applied to the objects.
  - Message: a method is invoked by a client by sending a message to the object.
- Class: objects can be categorized into classes, which describe the common behavior of the object with respect to its family.

- For those who have learnt the object-oriented programming (C++), the above concepts should be easy to follow. Following is an example
  - Object: robot
  - Class:

    Class name: robot
    Attribute: robot_id
    Robot_type
    Method: move
    Pickup
    Drop off
  - A particular instance is:

    Class name: PUMP1
    Attribute: 1023
    Articulate
    Method: Pickup(Work1)

  Note that “Work11” is another object (a workpiece), the interactions between the two objects are defined by the operation (association) “Pickup”.
- The procedure of designing an object-oriented database system is as follows:
  (a) develop a conceptual model of the system by identifying key objects
  (b) associate attributes and methods with each object identified in step 1
  (c) arrange objects into a class inheritance hierarchy
  (d) refine the hierarchy by emphasizing, specialization, and generalizing
  (e) identify client-server relationships and message exchanges among objects to capture system dynamics
  (f) develop a prototype implementation to validate requirements
  (g) refine the system design iteratively by modifying or adding objects, attributes, operations, or associations.

Groupware

- Groupware is the networked hardware and software that allow people to support each other in their effort to achieve work goals regardless of where and when they want to do this.
- Groupware shall have consider the following issues
  - Re-eneineer, re-tool, re-size, re-invent, re-manufacture, …
  - Teamwork, virtual teaming
  - Focus on customer needs
  - Focus on core competencies
  - The network enterprise
  - Flatter, leaner organizations
  - Drive for efficiency and productive gain.
- Two of the most important groupware handware tools are email and networking.
- Also, now there are several software systems that can be used as groupwares, such as I-DEAS, Unigrphics, and ProEngineering.

By now we have pretty much described all the important technologies used in modern manufacturing systems. These technologies will help you to understand and hence, to solve the practical problems in manufacturing systems. If you have any problems, please do not hesitate to contact me at the following address.

CIM Databases overview

Objectives

- ❑ Define a database and a database management system (DBMS) and describe the components of a DBMS.
- ❑ Describe the architecture of a DBMS.
- ❑ Define the three traditional database models: hierarchical, networking and relational.
- ❑ Describe the relational model and relations.

- Understand operations on a relational database based on commands available in SQL.
- Describe the steps in database design.
- Define ERM and E-R diagrams and explain the entities and relationships in this model.
- Define the hierarchical levels of normalization and understand the rationale for normalizing the relations.
- List database types other than the relational model.

Data storage traditionally used individual, unrelated files, sometimes called **flat files**. In the past, each application program in an organization used its own file. In a university, for example, each department might have its own set of files: the record office kept a file about the student information and their grades, the scheduling office kept the name of the professors and the courses they were teaching, the payroll department kept its own file about the whole staff and so on. Today, however, all of these flat files can be combined in a single entity; the database for the whole university.

Although it is difficult to give a universally agreed definition of a database, we use the following common definition:

A database is a collection of related, logically coherent data used by the application programs in an organization.

Advantages of databases

Comparing the flat-file system, we can mention several advantages for a database system.

Less redundancy

In a flat-file system there is a lot of redundancy. For example, in the flat file system for a university, the names of professors and students are stored in more than one file.

Inconsistency avoidance

If the same piece of information is stored in more than one place, then any changes in the data need to occur in all places that data is stored.

Efficiency

A database is usually more efficient that a flat file system, because a piece of information is stored in fewer locations.

Data integrity

In a database system it is easier to maintain data integrity, because a piece of data is stored in fewer locations.

Confidentiality

It is easier to maintain the confidentiality of the information if the storage of data is centralized in one location.

Database Management Systems

A database management system (DBMS) defines, creates and maintains a database. The DBMS also allows controlled access to data in the database. A DBMS is a combination of five components: hardware, software, data, users and procedures (Fig 110).

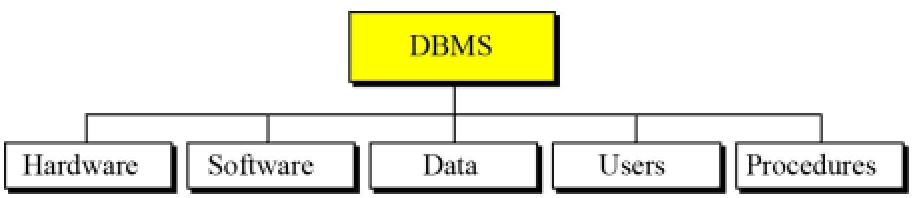

Fig 110 DBMS components

Hardware

The hardware is the physical computer system that allows access to data.

Software

The software is the actual program that allows users to access maintain and update data. In addition, the software controls which user can access which parts of the data in the database.

Confidentiality

The data in a database is stored physically on the storage devices. In a database, data is a separate entity from the software that accesses it.

Users

In a DBMS, the term users has a broad meaning. We can divide users into two categories: **end users** and **application programs**.

Procedures

The last component of a DBMS is a set of procedures or rules that should be clearly defined and followed by the users of the database.

Database Architecture

The American National Standards Institute/Standards Planning and Requirements Committee (ANSI/SPARC) has established a three-level architecture for a DBMS: **internal**, **conceptual** and **external** (Fig 111).

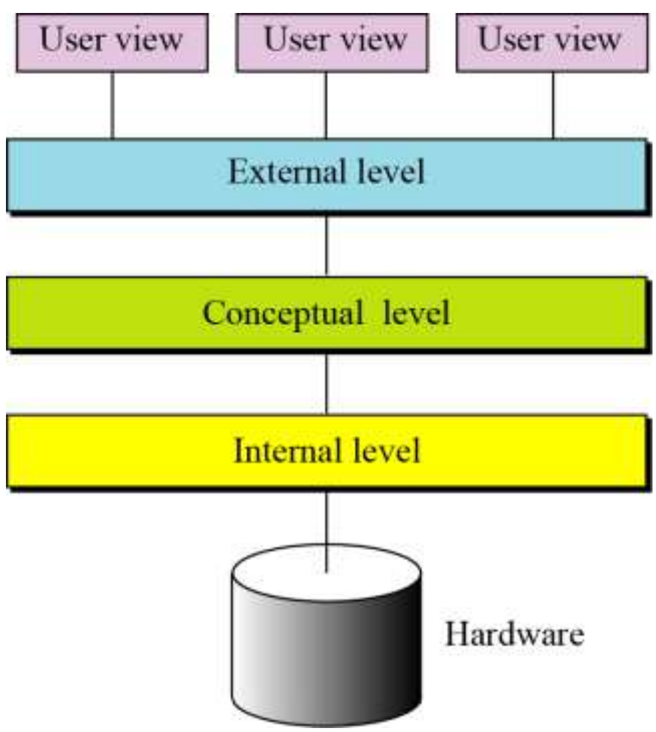

Fig 111 Database architecture

Internal level

The **internal level** determines where data is actually stored on the storage devices. This level deals with low-level access methods and how bytes are transferred to and from storage devices. In other words, the internal level interacts directly with the hardware.

Conceptual level

The **conceptual level** defines the logical view of the data. The data model is defined on this level, and the main functions of the DBMS, such as queries, are also on this level. The DBMS changes the internal view of data to the external view that users need to see. The conceptual level is an intermediary and frees users from dealing with the internal level.

External level

The external level interacts directly with the user (end users or application programs). It changes the data coming from the conceptual level to a format and view that is familiar to the users.

Database Models

A database model defines the logical design of data. The model also describes the relationships between different parts of the data. In the history of database design, three models have been in use: the hierarchical model, the network model and the relational model.

Hierarchical database model

In the hierarchical model, data is organized as an inverted tree. Each entity has only one parent but can have several children. At the top of the hierarchy, there is one entity, which is called the root.

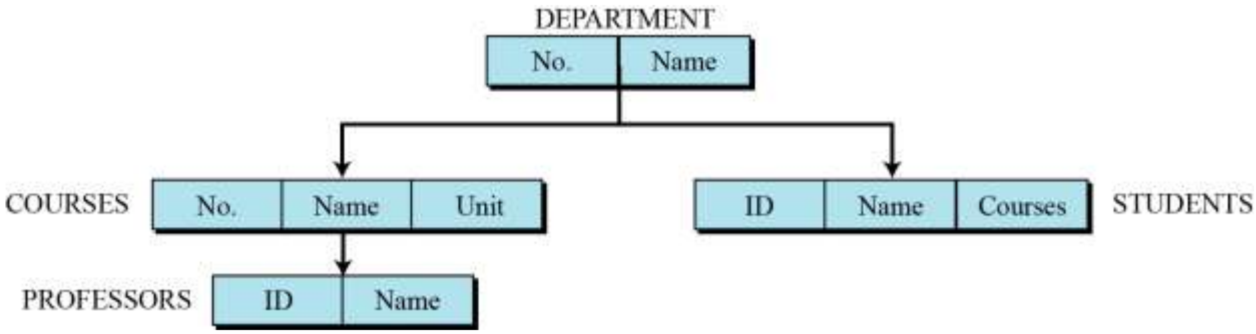

Fig 112 An example of the hierarchical model representing a university

Network database model

In the network model, the entities are organized in a graph, in which some entities can be accessed through several paths (Fig 113).

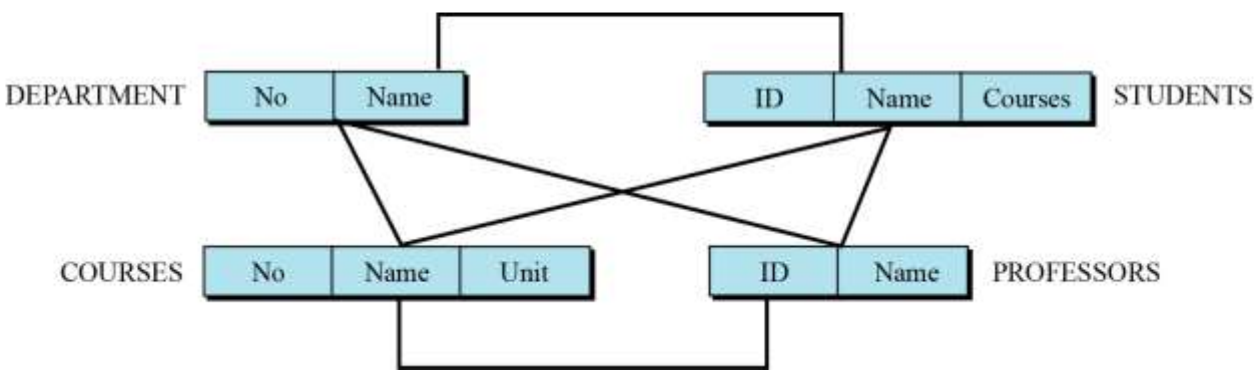

Fig 113 An example of the network model representing a university

Relational database model

In the relational model, data is organized in two-dimensional tables called relations. The tables or relations are, however, related to each other, as we will see shortly.

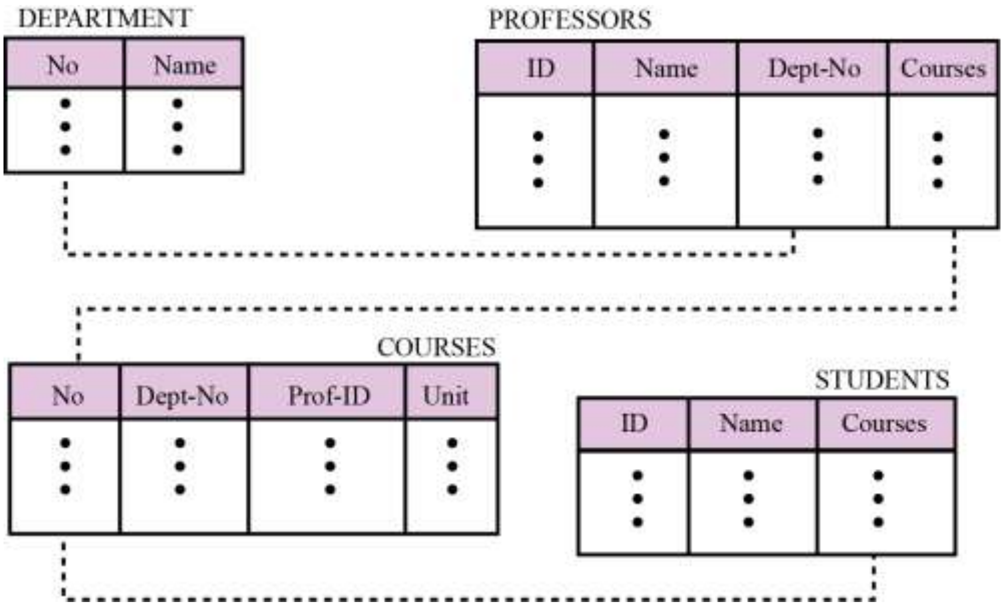

Fig 114 An example of the relational model representing a university

The Relational Database Model

In the **relational database management system (RDBMS)**, the data is represented as a set of ***relations***.

Relations

A **relation** appears as a two-dimensional table. The RDBMS organizes the data so that its external view is a set of relations or tables. This does not mean that data is stored as tables: the physical storage of the data is independent of the way in which the data is logically organized.

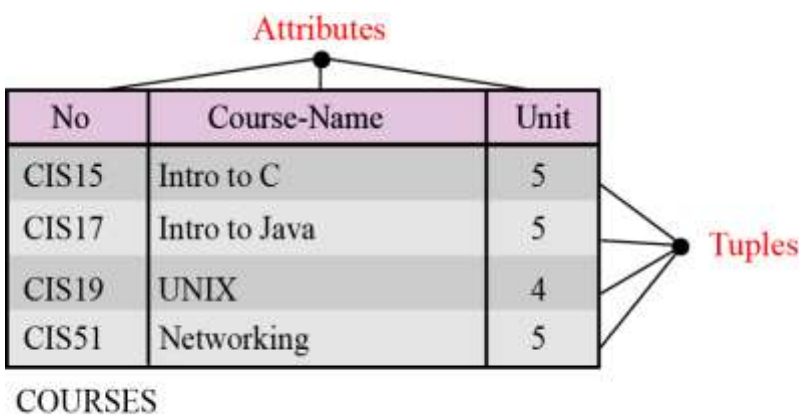

Fig 115 An example of a relation

A relation in an RDBMS has the following features:

- **Name**. Each relation in a relational database should have a name that is unique among other relations.
- **Attributes**. Each column in a relation is called an attribute. The attributes are the column headings in the table in Figure 6.
- **Tuples**. Each row in a relation is called a tuple. A tuple defines a collection of attribute values. The total number of rows in a relation is called the cardinality of the relation. Note that the cardinality of a relation changeswhen tuples is added or deleted. This makes the database dynamic.

Operations on Relations

In a relational database we can define several operations to create new relations based on existing ones. We define nine operations in this section: insert, delete, update, select, project, join, union, intersection and difference. Instead of discussing these operations in the abstract, we describe each operation as defined in the database query language SQL (Structured Query Language).

Structured Query Language

Structured Query Language (SQL) is the language standardized by the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) for use on relational databases. It is a ***declarative*** rather than ***procedural*** language, which means that users declare what they want without having to write a step-by-step procedure. The SQL language was first implemented by the Oracle Corporation in 1979, with various versions of SQL being released since then.

Insert

The ***insert operation*** is a unary operation—that is, it is applied to a single relation. The operation inserts a new tuple into the relation. The insert operation uses the following format:

```
insert into   RELATION-NAME
values   (..., ..., ...)
```

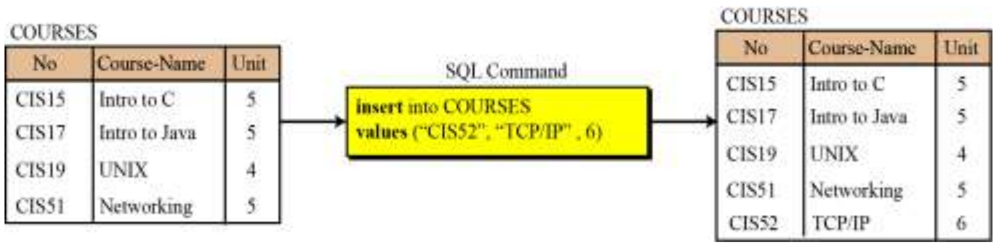

Fig 116 An example of an insert operation

Delete

The delete operation is also a unary operation. The operation deletes a tuple defined by a criterion from the relation. The delete operation uses the following format:

```
delete from RELATION-NAME
where criteria
```

Fig 117 An example of a delete operation

Update

The update operation is also a unary operation that is applied to a single relation. The operation changes the value of some attributes of a tuple. The update operation uses the following format:

```
update   RELATION-NAME
set attribute1 = value1,   attribute2 = value2, ...
where   criteria
```

Fig 118 An example of an update operation

Select

The select operation is a unary operation. The tuples (rows) in the resulting relation are a subset of the tuples in the original relation.

```
select   *
from RELATION-NAME
where   criteria
```

Fig 119 An example of an select operation

Project

The project operation is also a unary operation and creates another relation. The attributes (columns) in the resulting relation are a subset of the attributes in the original relation.

```
select   attribute-list
from RELATION-NAME
```

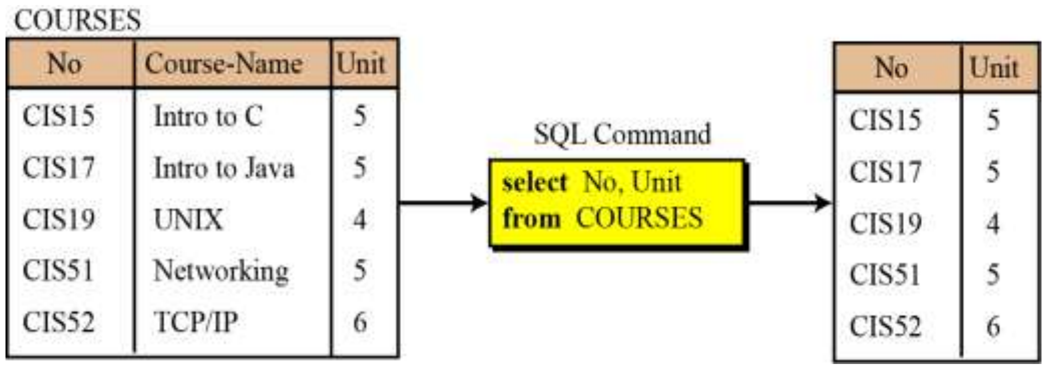

Fig 120 An example of a project operation

Join

The join operation is a binary operation that combines two relations on common attributes.

```
select   attribute-list
from RELATION1, RELATION2
where criteria
```

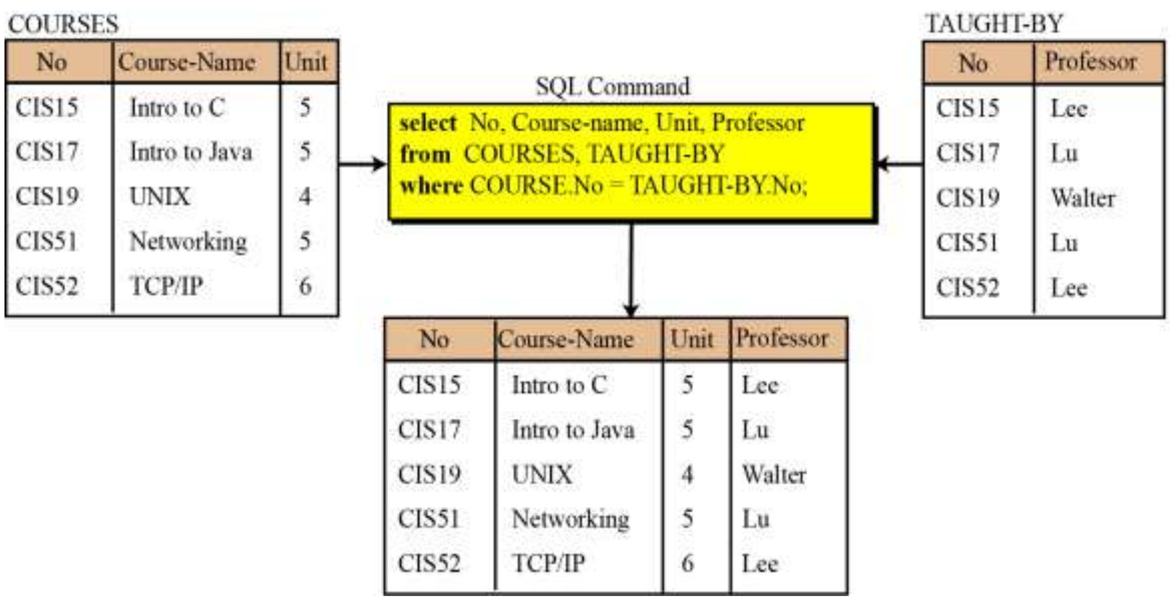

Fig 121 An example of a join operation

Union

The union operation takes two relations with the same set of attributes.

```
select *
from RELATION1
union
select *
from RELATION2
```

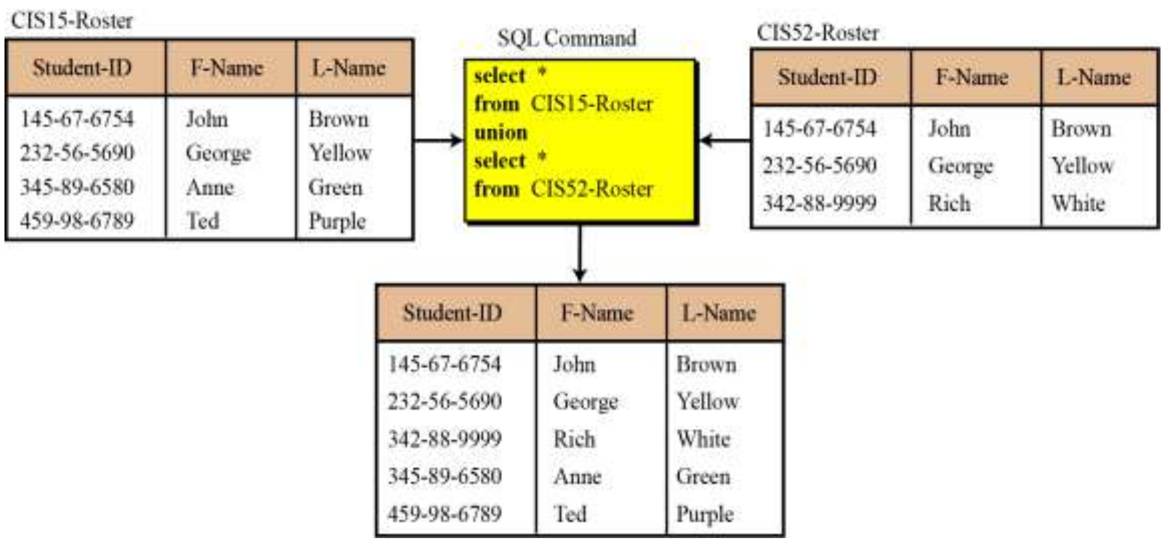

Fig 122 An example of a union operation

Intersection

The intersection operation takes two relations and creates a new relation, which is the intersection of the two.

```
select *
from RELATION1
intersection
select *
from RELATION2
```

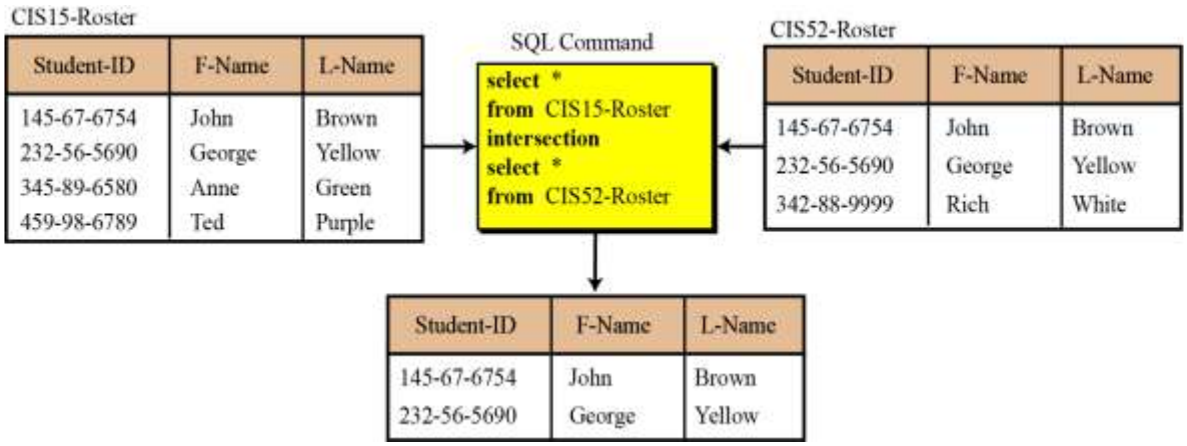

Fig 123 An example of an intersection operation

Difference

The difference operation is applied to two relations with the same attributes. The tuples in the resulting relation are those that are in the first relation but not the second.

```
select *
from RELATION1
minus
select *
from RELATION2
```

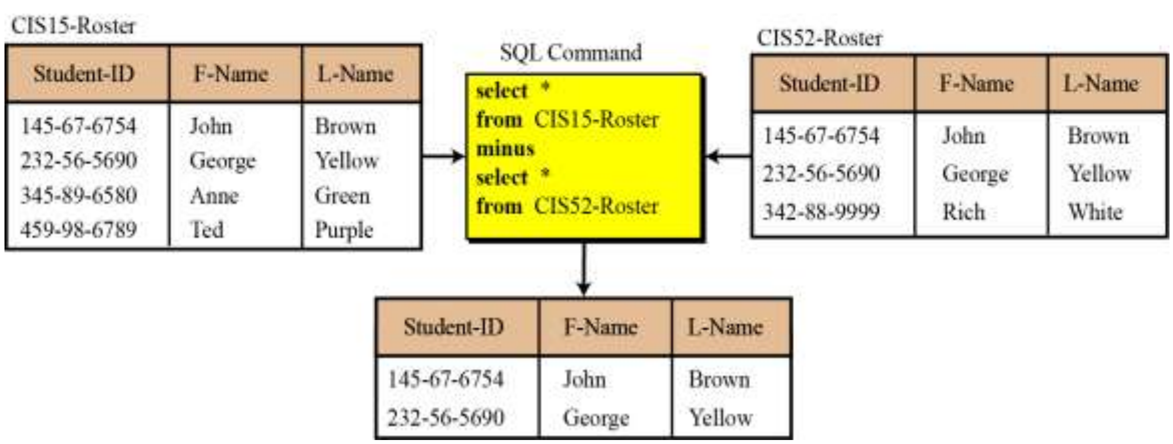

Fig 124 An example of a difference operation

Database Design

The design of any database is a lengthy and involved task that can only be done through a step-by-step process. The first step normally involves interviewing potential users of the database. The second step is to build an **entity-relationship model (ERM)** that defines the entities, the attributes of those entities and the relationship between those entities.

Entity-relationship models (ERM)

In this step, the database designer creates an **entity-relationship (E-R) diagram** to show the entities for which information needs to be stored and the relationship between those entities. E-R diagrams use several geometric shapes, but we use only a few of them here:

Rectangles represent entity sets

Ellipses represent attributes

Diamonds represent relationship sets

Lines link attributes to entity sets and link entity sets to relationships sets

Example 1

Figure 125 shows a very simple E-R diagram with three entity sets, their attributes and the relationship between the entity sets.

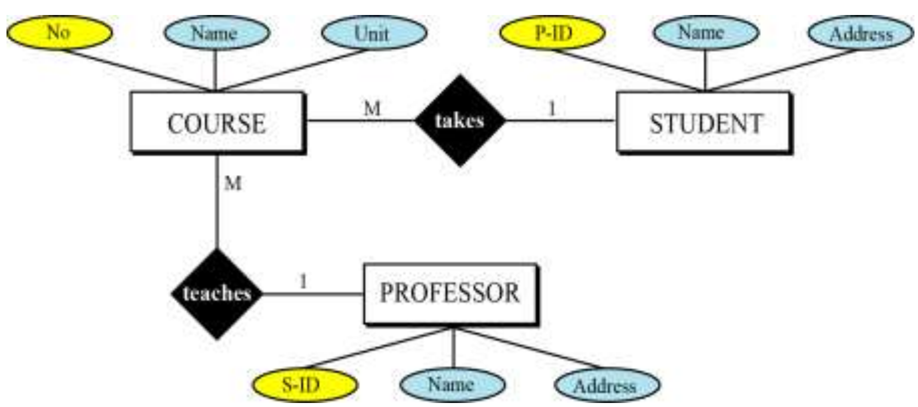

Fig 125 Entities, attributes and relationships in an E-R diagram

From E-R diagrams to relations

After the E-R diagram has been finalized, relations (tables) in the relational database can be created.

Relations for entity sets

For each entity set in the E-R diagram, we create a relation (table) in which there are *n* columns related to the *n* attributes defined for that set.

Example 2

We can have three relations (tables), one for each entity set defined in Figure 127, as shown in Figure 126.

COURSE

No	Name	Unit
⋮	⋮	⋮

STUDENT

S-ID	Name	Address
⋮	⋮	⋮

PROFESSOR

P-ID	Name	Address
⋮	⋮	⋮

Fig 126 Relations for entity set

Relations for relationship sets

For each relationship set in the E-R diagram, we create a relation (table). This relation has one column for the key of each entity set involved in this relationship and also one column for each attribute of the relationship itself if the relationship has attributes (not in our case).

Example 3

There are two relationship sets in Figure 16, teaches and takes, each connected to two entity sets. The relations for these relationship sets are added to the previous relations for the entity set and shown in Figure 127.

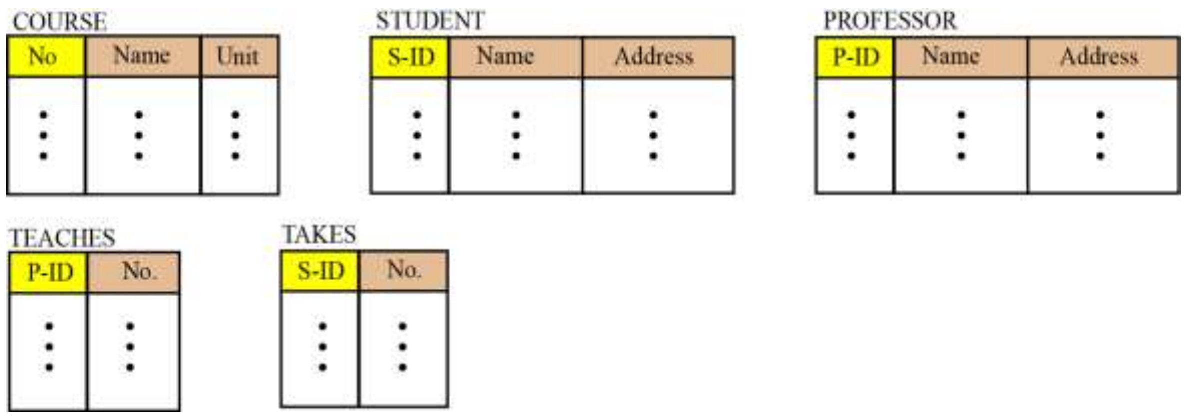

Fig 127 Relations for E-R diagram in Figure 16

Normalization

Normalization is the process by which a given set of relations are transformed to a new set of relations with a more solid structure. Normalization is needed to allow any relation in the database to be represented, to allow a language like SQL to use powerful retrieval operations composed of atomic operations, to remove anomalies in insertion, deletion, and updating, and reduce the need for restructuring the database as new data types are added.

The normalization process defines a set of hierarchical normal forms (NFs). Several normal forms have been proposed, including 1NF, 2NF, 3NF, BCNF (Boyce-Codd Normal Form), 4NF, PJNF (Projection/Joint Normal Form), 5NF and so on.

First normal form (1NF)

When we transform entities or relationships into tabular relations, there may be some relations in whom there are more values in the intersection of a row or column.

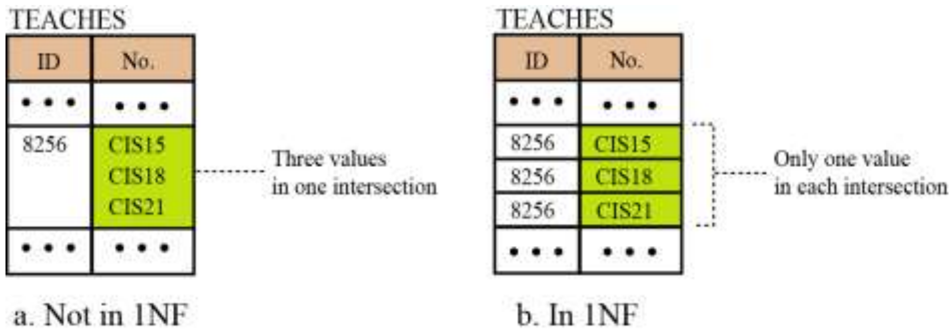

Fig 128 An example of 1NF

Second normal form (2NF)

In each relation we need to have a key (called a primary key) on which all other attributes (column values) need to depend. For example, if the ID of a student is given, it should be possible to find the student's name.

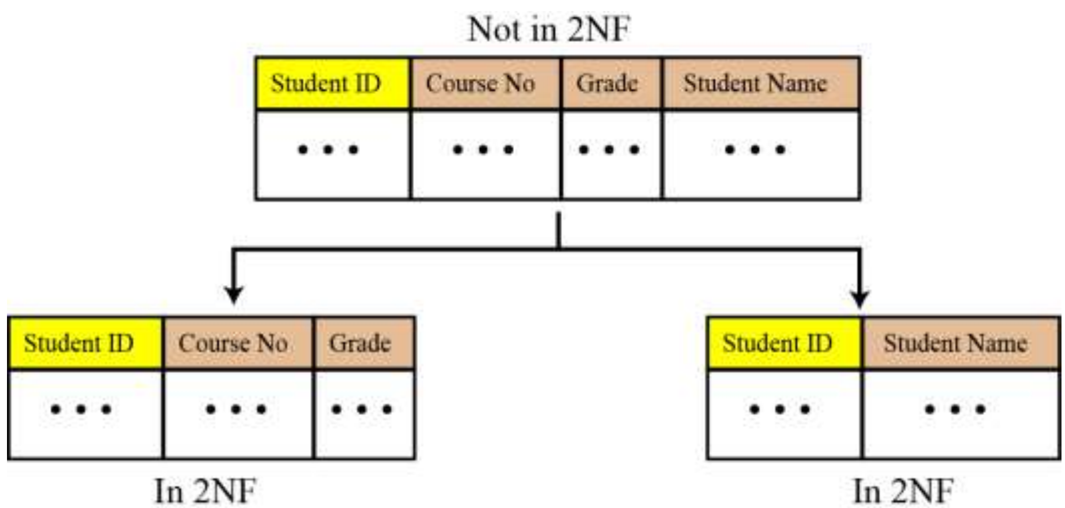

Fig 129 An example of 2NF

Other normal forms

Other normal forms use more complicated dependencies among attributes. We leave these dependencies to books dedicated to the discussion of database topics.

Other Database Models

The relational database is not the only database model in use today. Two other common models are **distributed databases** and **object-oriented databases**. We briefly discuss these here.

Distributed databases

The distributed database model is not a new model, but is based on the relational model. However, the data is stored on several computers that communicate through the Internet or a private wide area network. Each computer (or site) maintains either part of the database or the whole database.

Fragmented distributed databases

In a fragmented distributed database, data is localized—locally used data is stored at the corresponding site. However, this does not mean that a site cannot access data stored at another site. Access is mostly local, but occasionally global.

Replicated distributed databases

In a replicated distributed database, each site holds an exact replica of another site. Any modification to data stored in one site is repeated exactly at every site. The reason for having such a database is security. If the system at one site fails, users at the site can access data at another site.

Object-oriented databases

An object-oriented database tries to keep the advantages of the relational model and at the same time allows applications to access structured data. In an object-oriented database, objects and their relations are defined. In addition, each object can have attributes that can be expressed as fields.

XML

The query language normally used for objected-oriented databases is XML (Extensible Markup Language). XML was originally designed to add markup information to text documents, but it has also found its application as a query language in databases. XML can represent data with nested structures.

Overview:

Open system interconnection (OSI) model

- The physical layer
- The data link layer
- The network layer
- The transport layer
- The session layer
- The presentation layer
- The application layer

Manufacturing automation protocol and technical office protocol

Basic database terminology

- Database management system
- Database system
- Data model
- Transaction
- Schema
- Data definition language
- Data manipulation language
- Applications program
- Host language
- Database administrator

The architecture of a database system

- Internal schema
- External schema
- Conceptual schema

Data modeling and data associations

Data modeling is carried out by using a data modeling method and one of a number of graphic representations to depict data groupings and the relationship between groupings.

Data modeling diagram – Entity-Relationship diagram

Data associations

- One-to-One
- One-to-Many
- Many-to-One
- Many-to-Many

Relational databases

The terms illustrated are relation, tuple, attribute, domain, primary key and foreign key.

Database operators

- Union
- Intersection
- Difference
- Product
- Project
- Select
- Join
- Divide