\– Flexible Manufacturing System

A flexible manufacturing system (FMS) is a production method that is designed to easily adapt to changes in the type and quantity of the product being manufactured. Machines and computerized systems can be configured to manufacture a variety of parts and handle changing levels of production. A flexible manufacturing system (FMS) can improve efficiency and thus lower a company's production cost. Flexible manufacturing also can be a key component of a make-to-order strategy that allows customers to customize the products they want. Such flexibility can come with higher upfront costs. Purchasing and installing the specialized equipment that allows for such customization may be costly compared with more traditional systems. A flexible manufacturing system is group of processing stations interconnected by means of an automated material handling and storage systems, and controlled by an integrated computer system.

Thus, a **Flexible Manufacturing System** (FMS) consists of several machine tools along with part and tool handling devices such as robots, arranged so that it can handle any family of parts for which it has been designed and developed.

Different FMSs levels are:

- *Flexible Manufacturing Module* (FMM). Example : a NC machine, a pallet changer and a part buffer;
- *Flexible Manufacturing (Assembly) Cell* (F(M/A)C). Example : Four FMMs and an AGV(automated guided vehicle);
- *Flexible Manufacturing Group* (FMG). Example : Two FMCs, a FMM and two AGVs which will transport parts from a Part Loading area, through machines, to a Part Unloading Area;
- *Flexible Production Systems* (FPS). Example : A FMG and a FAC, two AGVs, an Automated Tool Storage, and an Automated Part/assembly Storage;
- *Flexible Manufacturing Line* (FML). Example : multiple stations in a line layout and AGVs.

Advantages and disadvantages of FMSs implementation

Advantages:

- Faster, lower- cost changes from one part to another which will improve capital utilization
- Lower direct labor cost, due to the reduction in number of workers
- Reduced inventory, due to the planning and programming precision
- Consistent and better quality, due to the automated control
- Lower cost/unit of output, due to the greater productivity using the same number of workers
- Savings from the indirect labor, from reduced errors, rework, repairs and rejects

Disadvantages:

- Limited ability to adapt to changes in product or product mix (ex. machines are of limited capacity and the tooling necessary for products, even of the same family, is not always feasible in a given FMS)
- Substantial pre-planning activity
- Expensive, costing millions of dollars
- Technological problems of exact component positioning and precise timing necessary to process a component
- Sophisticated manufacturing systems

1.1 Flexibility And Its Types

The three capabilities that a manufacturing system must process in order to the flexible

- The ability to identify and distinguish among the different incoming part or product styles processed by the system.
- Quick changeover of operating instructions.
- Quick changeover of physical setup. Flexibility is an attribute that applies to both manual and automated systems. In manual systems the human workers are often the enables of the systems flexibility.

Types of flexibility;

The flexibility allows a mixed model manufacturing system to cope with level of variation in part or product style without interruptions in production for changeover between models. It is generally a desirable feature of a manufacturing system. The term flexible manufacturing system, or FMS, refers to a highly automated GT machine cell, consisting of a group of computer numerical control (CNC) machine tools and supporting workstations, interconnected by an automated material handling and storage system, and all controlled by a distributed computer system. The reason, the FMS is called flexible, is that it is capable of processing a variety of different part styles simultaneously with the

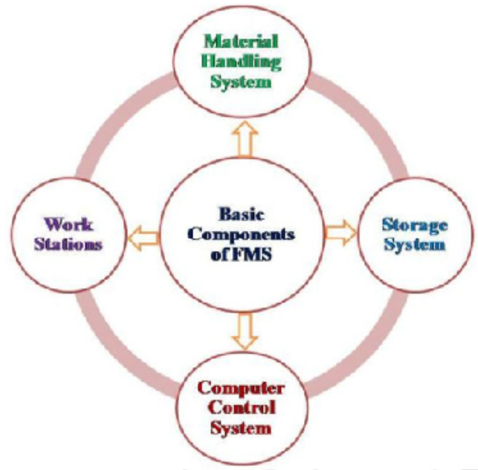
quick tooling and instruction changeovers. Also, quantities of productions can be adjusted easily to changing demand patterns.
The feature of flexibility is broadly classified in to following ways

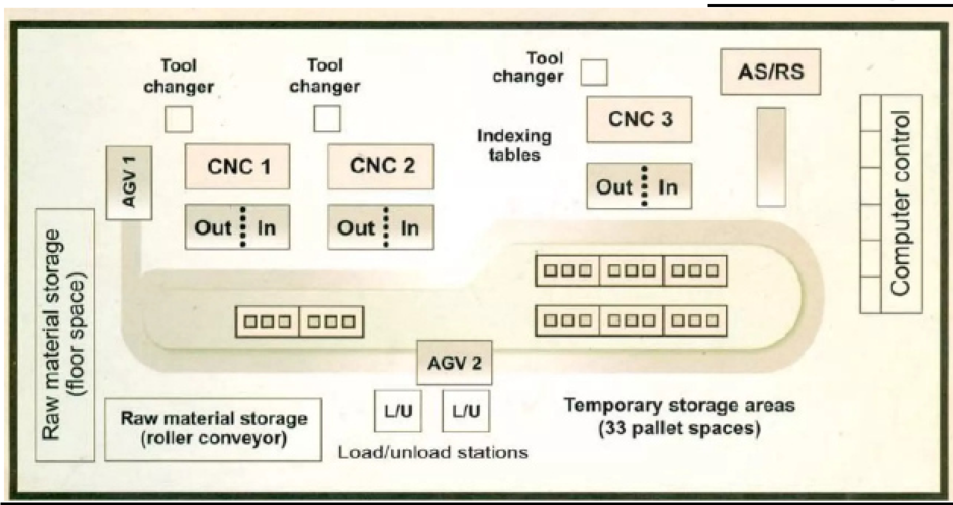
- Machine flexibility
- Production flexibility
- Mix Flexibility.
- Product Flexibility
- Route flexibility
- Volume flexibility
- Expansion Flexibility.

Machine Flexibility. It is the capability to adapt a given machine in the system to a wide range of production operations and part styles. The greater the range of operations and part styles the greater will be the machine flexibility.
The various factors on which machine flexibility depends are: Setup or changeover time• Ease with which part-programs can be downloaded to machines•Tool storage capacity of machines Skill and versatility of workers in the systems
Production Flexibility. It is the range of part styles that can be produced on the systems. The range of part styles that can be produced by a manufacturing system at moderate cost and time is determined by the process envelope. It depends on following factors: Machine flexibility of individual stations• Range of machine flexibilities of all stations in the system.
Mix Flexibility. It is defined as the ability to change the product mix while maintaining the same total production quantity that is, producing the same parts only in different proportions. It is also known as process flexibility. Mix flexibility provides protection against market variability by accommodating changes in product mix due to the use of shared resources. However, high mix variations may result in requirements for a greater number of tools, fixtures, and other resources. Mixed flexibility depends on factors such as: Similarity of parts in the mix• Machine flexibility• Relative work content times of parts produced
*Product Flexibility.*It refers to ability to change over to a new set of products economically and quickly in response to the changing market requirements. The change over time includes the time for designing, planning, tooling, and fixturing of new products introduced in the manufacturing line-up. It depends upon following factors: Relatedness of new part design with the existing part family• Off-line part program preparation• Machine flexibility
*Routing Flexibility.*It can define as capacity to produce parts on alternative workstation in case of equipment breakdowns, tool failure, and other interruptions at any particular station. It helps in increasing throughput, in the presence of external changes such as product mix, engineering changes, ornew product introductions. Following are the factors which decides routing flexibility: Similarity of parts in the mix• Similarity of workstations• Common tooling
*Volume Flexibility.*It is the ability of the system to vary the production volumes of different products to accommodate changes in demand while remaining profitable. It can also be termed as capacity flexibility. Factors affecting the volume flexibility are: Level of manual labor performing production• Amount invested in capital equipment
*Expansion Flexibility.*It is defined as the ease with which the system can be expanded to foster total production volume. Expansion flexibility depends on following factors: Cost incurred in adding new workstations and trained workers• Easiness in expansion of layout• Type of part handling system used
Since flexibility is inversely proportional to the sensitivity to change, a measure of flexibility must quantify the term “penalty of change (POC)”, which is defined as follows:
POC = penalty x probability
Here, penalty is equal to the amount upto which the system is penalized for changes made against the system constraints, with the given probability. Lower the value of POC obtained, higher will be the flexibility of the system.

1.2 Components of FMS systems; The basic components of an FMS are: workstations, material handling and storage systems, computer control system, and the personnel that manage and operate the system.

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





1.2.1 Workstations The first element in the FMS is work stations. The processing or assembly equipment used in an FMS depends on the type of work accomplished by the system. In a system designed for machining operations, the principle types of processing station are CNC machine tools. However, the FMS concept is also applicable to various other processes as well. Following are the types of workstations typically found in an FMS.; it may,

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

Load/Unload Stations. The load/unload station is the physical interface between the FMS and the rest of the factory. Raw work-parts enter the system at this point, and finished parts exit the system from here. Loading and unloading can be accomplished either manually or by automated handling systems. Manual loading and unloading is prevalent in most FMSs today. The load/unload station should be ergonomically designed to permit convenient and safe movement of work parts. For parts that are too heavy to lift by the operator, mechanized cranes and other handling devices are installed to assist the operator. A certain level of cleanliness must be maintained at the workplace. and air hoses or other washing facilities are often required to flush away chips and ensure clean mounting and locating points. The station is often raised slightly above floor level using an open-grid platform to permit chips and cutting fluid to drop through the openings for subsequent recycling or disposal The load/unload station should include a data entry unit and monitor for communication between the operator and the computer system. Instructions must be given to the operator regarding which part to load onto the next pallet to adhere to the production schedule. In cases when different pallets are required for different parts, the correct pallet must be supplied to the station. In cases where modular fixturing is used, the correct fixture must be specified. and the required components and tools must be available at the workstation to build it. 'When the part loading procedure has been completed.the handling system must proceed to launch the pallet into the system; however, the handling system must be prevented from moving the pallet while the operator is still working. All of these circumstances require communication between the computer system and the operator at the load/unload station

Machining Stations. The most common applications of FMSs arc machining operations, The workstations used in these systems are therefore predominantly CNC machine tools. Most common is the CNC machining center in particular. the horizontal rnachining center. CNC machining centers possess features that make them compatible with the FMS, including automatic tool changing and tool storage, use of palletized work-parts, CNC, and capacity for distributed numerical control (DNC), Machining centers can be ordered with automatic pallet changers that can be readily interfaced with the FMS part handling system. Machining centers are generally used for non-rotational parts. For rotational parts, turning centers are used; and for parts that are mostly rotational hut require multi-tooth rotational cutters (milling and drilling), mi11·turn centers can be used. In some machining systems, the types of operations performed are concentrated in a certain category, such as milling or turning. For milling, special milling machine modules can be used to achieve higher production levels than a machining center is capable of. The milling module can be vertical spindle, horizontal spindle, or multiple spindle. For turning operations. Special turning modules can be designed for the FMS, In conventional turning, the work-piece IS rotated against a tool that is held in the machine and fed in a direction parallel to the axis of work rotation. Parts made on most FMSs are usually non-rotational: however, they may require some turning in their process sequence. For these cases, the parts are held in a pallet fixture throughout processing on the FMS, and a turning module is designed to rotate the single point tool around the work.

Other Processing Stations. The FMS concept has been applied to other processing operations in addition to machining. One such application is sheet metal fabrication processes. The processing workstations consist of press-working operations, such as punching, shearing, and certain bending and forming processes. Also, flexible systems are being developed to automate the forging process. Forging is traditionally a very labor-intensive operation. The workstations in the system consist principally of a heating furnace, a forging press. and a trimming station.

Assembly. Some FMSs are designed to perform assembly operations. Flexible automated assembly systems are being developed to replace manual labor in the assembly of products typically made in batches. Industrial robots are often used as the automated workstations in these flexible assembly systems. They can be programmed to perform tasks with variations in sequence and motion pattern to accommodate the different product styles assembled in the system. Other examples of flexible assembly workstations are the programmable component placement machines widely used in electronics assembly.

Other Stations and Equipment. Inspection can be incorporated into an FMS, cither by including, an inspection operation at a processing workstation or by including a station specifically designed for inspection. Coordinate measuring machines, special inspection probes that can be used in a machine tool spindle, and machine vision are three possible technologies for performing inspection on an FMS. Inspection has been found to be particularly important in flexible assembly systems to ensure that components have been properly added at the workstations. In addition to the above, other operations and functions are often accomplished on an FMS. These include stations for cleaning parts and/or pallet fixtures. Central coolant delivery systems for the entire FMS, and centralized chip removal systems often installed below floor level

1.2.2. Material handling and storage systems

The second major component of an FMS is its material handling and storage system. In this subsection, we discuss the functions of the handling system, material handling equipment typically used in an FMS, and types of FMS layout.

Functions of the Handling and storage System.

- *Random, independent movement of work-parts between stations:* This means that parts must be capable of moving from anyone machine in the system to any other machine. to provide various routing alternatives for the different parts and to make machine substitutions when certain stations are busy.
- *Handle a variety of work part configurations:* For prismatic parts, this is usually accomplished by using modular pallet fixtures in the handling system. The fixture is located on the top face of the pallet and is designed to accommodate different part configurations by means of common components, quick change features, and other devices that permit a rapid buildup of the fixture for a given part. The base of the pallet is designed for the material handling system. For rotational parts, industrial robots are often used to load and unload the turning machines and to move parts between stations.

- *Temporary storage:* The number of parts in the FMS will typically exceed the number of parts actually being processed at any moment. Thus, each station has a small queue of parts waiting to be processed. which helps to increase machine utilization.
- *Convenient access for loading and unloading work part control's*: The handling system must include locations for load/unload stations.
- *Compatible with computer:* The handling system must be capable of being controlled directly by the computer system to direct it to the various workstations, load/unload stations, and storage areas

The material handling is classified into two types they are,

- *Primary handling system* - establishes the basic layout of the FMS and is responsible for moving work parts between stations in the system. The primary handling system is sometimes supported by an automated storage system. The FMS is integrated with an automated storage/retrieval system (AS/RS), and the S/R machine serves the work handling function for the workstations as well as delivering parts to and from the storage racks
- *Secondary handling system:* The secondary handling system consists of transfer devices, automatic pallet changers. and similar mechanisms located at the workstations in the FMS. The function of the secondary handling system is to transfer work from the primary system to the machine tool or other processing station and to position the parts with sufficient accuracy and repeatability to perform the processing or assembly operation. Other purposes served by the secondary handling system include: (1) reorientation of the work-part if necessary to present the surface that is to be processed and (2) buffer storage of parts to minimize work change time and maximize station utilization. In some FMS installations, the positioning and requirements at the individual workstations are satisfied by the primary work handling system. In these cases, the secondary handling system is not included,

The types of material handling equipment typically utilized for FMS layouts are summarized in Table.

Layout Configuration	*Typical Material Handling System (Chapter or Section)*
In-line layout	In-line transfer system (Section 18.1.2) Conveyor system (Section 10.4) Rail guided vehicle system (Section 10.3)
Loop layout	Conveyor system (Section 10.4) In-floor towline carts (Section 10.4)
Ladder layout	Conveyor system (Section 10.4) Automated guided vehicle system (Section 10.2) Rail guided vehicle system (Section 10.3)
Open field layout	Automated guided vehicle system (Section 10.2) In-floor towline carts (Section 10.4)
Robot-centered layout	Industrial robot (Chapter 7)

***1.2.3. Computer control system*:** The FMS includes a distributed computer system that is interfaced to the workstations, material handling system, and other hardware components. A typical FMS computer system consists of a central computer and microcomputers controlling the individual machines and other components. The central computer coordinates the activities of the components to achieve smooth overall operation of the system.

1.2.3.1 Functions performed by FMS computer control system can be grouped in following categories:

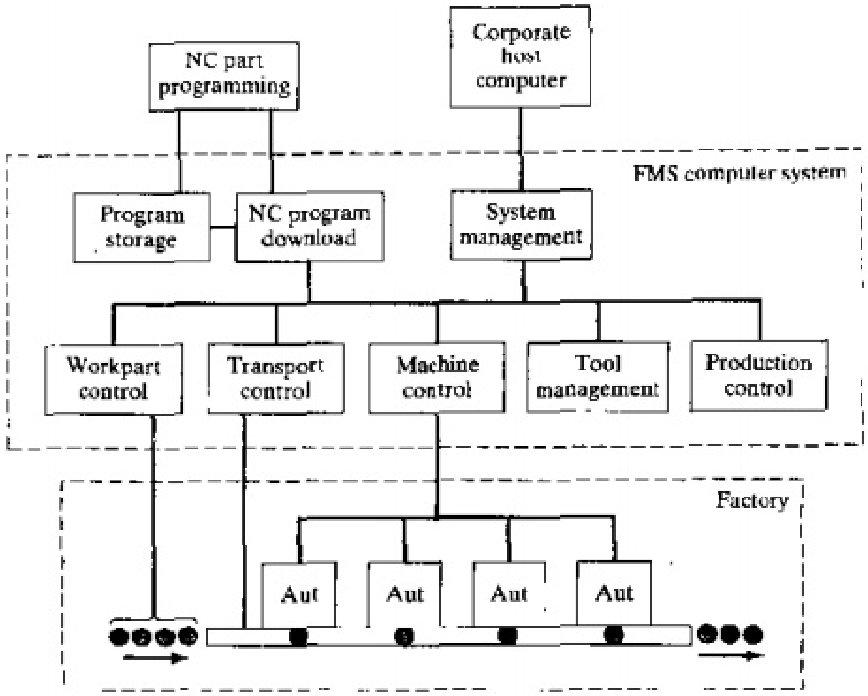
- Workstation control
- Distribution of control instructions to workstations
- Production control
- Traffic control
- Shuttle control
- Work piece monitoring
- Tool control
- Performance monitoring and reporting
- Diagnostics
- Human Resources

- **Workstation control:** In a fully automated FMS, the individual processing or assembly stations generally operate under some form of computer control. For a machining system, CNC is used to control the individual machine tools.

- **Distribution of control instructions to workstations:** Some form of central intelligence is also required to coordinate the processing at individual stations. In a machining FMS, part programs must be downloaded to machines, and DNC is used for this purpose, The DNC system stores the programs, allows submission of new programs and editing of existing programs as needed, and performs other DNC functions
- **Production control :** The part mix and rate at which the various parts are launched into the system must be managed. Input data required for production control includes desired daily production rates per part. numbers of raw work-parts available, and number of applicable pallets.' The production control function is accomplished by routing an applicable pallet 10 the load/unload area and providing instructions to the operator for loading the desired work-part.
- **Traffic control :** This refers to the management of the primary material handling system that moves workparts between stations. Traffic control is accomplished by actuating switches at branches and merging points. stopping parts at machine transfer location & moving pallets to load/unload stations.
- **Shuttle control :** This control function is concerned with the operation and control of the secondary handling system at each workstation. Each shuttle must be coordinated with the primary handling system and synchronized with the operation of the machine tool it serves,
- **Work-piece monitoring:** The computer must monitor the status of each cart and/or pallet in the primary and secondary handling systems as well as the status of each of the various workpiece types.
- **Tool control :** In a machining system, cutting tools are required. Tool control is concerned with managing two aspects of the cutting tools: Tool location : This involves keeping track of the cutting tools at each workstation, If one or mere tools required to process a particular workpiece is not present at the station that is specified in the part's routing, the tool control subsystem takes one or both of the following actions: (a) determines whether an alternative workstation that has the required tool is available and/or (b) notifies the opera tor responsible for tooling in the system that the tool storage unit at the station must be loaded with the required cutter(s). Tool life monitoring. In this aspect of tool control, a tool life isspecif.ied to the computer for each cutting tool in the FMS. A record of the machining time usage i••maintained for each of the tools, and when the cumulative machining time reaches the specified life of the tool, the operator is notified that a tool replacement is needed.
- **Performance monitoring and reporting**. The computer control system is programmed to collect data on the operation and performance of the FMS. This data is periodically summarized, and reports are prepared for management on system performance. Some of the important reports that indicate FMS performance are listed in Table.

Type of Report	*Description*
Availability	Availability is a reliability measure. This report summarizes the uptime proportion of the workstations. Details such as reasons for downtime are included to identify recurring problem areas.
Utilization	This report summarizes the utilization of each workstation in the system as well as the average utilization of the FMS for specified periods (days, weeks, months).
Production performance	This report summarizes data on daily and weekly quantities of different parts produced by the FMS. The reports compare the actual quantities against the production schedule.
Tooling	Tooling reports provide information on various aspects of tool control, such as a listing of tools at each workstation and tool life status.
Status	The status report provides an instantaneous "snapshot" of the present condition of the FMS. Line supervision can request this report at any time to learn the current status of system operating parameters such as workstation utilization, availability (reliability), cumulative piece counts, pallets, and tooling.

- **Diagnostics :** This function is available to a greater or lesser degree on many manufacturing systems to indicate the probable source of the problem when a malfunction occurs. It can also be used to plan preventive maintenance iu the system and to identify Impending failures. The purpose of the diagnostics function is to reduce breakdowns and downtime and increase availability of the system.

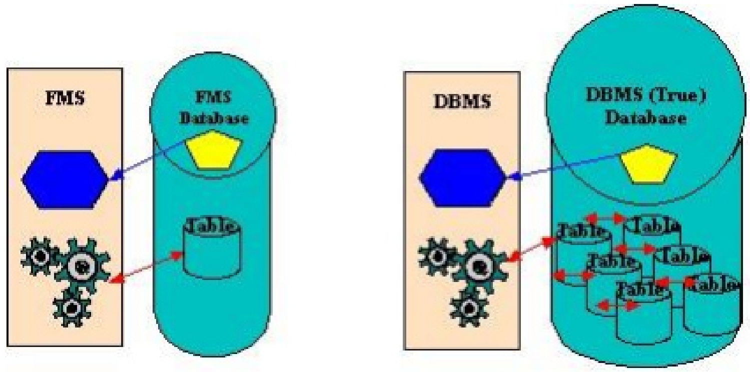


The modular structure of the FMS application software for system control is illustrated in Figure 1.8. It should be noted that an FMS possesses the characteristic architecture or a DNC system. As in other DNC systems. Two-way communication is used. Data and commands an: sent from the central computer to the individual machines and other hardware components, and data on execution and performance are transmitted from the components hack up to the central computer.

<u>1.2.3.2 TYPES OF FMS SOFTWARE</u>: Software for FMS can be divided into three broad categories: design, extrinsic functions, and intrinsic functions. The design software is used to identify the major components of the system concept, to evaluate design sensitivities and trade-offs for a given concept, and to demonstrate that the system is capable of meeting the planned production requirements. Some of the extrinsic and intrinsic functions that support the FMS. Software for the extrinsic functions is used to plan and control the functions that take place outside the physical boundaries of the FMS. Software for the intrinsic functions is used to load and control the components within the physical boundaries of the FMS.

- *<u>MANUFACTURING DATA SYSTEMS</u>* Product life cycles are getting shorter and customers want variations. Production system flexibility is the key factor and systems are getting more complex
  - ✓ Time-to-market is critical; this means faster manufacturing system designs and faster ramp-up processes. Production simulation and virtual manufacturing tools are valuable in shortening the design steps, Figure 2. Virtual production system speeds also the production ramp-up, because the operators know better the planned system and can study the parameters and features of the new system before anything is installed to the factory floor.
  - ✓ Manufacturing system design involves a number of interrelated subjects, e.g., tooling strategy, materialhandling system, system size, process flow configuration, flexibility needed for future engineering changes or capacity adjustment and space strategy. Manufacturing process design is critical area. Material handling is another area that deserves intensive study. Although this function does not add value to the product, it facilitates production process flow. The right kind of parts should be delivered in the right quantity to the right place at the right time in the right manner.
  - ✓ Time-to-customer, punctuality and throughput time, are important competition factors in make-toorder manufacturing. The products are usually complex systems consisting of components, which are manufactured in different factories, sometimes in different countries. Manufacturing is performed on the basis of customer orders and each order can be unique. Naturally, the throughput times of the components may differ from one another. The production systems have to be flexible and able to react to changing production capacity requirements. All this makes planning and management of production networks a complex task.
- *<u>FMS DATA BASE SYSTEMS</u>* A Database Management System (DMS) is a combination of computer software, hardware, and information designed to electronically manipulate data via computer processing. Two types of database management systems are DBMS's and FMS's. In

simple terms, a File Management System (FMS) is a Database Management System that allows access to single files or tables at a time. FMS's accommodate flat files that have no relation to other files. The FMS was the predecessor for the Database Management System (DBMS), which allows access to multiple files or tables at a time (see Figure 1 below).



1.2.3.3 THE FMS DATA FILE TRAFFIC consists of large files and short messages, and mostly come from nodes, devices and instruments. The message size ranges between a few bytes to several hundreds of bytes. Executive software and other data, for example, are files with a large size, while messages for machining data, instrument to instrument communications, status monitoring, and data reporting are transmitted in small size.

There is also some variation on response time. Large program files from a main computer usually take about 60 seconds to be down loaded into each instrument or node at the beginning of FMS operation. Messages for instrument data need to be sent in a periodic time with deterministic time delay. Other types of messages used for emergency reporting are quite short in size and must be transmitted and received with an almost instantaneous response.

The demands for **reliable FMS protocol** that support all the FMS data characteristics are now urgent. The existing IEEE standard protocols do not fully satisfy the real time communication requirements in this environment. The delay of CSMA/CD is unbounded as the number of nodes increases due to the message collisions. Token Bus has a deterministic message delay, but it does not support prioritized access scheme which is needed in **FMS communications**. Token Ring provides prioritized access and has a low message delay, however, its data transmission is unreliable. A single node failure which may occur quite often in FMS causes transmission errors of passing message in that node. In addition, the topology of Token Ring results in high wiring installation and cost.

A design of **FMS communication** that supports a real time communication with bounded message delay and reacts promptly to any emergency signal is needed. Because of machine failure and malfunction due to heat, dust, and electromagnetic interference is common, a prioritized mechanism and immediate transmission of emergency messages are needed so that a suitable recovery procedure can be applied. A modification of standard Token Bus to implement a prioritized access scheme was proposed to allow transmission of short and periodic messages with a low delay compared to the one for long messages.

1.2.4 ***Human Resources:*** One additional component in the FMS is human labor. Humans are needed to manage the operations of the FMS. Functions typically performed by humans include: (1) loading raw workparts into the system, (2) unloading finished parts (or assemblies) from the system.(3) changing and setting tools. (4) equipment maintenance and repair, (5) NC part programming in a machining system, (6) programming and operating the computer system, and (7) overall management of the system

1.3 Material Handling Equipments: Materials handling include all movements of materials in a manufacturing situation. It is an art and science involving the moving, packing and storing of substances in any form. Material handling involves the movements of materials, manually or mechanically, in batches or one item at a time within the plant. The movement may be horizontal, vertical or the combination of horizontal and vertical. The overall objectives of materials handling is to reduce production cost.

1.3.1 This general objective can be sub-divided into more specific goals, such as:

- To increase equipment and space utilization.
- To reduce costs
- To increase capacity

- To improve working conditions.
- To improve customer service.

1.3.2 Functions of Materials Handling:

Material handling embraces three functions namely;

- ✓ **Moving**: It includes movement between machines or workstations, between dept., between buildings, loading and unloading of carrier's, as well as much of more handling done at work place.
- ✓ **Storage**: It includes storage of material and tools and supplies between and around all of the above location, including finishing good, warehousing, and the other storage related activities that lie between the producer and consumer.
- ✓ **Selection:** To choose production machinery and assist in plant layout so as to eliminate as far as possible the need of material handling; and To choose most appropriate material handling equipment which is safe and can fulfill material handling requirement at the minimum possible overall cost.
- ✓ **Other functions:** (a) Using the principles of centralization, unit load or cartelization, aim at moving optimum number of pieces in one unit.
  (b) Safe, standard, efficient, effective, appropriate, flexible and proper sized materials handling equipments should be selected.
  (c) To employ mechanical aids in place of manual labour in order to speed up the materials movement.
  (d) To minimize the movement involved in a production operation.
  (e) Changes in sequence of production operations may be suggested in order to minimize backtracking and duplicate handling.
  (f) Handling equipments' arrangement should minimize distance moved by products and at the same time handling equipments should not interfere with the production line.
  (g) To minimize the distances moved, by adopting shortest routes.
  (h) To design containers, packages, drums etc., to economise handling and to reduce damage to the materials in transit.
  (i) To utilize gravity for assisting materials movement wherever possible.
  (j) Materials handling equipments should periodically be resorted to check ups, repairs and maintenance.

1.3.3 Types of Material Handling Equipment

The four main categories of material handling equipment include storage, engineered systems, industrial trucks, and bulk material handling.

1.3.3.1 Storage and Handling Equipment:

- Racks, such as pallet racks, drive-through or drive-in racks, push-back racks, and sliding racks, are a basic but important method of storage, saving floor space while keeping their contents accessible.
- Stacking frames are stackable like blocks, as their name implies. They allow crushable pallets of inventory, such as containers of liquid, to be stacked to save space without damage.
- Shelves, bins, and drawers. Shelves, another basic storage method, are less open than racks. Used with bins and drawers, they're more able to keep smaller and more difficult to manage materials and products stored and organized. Shelving types can include boltless, cantilever, revolving, and tie-down.
- Mezzanines, a type of indoor platform, help to create more floor space in a warehouse or other storage building for offices or more storage. Typical types include modular, movable, rack supported, building supported, and free-standing versions.
- Work assist tooling enables safe and efficient product handling across numerous industries in applications that require the movement of products, enhancing the efficiency of assembly and manufacturing operations.
- Pallet inverters are similar to upender inverters and help heavy items and fully loaded pallets be rotated or repositioned with ease.

IV. Storage Equipment

1. Block stacking (no equipment)
2. Selective pallet rack
3. Drive-in rack
4. Drive-through rack
5. Push-back rack
6. Flow-through rack
7. Sliding rack
8. Cantilever rack
9. Stacking frame
10. Bin shelving
11. Storage drawers
12. Storage carousel
13. Vertical lift module
14. A-frame
15. Automatic storage/ retrieval system

Storage equipment is usually limited to non-automated examples, which are grouped in with engineered systems. Storage equipment is used to hold or buffer materials during "downtimes," or times when they are not being transported. These periods could refer to temporary pauses during long-term transportation or long-term storage designed to allow the buildup of stock. The majority of storage equipment refers to pallets, shelves or racks onto which materials may be stacked in an orderly manner to await transportation or consumption. Many companies have investigated increased efficiency possibilities in storage equipment by designing proprietary packaging that allows materials or products of a certain type to conserve space while in inventory. Equipment used for holding or buffering materials over a period of time. Some storage equipment may include the transport of materials (e.g., the S/R machines of an AS/RS, or storage carousels). If materials are block stacked directly on the floor, then no storage equipment is required. Examples of storage and handling equipment include:

1.3.3.2 Positioning Equipment.

Equipment used to handle material at a single location (e.g., to feed and/or manipulate materials so that are in the correct position for subsequent handling, machining, transport, or storage). Unlike transport equipment, positioning equipment is usually used for handling at a single workplace. Material can also be positioned manually using no equipment.	II. Positioning Equipment 1. Manual (no equipment) 2. Lift/tilt/turn table 3. Dock leveler 4. Ball transfer table 5. Rotary index table 6. Parts feeder 7. Air film device 8. Hoist 9. Balancer 10. Manipulator 11. Industrial robot

1.3.3.3 Engineered Systems for storage and transportation: Engineered systems cover a variety of units that work cohesively to enable storage and transportation. They are often automated. A good example of an engineered system is an Automated Storage and Retrieval System, often abbreviated AS/RS, which is a large automated organizational structure involving racks, aisles and shelves accessible by a "shuttle" system of retrieval. The shuttle system is a mechanized cherry picker that can be used by a worker or can perform fully automated functions to quickly locate a storage item's location and quickly retrieve it for other uses. Transport Equipment. Equipment used to move material from one location to another (e.g., between workplaces, between a loading dock and a storage area, etc.). The major subcategories of transport equipment are conveyors, cranes, and industrial trucks. Material can also be transported manually using no equipment. Other types of engineered systems include:

- Conveyor systems come in a variety of types, depending on what they are meant to transport, including vibrating, overhead, chain, vertical, and apron conveyors.
- Automatic Guided Vehicles (AGV) are independent computer-operated trucks that transport loads along a predetermined path, with sensors and detectors to avoid bumping into anything.

The following general equipment characteristics can be used to describe the functional differences between conveyors, cranes, and industrial trucks (see Table 3):

- *Path*: Fixed—move between two specific points
- Variable—move between a large variety of points
- *Area*: Restricted—move restricted to a limited area
- Unrestricted—unlimited area of movement
- *Move frequency*: Low—low number of moves per period, or intermittent moves
- High—high number of moves per period
- *Adjacent move*: Yes—move is between adjacent activities
- No—move is between activities that are not adjacent

I. Transport Equipment			
A. Conveyors	B. Cranes	C. Industrial Trucks	D. No Equipment
1. Chute conveyor	1. Jib crane	1. Hand truck	1. Manual
2. Wheel conveyor	2. Bridge crane	2. Pallet jack	
3. Roller conveyor	3. Gantry crane	3. Walkie stacker	
4. Chain conveyor	4. Stacker crane	4. Pallet truck	
5. Slat conveyor		5. Platform truck	
6. Flat belt conveyor		6. Counterbalanced lift truck	
7. Magnetic belt conveyor		7. Narrow-aisle straddle truck	
8. Troughed belt conveyor		8. Narrow-aisle reach truck	
9. Bucket conveyor		9. Turret truck	
10. Vibrating conveyor		10. Order picker	
11. Screw conveyor		11. Sideloader	
12. Pneumatic conveyor		12. Tractor-trailer	
13. Vertical conveyor		13. Personnel and burden carrier	
14. Cart-on-track conveyor		14. Automatic guided vehicle	
15. Tow conveyor			
16. Trolley conveyor			
17. Power-and-free conveyor			
18. Monorail			
19. Sortation conveyor			

Table 3. Transport Equipment Characteristics

Path	Fixed			Variable		
Area	Restricted			Restricted		Unrestricted
Frequency	High	Low		High	Low	
Adjacent	—	Yes	No	—	—	—
Equipment Category	*Conveyor*	*Conveyor*	*Industrial Truck/Crane*	*Industrial Truck*	*Crane*	*Industrial Truck*

1.3.3.4 Industrial Material Handling Trucks: Industrial trucks (material handling trucks) refer to the different kinds of transportation items and vehicles used to move materials and products in materials handling. These transportation devices can include small hand-operated trucks, pallet jacks, and various kinds of forklifts. These trucks have a variety of characteristics to make them suitable for different operations. Some trucks have forks, as in a forklift, or a flat surface with which to lift items, while some trucks require a separate piece of equipment for loading. Trucks can also be manual or powered lift and operation can be walk or ride, requiring a user to manually push them or to ride along on the truck. A stack truck can be used to stack items, while a non-stack truck is typically used for transportation and not for loading. There are many types of industrial trucks:

- Hand trucks, one of the most basic pieces of material handling equipment, feature a small platform to set the edge of a heavy object on, and a long handle to use for leverage. Whatever is being moved must be tipped so that it rests on the handle, and is carried at a tilt to its destination.
- Pallet Trucks, also known as pallet jacks, are a type of truck specifically for pallets. They slide into a pallet and lift it up to move it. Pallet trucks come in both manual and electrical types.
- Walkie Stackers transport and lift pallets like a forklift, though they don't include a place for the operator to ride in. They come in both powered or manual versions.
- Platform trucks are hand trucks low to the ground, with a wide platform for transporting goods.
- Order pickers lift the operator several feet above the ground on a platform so they can retrieve or store goods on high shelves.
- Sideloaders, also known as VNA (Very Narrow Aisle) trucks, are meant to fit in narrow warehouse aisles, as they can load objects from different directions. They're also good for long, awkward products that need moving.
- Many types of AGV, or automatic guided vehicles, as discussed above, shuttle products along a route automatically, without human guidance.

1.3.3.5 Unit Load Formation Equipment. Equipment used to restrict materials so that they maintain their integrity when handled a single load during transport and for storage. If materials are self-restraining (e.g., a single part or interlocking parts), then they can be formed into a unit load with no equipment.

Table 4. Unit Load Formation Equipment

1. Self-restraining (no equipment)	10. Bulk load containers
2. Pallets	11. Crates
3. Skids	12. Intermodal containers
4. Slipsheets	13. Strapping/tape/glue
5. Tote pans	14. Shrink-wrap/stretch-wrap
6. Pallet boxes/skid boxes	15. Palletizers
7. Bins/baskets/racks	(a) Manual palletizing
8. Cartons	(b) Robotic pick and place palletizers
9. Bags	(c) Conventional stripper plate palletizers

1.3.3.6 Bulk Material Handling Equipment: Bulk material handling refers to the storing, transportation and control of materials in loose bulk form. These materials can include food, liquid, or minerals, among others. Generally, these pieces of equipment deal with the items in loose form, such as conveyor belts or elevators designed to move large quantities of material, or in packaged form, through the use of drums and hoppers.

- Conveyors, as mentioned above, come in a wide variety of types for different types of bulk material.
- Stackers, which are usually automated, pile bulk material onto stockpiles, moving between two points along rails in a yard.
- Reclaimers are the opposite of stackers, retrieving materials from stockpiles, some using bucket wheels to carry the material while others are scraper or portal style.
- Bucket elevators, also known as grain legs, use buckets attached to a rotating chain or belt to carry material vertically.
- Grain elevators are tall buildings specifically for storing grain. They include equipment to convey the grain to the top of the elevator, where it is sent out for processing.
- Hoppers are funnel-shaped containers that allow material to be poured or dumped from one container to another. Unlike a funnel, though, hoppers can hold material until it's needed, then release it.
- Silos are generally large storage structures for bulk materials, though they don't necessarily include equipment to convey the material to the top of the structure like grain elevators. Different varieties include tower, bunker, and bag silos.
- Elevated lift tables are available in hydraulic, pneumatic, and scissor lift versions, and are designed to slowly lift and lower heavy loads for easier transference to other handling equipment like forklifts. Lift tables are simple devices that can enhance productivity and ensure employee safety when used correctly.

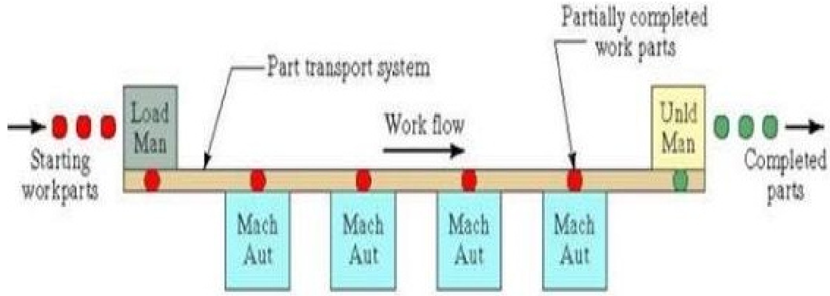
1.3.3.7 Identification and Control Equipment. Equipment used to collect and communicate the information that is used to coordinate the flow of materials within a facility and between a facility and its suppliers and customers. The identification of materials and associated control can be performed manually with no specialized equipment.

V. Identification and Control Equipment
1. Manual (no equipment)
2. Bar codes
3. Radio frequency identification tags
4. Voice recognition
5. Magnetic stripes
6. Machine vision
7. Portable data terminals

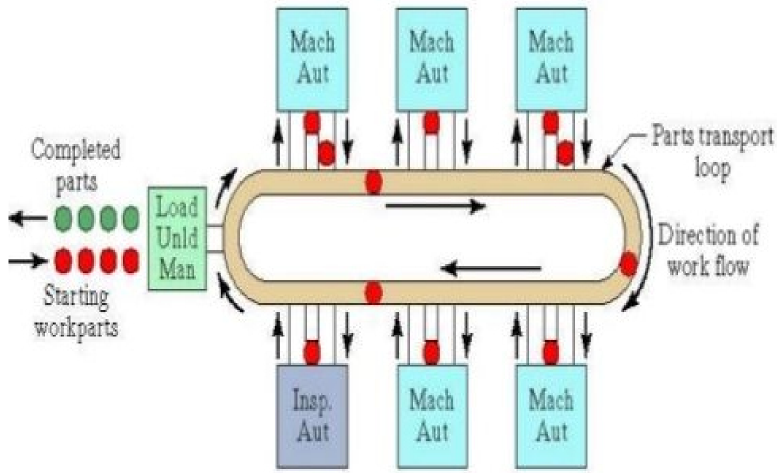
1.4 FMS layout

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

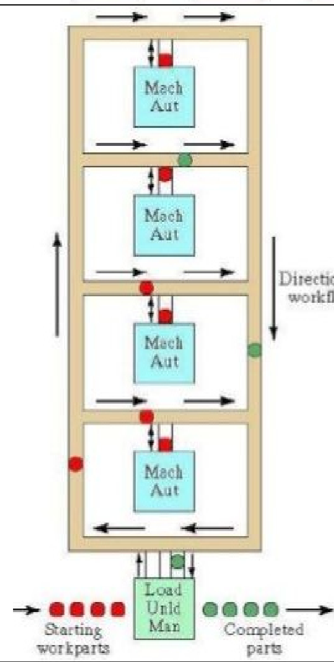
Progressive or Line type : The machines and handling system are arranged in a line in this type of system. It is most appropriate for a system in which the part progress from one workstation to the next in a well-defined sequence with no back flow. The operation of this type of system is very similar to transfer type. Work always flows in unidirectional path as shown in the figure below.



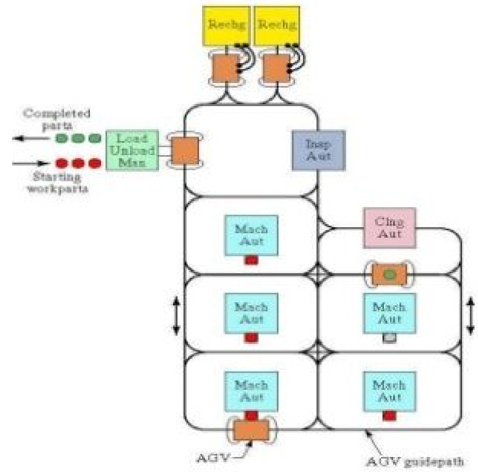
Loop Type : The basic loop configuration is as shown in figure below. The parts usually move in one direction around the loop, with the capability to stop and be transferred to any station. The loading and unloading station are typically located at one end of the loop as shown in the figure below.



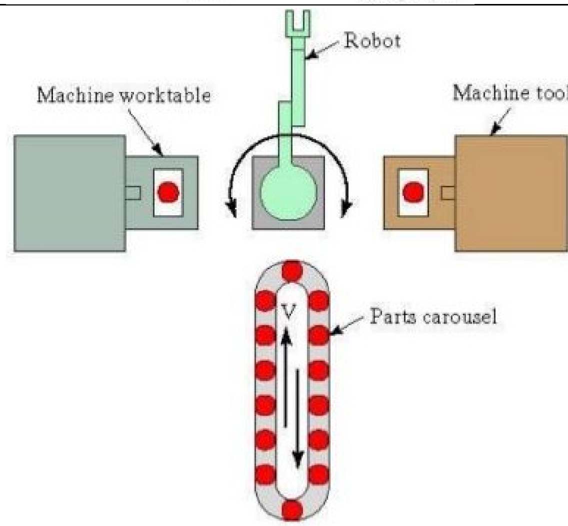
Ladder Type: The configuration is as shown in the figure below. The loading and unloading station is typically located at the same end. The sequence to the operation/transfer of parts from one machine tool to another is in the form of ladder steps as shown in the figure below.



Open Field Type : The configuration of the open field is as shown in the figure. The loading and unloading station is typically located at the same end. The parts will go through all the substations, such as CNC machines, coordinate measuring machines and wash station by thehelp of AGV'sfrom one substation to another.



Robot Centered Type : Robot centered cell is a relatively new form of flexible system in which one or more robots are used as the material handling systems as shown in the figure below. Industrial robots can be equipped with grippers that make them well suited for handling of rotational parts.



Factors Influencing FMS : The various factors influencing the layouts of FMS are:

- Availability of raw material
- Proximity to market
- Transport facilities
- Availability of efficient and cheap labor
- Availability of power, water and fuel
- Atmospheric and climatic condition
- Social and recreation facilities
- Business and economic conditions

<u>1.5 FMS analysis techniques</u> can be classified into:
1) deterministic models,
2) queuing models,
3) discrete event simulation, and
4) other approaches, including heuristics.

<u>Deterministic model</u> Deterministic models are useful in obtaining starting estimates of system performance. We present a deterministic model that is useful in the beginning stages of FMS design to provide rough estimates of system parameters such as production rate, capacity, and utilization. Deterministic models do not permit evaluation of operating characteristics such as the build-up of queues and other dynamics that can impair system performance. Consequently, deterministic models tend to overestimate FMS performance. On the other hand, if actual system performance is much lower than the estimates provided by these models, it may be a sign of either poor system design or poor management of FMS operations.

<u>Queuing Model</u> Queuing models can be used to describe some of the dynamics not accounted for in deterministic approaches These models are based on the mathematical theory of queues. They permit the inclusion of queues, but only in a general way and for relatively simple system configurations. The performance measures that are calculated are usually average values for steady-state operation of the system.

Discrete Event Simulation Model In the later stages of design, discrete event simulation probably offers the most accurate method for modeling the specific aspects of a given flexible manufacturing system. The computer model can be constructed to closely resemble the details of a complex FMS operation. Characteristics such as layout configuration, number of pallets in the system, and production scheduling rules can be incorporated into the FMS simulation model. Indeed, the simulation can be helpful in determining optimum values for these parameters.

1.6 Benefits of flexible manufacturing system

- Large variety of same products Flexible Manufacturing System (FMS) can produce a large variety of the same type (homogeneous) of products.
- Profitable investment The company invests a lot of money (capital) in machines. However, FMS makes optimum use of these machines. Therefore, though costly, FMS is still a profitable investment.
- Requires limited inventory FMS requires limited inventories compared to other production systems.
- Low labour cost In FMS, most of the work is done by automated machines and robots. There is hardly any need of a manual work or some human intervention. Therefore, in FMS, the labour cost becomes very low.
- Flexible system FMS is a very flexible system. This is because it can produce a large variety of similar products. The quantity and design of production can also be changed very quickly.
- Speedy production The products can be produced very quickly because the materials are loaded, unloaded and transferred from one machine to another by robots.
- Large variety of same products. Flexible Manufacturing System (FMS) can produce a large variety of the same type (homogeneous) of products.
- Profitable investment. ...
- Requires limited inventory. ...
- Low labour cost. ...
- Flexible system. ...
- Speedy production.
- Reduced manufacturing cost
- Lower cost per unit produced,
- Greater labor productivity,
- Greater machine efficiency,
- Improved quality,
- Increased system reliability,
- Reduced parts inventories,
- Adaptability to CAD/CAM operations.
- Shorter lead times
- Improved efficiency
- Increase production rate

1.7 Disadvantages

- Initial set-up cost is high,
- Substantial pre-planning
- Requirement of skilled labor
- Complicated system
- Maintenance is complicated

1.8 FMS Applications

Metal-cutting machining

1. Metal forming -forging,
2. plastic injection molding
3. Assembly of parts and/or equipments (Auto)
4. Joining-welding (arc , spot)
5. Sheet metal – press working
6. Surface treatment
7. Inspection
8. Testing