UNIT V

CELLULAR MANUFACTURING AND FLEXIBLE MANUFACTURING SYSTEM (FMS)

GROUP TECHNOLOGY:

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

Role of GT in CAD/CAM

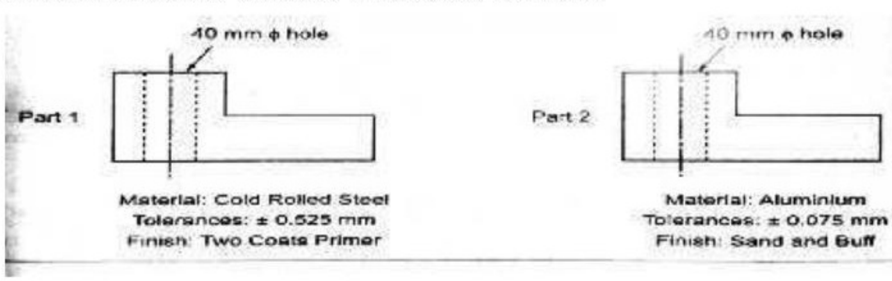
- For closer dimensional tolerances
- More economical in higher accuracy
- Increased variety of materials , by manufacturing needs.
- Lowering scrap rates

Important Elements of CAD/CAM Integration

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

Part Families

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



METHODS FOR PART FAMILY FORMATION

1.Visual inspection

2. part classification & Coding

Methods 3.production flow analysis

Design & Manufacturing Attributes

1.System based on Part Design Attributes

2.System based on Manufacturing Attributes

3.System based on Both Design & Manufacturing Attributes

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

Coding System Structure

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

Types of Basic Code Structures

- . Hierarchical codes

(Mono codes or tree sttructure)

- 2. Attributes codes

  (Poly code or chain tyype structure)

- 3. Decision tree codes (hybrid

  code or mixed codes)

Hierarchical codes

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

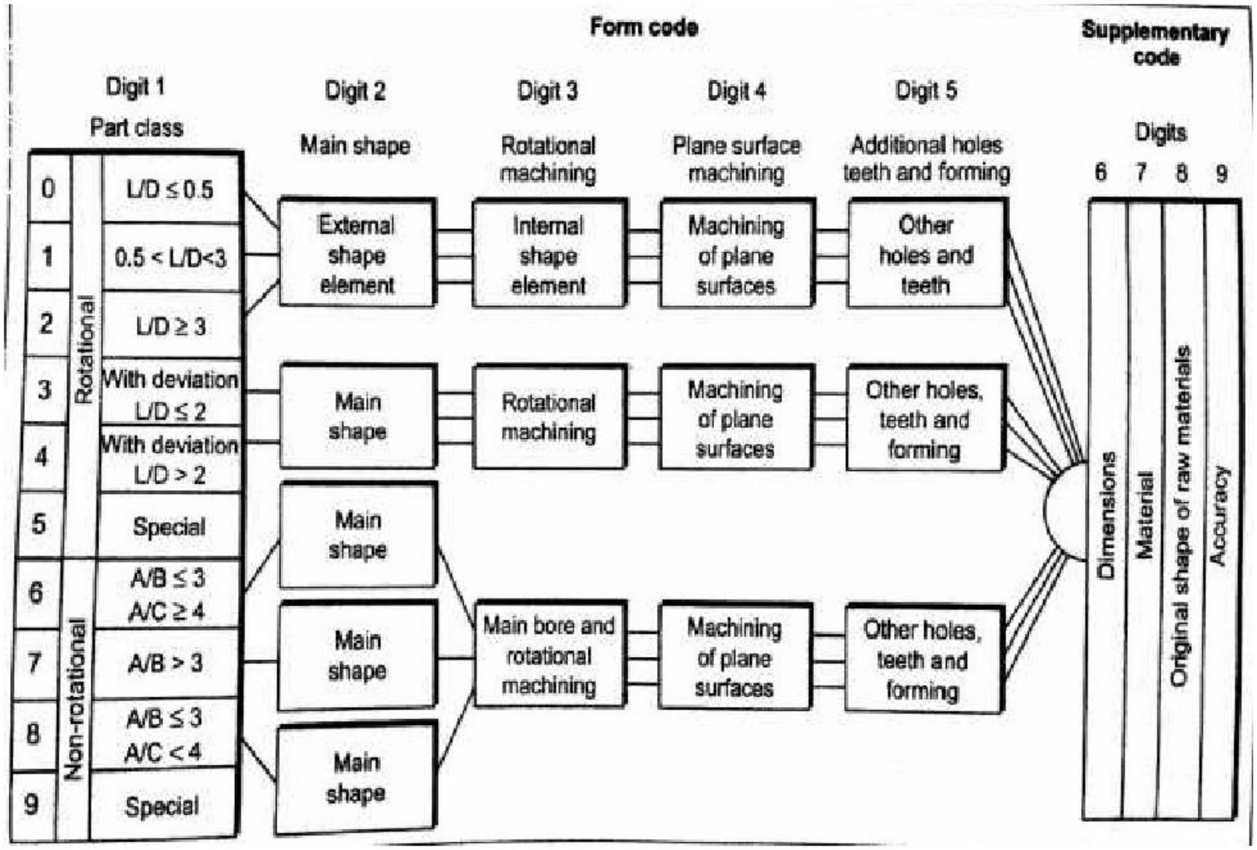
Opitz Classification Systemss

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

12345	6789	ABCD
FORM CODE	SUPPLEMENTARY CODE	SECONDARY CODE

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

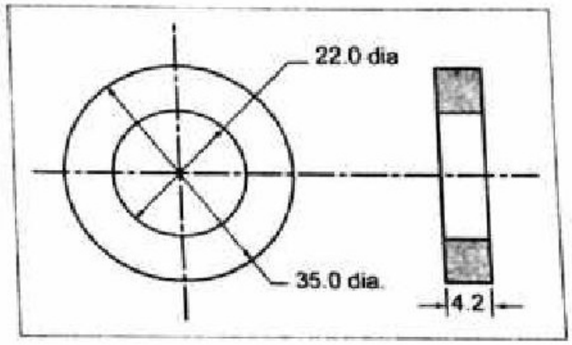
1. Opitz classification system,
2. MICLASS system,
3. DCLASS system,
4. KK-3 system,
5. CODE system,
6. CUTPLAN system,
7. RNC system,
8. Part Analog system,
9. Brisch system,
10. COFORM.



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

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

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



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

$\therefore$ Digit 1 = 0

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

$\therefore$ Digit 2 = 0

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

$\therefore$ Digit 3 = 1

Step 4: Plane surface machining: None.

$\therefore$ Digit 4 = 0

Step 5: Auxiliary holes and gear teeth: None.

$\therefore$ Digit 5 = 0

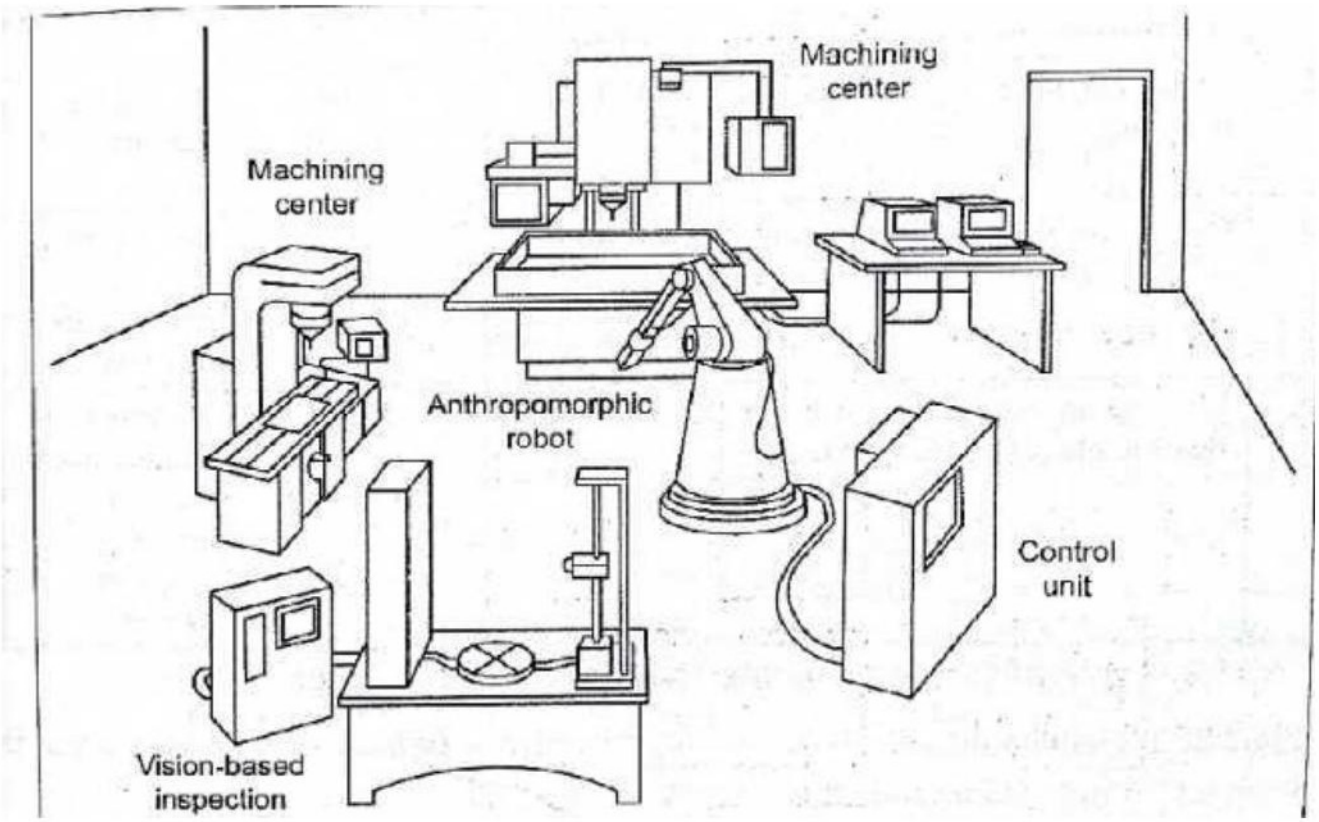
Thus the form code in the Opitz system for the part is **00100** **Ans.**

Cellular Manufacturing

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

Flexible manufacturing cell or flexible manufacturing system

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



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

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

Flexibility and its Types

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

Tests of Flexibility

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

Types of Flexibility

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

Machine flexibility

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

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

Production flexibility

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

Mix (or Process) flexibility

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

Product flexibility

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

Routing flexibility

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

- **Similarity of parts in the mix**
- **Similarity of workstations**
- **Common testing**

Volume (or capacity) flexibility

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

Expansion flexibility

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

Types of FMS

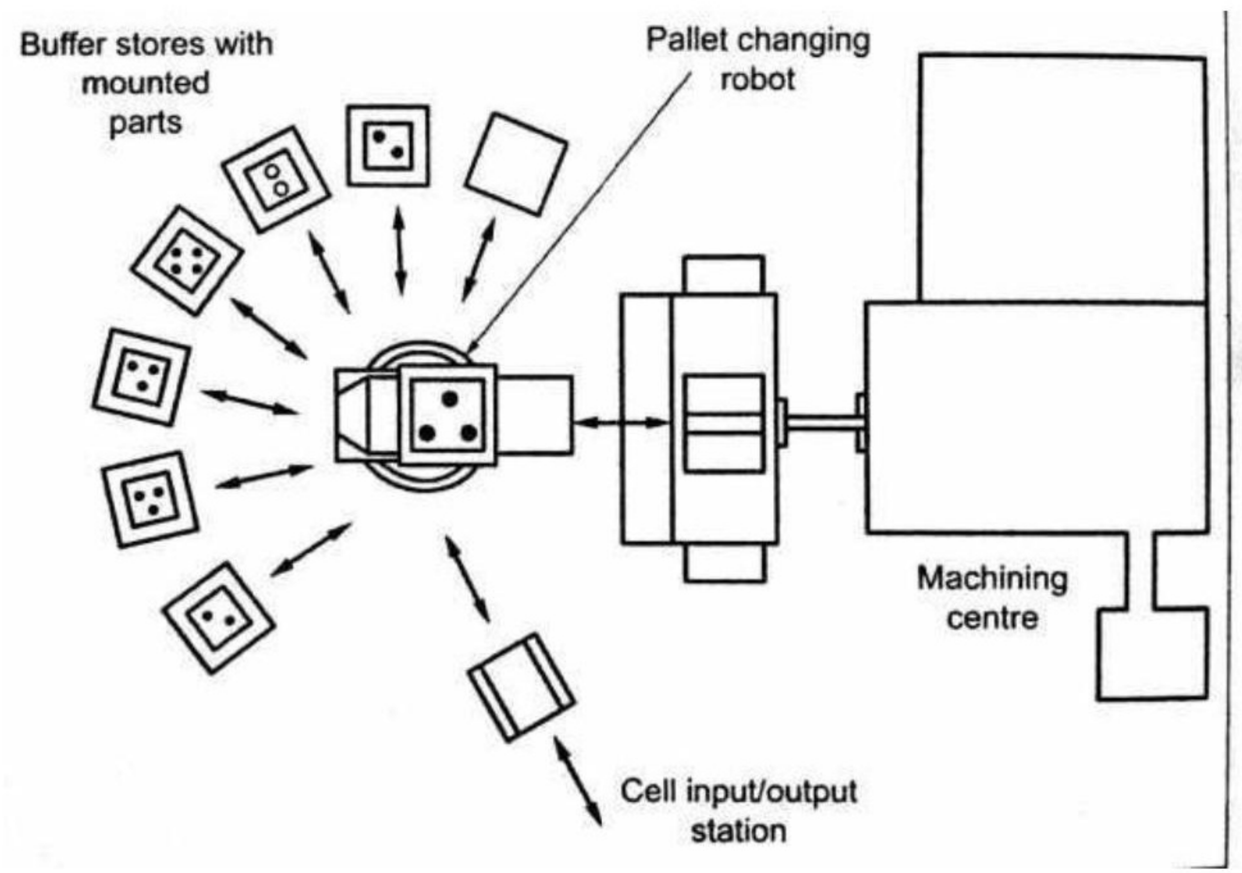
- **Classification based on the kinds of operations they perform**
  - **Processing operation**
  - **Assembly operation**
- **Classification based on the number of machines in the system**
  - **Single machine cell (SMC)**
  - **Flexible machine cell (FMC)**
  - **Flexible manufacturing system (FMS)**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

- Dedicated FMS
- Random order FMS

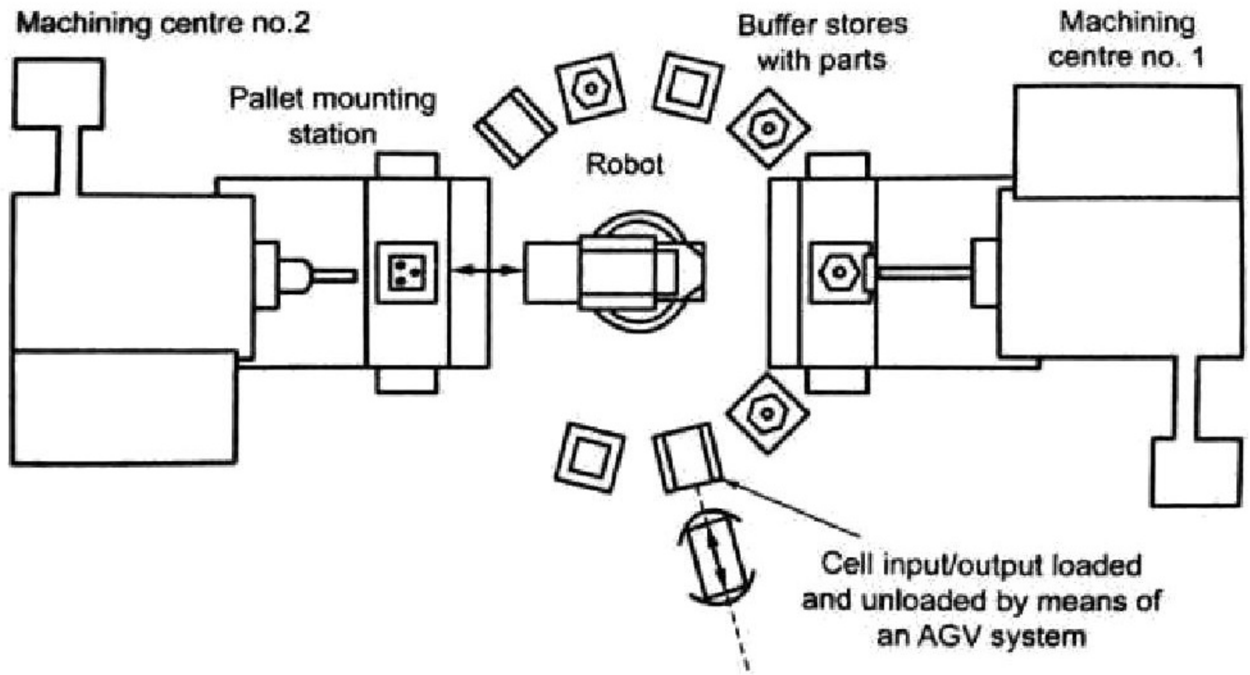
Classification based on the kinds of operations they perform

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

Classification based on the number of machines in the system



Flexible machine cell (FMC)



Functions of a FMS computer control system

Economics of FMS

- **5-20% reduction in personnel**
- **15-30% reduction in engineering design cost**
- **30-60% reduction in overall lead time**
- **30-60% reduction in work-in-process**
- **40-70% gain in overall production**
- **200-300% gain in capital equipment operating time**
- **200-500% gain in product quality**
- **300-500% gain in engineering productivity**

- **Increased machine utilization**
- **Reduced inventory**
- **Reduced manufacturing lead time**

- **Greater flexibility in production scheduling**
- **Reduced direct labour cost**
- **Increased labour productivity**
- **Shorter response time**
- **Consistent quality**
- **Reduced factory floor space**
- **Reduced number of tools and machines required**
- **Improved product quality**

Disadvantages of FMS

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

Composite Part Concept

Part families are defined by the fact that their members have similar design and/or manufacturing features. The composite part concept takes this part family definition to its logical conclusion. It conceives of a hypothetical part, a composite part for a given family, which 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 that characterize the family but not all of them. The composite part possesses all of the features. There is always a correlation between part design features and the production operations required 10 generate those features. Round holes are made by drilling, cylindrical shapes are made by turning, flat surfaces by milling, and so on. A production cell designed for the part family would include those machines required to make the composite part. Such a cell would be capable of producing any member of the family, simply by omitting those operations corresponding to features not possessed by the particular part. The cell would also be designed to allow for size variations within the family as well as feature variations. To illustrate, consider the composite part in Figure 15.1O(a).11 represents a family of rotational parts with features defined in Figure 15.1O(b). Associated with each feature is a certain machining operation as summarized in Table 15.6. A machine cell to produce this.

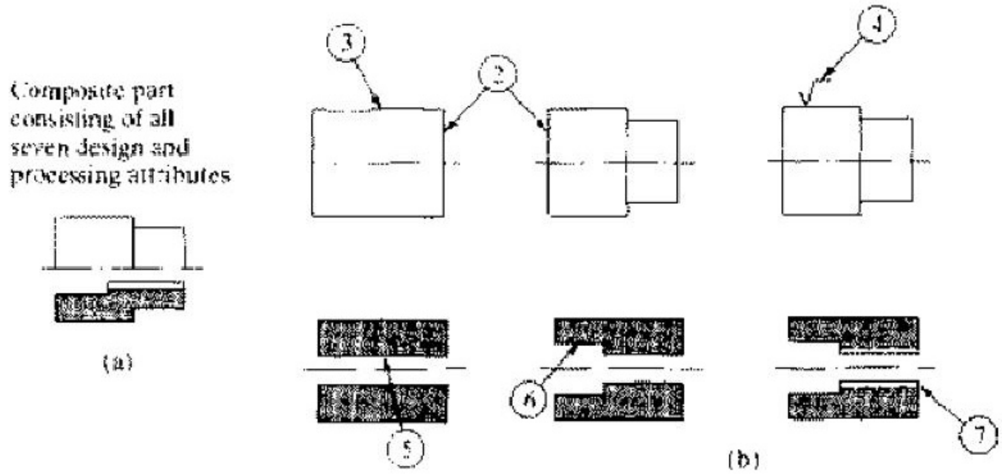


Figure 15.10 Composite part concept: (a) the composite part for a family of machined rotational parts and (b) the individual features of the composite part. See Table 15.6 for key to individual features and corresponding manufacturing operations.

part family would be designed with the capability to accomplish all seven operations required to produce the composite pan (the last column in the table). To produce a specific member of the family, operations would be included to fabricate the required features of the part. For parts without all seven features, unnecessary operations would simply be omitted. Machines, fixtures, and tools would be organized for efficient flow of workparls through the cell, In practice, the number of design and manufacturing attributes is greater than seven, and allowances must be made for variations in overall size and shape of the parts in the family. Nevertheless, the composite part concept is useful for visualizing the machine cell design problem.

Machine Cell Design

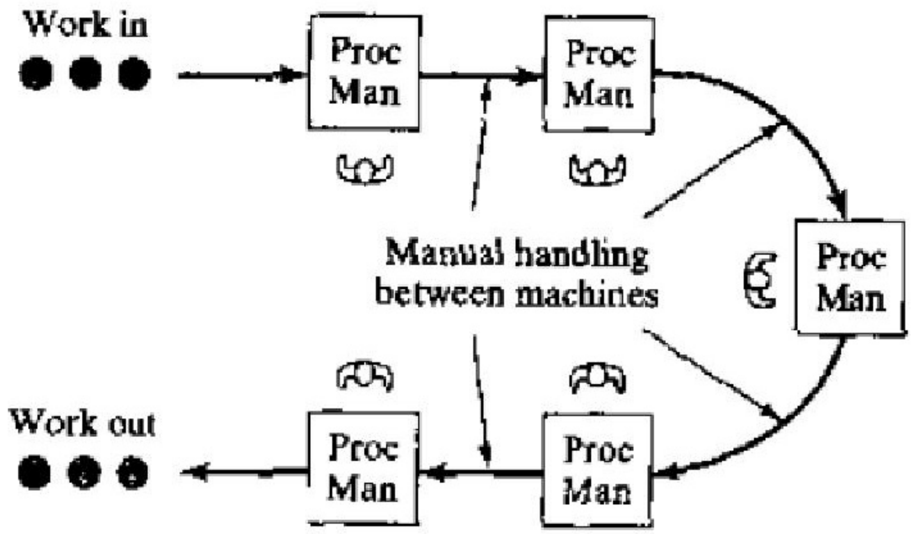
Design of the machine cell is critical in cellular manufacturing. The cell design determines to a great degree the performance of the cell. In this subsection, we discuss types of machine cells, ceJllayouts, and the key machine concept.

Types of Machine Cefls and Layouts.

GT manufacturing cells can be classifiedaccording to the number of machines and the degree to which the material flow is mechanizedbetween machines. In our classification scheme for manufacturing systems all GT cells are classified as type X in terms of part or product variety Here we identify four common GT cell configurations (with system type identifiedin parenthesis

1. single machine cell (type I M)
2. group machine cell with manual handling (type n M generally, type III M less common)
3. group machine cell with semi-integrated handling (type II M generally, type III M less common)
4. flexibic manufacturing cell or flexible manufacturing system

As its name indicates, the single machine cefl consists of one machine plus supportingfixtures and tooling. This type of cell can be applied to work parts whose attributesallow them to be made on one basic type of process, such as turning or milling. For example,the composite part of Figure 15.10 could be produced on a conventional turret lathe,with the possible exception of the cylindrical grinding operation (step 4)The group machine cell with manual handling is an arrangement of more than onemachine used collectively to produce one or more part families. There is no provision formechanized parts movement between the machines in the cell. Instead, the human operatorswho run the cell perform the material handling function. The cell is often organizedinto alj-ehaped layout, as shown in Figure 15.11. This layout is considered appropriatewhen there is variation in the work flow among the parts made in the cell. It also allows themultifunctional workers in the cell to move easily between machines [29].The group machine cell with manual handling is sometimes achieved in a conventionalprocess type layout without rearranging the equipment. This is done simply by assigningcertain machines to be included in the machine group and restricting their work to specifiedpart families. This allows many of the benefits of cellular manufacturing to be achievedwithout the expense of rearranging equipment in the shop. Obviously, the material handlingbenefits of OT are minimized with this organization.



Machine cell with manual handling between machines.

The group machine cell with semi-integrated handling uses a mechanized handling system, such as a conveyor, to move parts between machines in the cell. Theflexible manufacturing system (FMS) combines a fully integrated material handling system with automated processing stations. The FMS is the most highly automated of the group technology machine cells. The following chapter is devoted to this form of automation, and we defer discussion till then. A variety of layouts are used in GT cells, The Ucshape, as in Figure 15.11, is a popular configuration in cellular manufacturing. Other GT layouts include in-line, loop, and rectangular, shown in Figure 15.12 for the case of semi-integrated handling.Determining the most appropriate cell layout depends on the routings of parts produced in the cell. Four types of part movement can be distinguished in a mixed model part production system. They are illustrated in Figure 15.13 and are defined as follows, where the forward direction of work flow is defined a~heing from left to right in the figure:(l) repeat operation, in which a consecutive operation is carried out on the same machine, so that the part does not actually move; (2) in-sequence move, in which the part moves from the current machine to an immediate neighbor in the forward direction; (3) by-passing move, in which the part moves forward from the currenl machine to another machine that is two or mort machines ahead; and (4) backtracking move, in which the part moves from the current machine in the backward direction to another machine. When the application consists exclusively of in-sequence moves, then an in-line layout is appropriate. A V-shaped layout also works well here and has the advantage of closer interaction among the workers in the cell. When the application includes repeated operations, then multiple stations (machines) are often required. For cells requiring bypassing moves, the Li-shape layout is appropriate. When backtracking moves are needed, a loop or rectangular layout is appropriate to accommodate recirculation of parts within the cell. Additional factors that must be accounted for in the cell design include:

• Quantity of work to be done by the cdt. This includes the number of parts per year and the processing (or assembly) time per part at each station. These factors determine the workload that must be accomplished by the cell and therefore the number of machines that must be included, as well as total operating cost of the cell and the investment that can be justified .
• Part size, shape, weight, and other physical attributes. These factors determine the size and type of material handling and processing equipment that must be used. Key Machine Concept. In some respects, a GT machine cell operates like a manual assembly line (Chapter 17), and it is desirable to spread the workload evenly among the machines in the cell as much as possible. On the other hand, there is typically a certain rnachine in a cell (or perhaps more than one machine in a large cell) that is more expensive to operate than the other machines or that performs certain critical operations in the plant This machine is referred to as the key machine. It is important that the utilization of this key machine be high. even if it means that the other machines in the cell have relatively lowutilization. The other machines are referred to as.mpporting machines, and they should beorganized in the cell to keep the key machine busy. In a sense, the cell is designed so thatthe key machine becomes the bottleneck in the system.The key machine concept is sornetnues used to plan the GT machine cell. The approachi~ to decide what parts should be processed through the key machine and then determinewhat supporting machines are required to complete the processing of those parts. There are generally two measures of utilization that are of interest in a GT cell: theutilization of the kev machine and the utilization of the overall cell. The utilization of the key machine canbe'measured using the usual definition (Section 2.4.3). The utilization ofeach of the other machines can also be evaluated similarly. The cell utilization is obtainedby taking a simple arithmetic average of all the machines in the cell. One of the exercise
problems at the end of the chapter serves 10 illustrate the key machine concept and the determination of utilization.

In this chapter, we define and discuss flexible FMSs: what makes them flexible, their components, their applications, and considerations for implementing the technology. In the final section, we present a mathematical model for assessing the performance of FMSs.

A single machine cell (SMC) consists of one CNC machining center combined with a parts storage system for unattended operation (Section 14.2), as in Figure 16.2. Completed parts are periodically unloaded from the parts storage unit, and raw work parts are loaded into it. The cell can be designed to operate in either a batch mode or a flexible mode or in combinations of the two. When operated in a batch mode, the machine processes parts of a single style in specified lot sizes and is then changed over to process a batch of the next part style. When operated in a flexible mode, the system satisfies three of the four fl exibili1y tests (Section 16.1.1). It is capable of

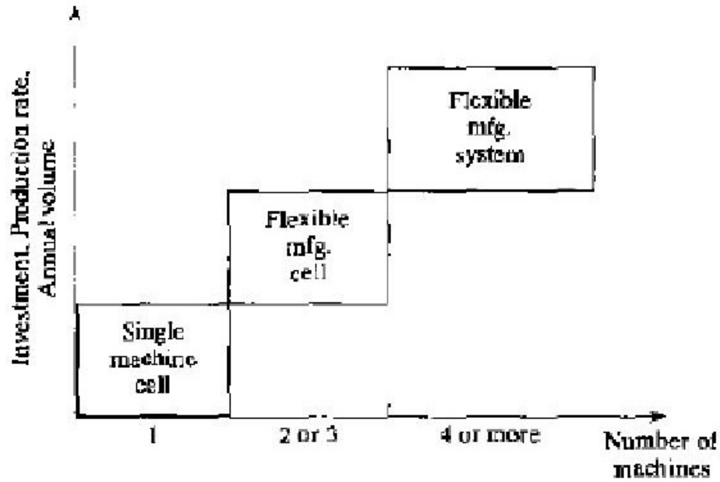
(1) processing different part styles,
(2) responding to changes in production schedule, and
(4) accepting new part introductions.

Criterion (3),errorrecovery,cannot be satisfied because if the single machine breaks down, production stops.

A flexible manufacturing all (FMC) consists of two or three processing workstations (typicatly CNC machining centers routing centers) plus a part handling system. The part handling system is connected to a load/unload station. In addition, the handling system usually includes a limited parts storage capacity. One possible FMC is illustrated in Figure16.3. A flexible manufacturing cell satisfies the four flexibility tests discussed previously.

A flexible manufacturing system (FMS) has four or more processing workstations connected mechanically by a common part handling system and electronically by a distributed computer system. Thus, an important distinction between an FMS and an FMC

A flexible manufacturing cell consisting of three identical processing stations (CNC machining centers), a load/unload station, and a part handling system.



Features of the three categories of flexible cells and systems.

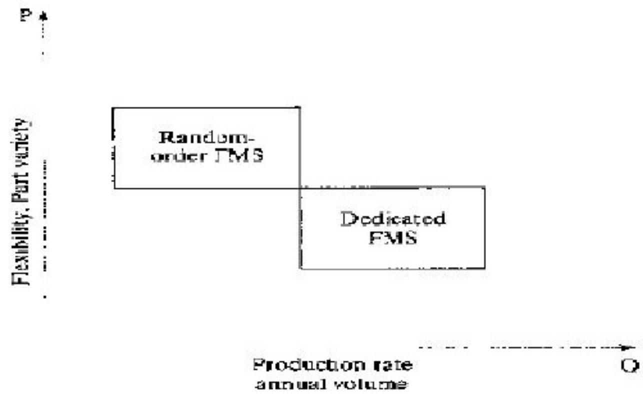
with any number of workstations, but its application seems most common with FMCs and FMSs.1\vo categories are distinguished here:

- dedicated FMS
- random-order FMS

A dedicated FMS is designed to produce a limited variety of part styles, and the complete universe of parts to be made on the system is known in advance. The term specialmanufacturing system has also been used in reference to this FMS type (e.g., [24». The part family is likely to be based on product commonality rather than geometric similarity. The product design is considered stable, and so the system can be designed with a certain amount of process specialization to make the operations more efficient. Instead of using general purpose machines, the machines can be designed for the specific processes required to make the limited part family, thus increasing the production rate of the system. In some instances, the machine sequence may be identical or nearly identical for all parts processed and so a transfer line may be appropriate. in which the workstations possess the necessary flexibility to process the different parts in the mix. Indeed, the term flexible transfer lint is sometimes used [or this case [19].

A random-order EMS is more appropriate when the part family is large, there are substantial variations in part configurations, there will be new part designs introduced into the system and engineering changes in parts currently produced, and the production schedule is subject to change from day-to-day, To accommodate these variations, the random- order FMS must be more flexible than the dedicated FMS. It is equipped with general-purpose machines to deal with the variations in product and is capable of processing parts in various sequences (random-order).

A more sophisticated computer control system is required for this FMS type. We see in these two system types the trade-off between flexibility and productivity. The dedicated FMS is less flexible but more capable of higher production rates. The random- order FMS is more flexible but at the price of lower production rates. A comparison of the features of these two FMS types is presented in Figure 16.5. Table 16.4 presents a comparison of the dedicated FMS and random-order FMS in terms of the four flexibility tests



FMS COMPONENTS

As indicated in OUI dcfiuiuon. there are several basic components of an FMS:

(1) workstations,

(2) material handling and storage system, and

(3) computer control system. In addition, even though an FMS is highly automated,

(4) people are required to manage and operate the system. We discuss these four FMS components in this section.

16.2.1 Workstations

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.

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 featuring 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 op erations, The workstations used in these systems are therefore predominantly CNC machine tools. Most common is the CNC machining center (Section 14.3.3): in particular. the horizontal rnachi-iing 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, one, and capacity for distributed numerical control (DNC) (Section 6.3). 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 p~ocesscs, reported in [44]. The processing workstations consist of press working operations, such as punching, shearing, and certain bending and funning processes. Also, flexible systems are being developed to automate the forging process [41].

Forging is traditionally a ve~' labor-intensive operation. The workstations in the system consist principally of a heating furnace, a forging press. and a trimming station.

Assembly.Some FMSs arc 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,<:ither by including, an inspection operation at a processing workstation or by including a station specifically designed for inspection. Coordinate measuring machines (Section 23.4), special inspection probes that can be used in a machine tool spindle (Section 23.4.b), and machine vision (Section 23.0) 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.

We examine the topic of automated inspection in more detail in Chapter 22 (Section 22.3). 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 leve1

Material Handling and Storage System

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 System.The material handling and storage system
in an FMS performs the fol1owing functions:

• 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 workpart configurations. For prismatic parts, this is usually accomplished by using modular pallet fixtures in the handling system. The fixture is 10· cated 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 build-up 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 accessory loading and unloading work part. The handling system must
include locations for load/unload Statius.

• Compatible with computer control. 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 Material Handling Equipment. The types of material handling systems used to transfer parts between stations in an F.\1S include a variety of conventional material transport equipment (Chapter 10), in-line transfer mechanisms (Section 18.1.2),and industrial robots (Charter 7) The material handling function in an FMS is often shared between two systems: (1) a primary handling system and (2) a secondary handling system.

The primaryhandUn!: system establishes the hasic layout of the f"MS and is responsible for moving workparts between stations in the system. The types of material handling equipment typically utilized for FMS layouts are summarized in Table 16.5

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 workpart if necessary to present the surface that is to be processed

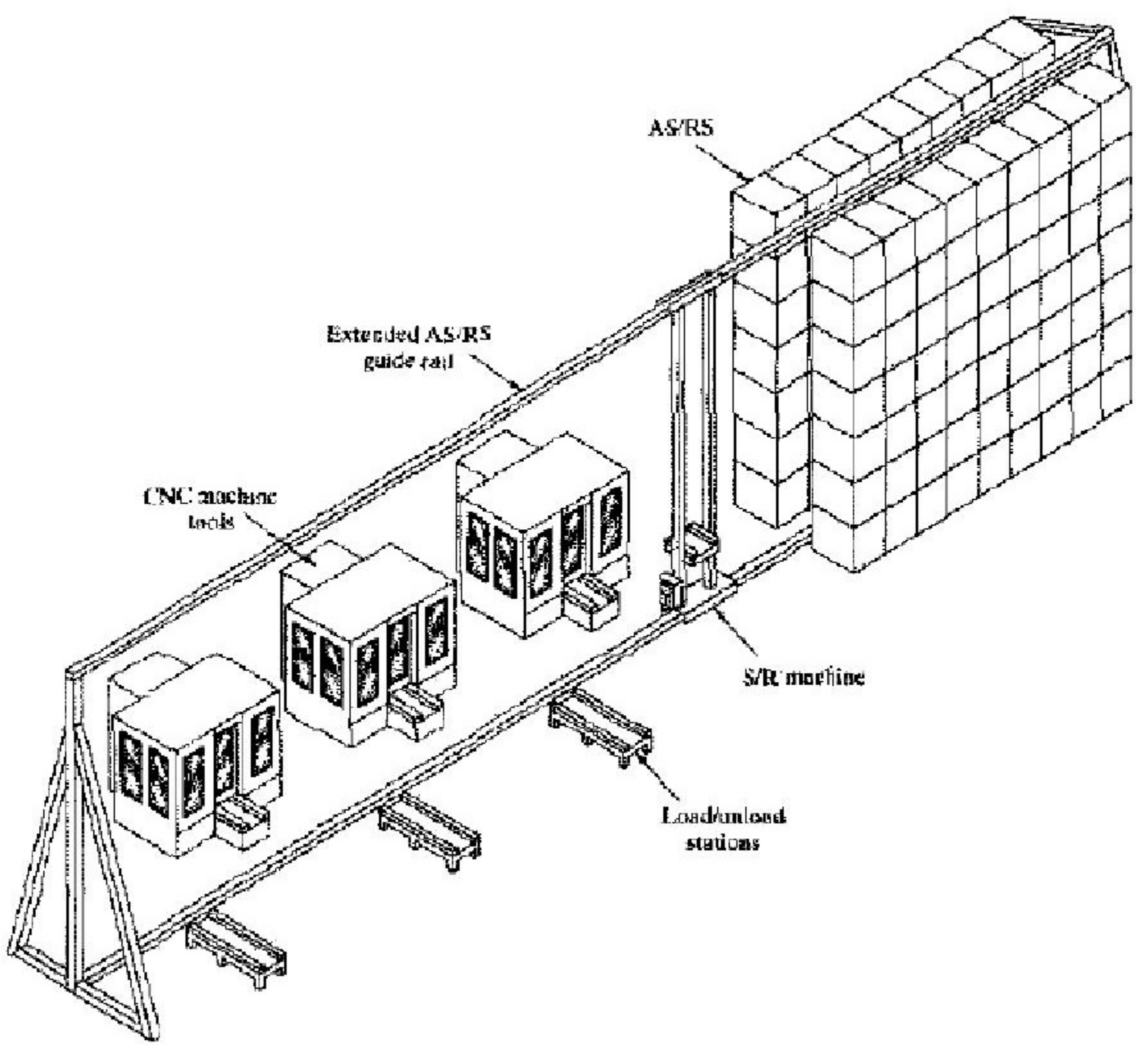
(2) buffer storage of parts to minimize work change time and maximize station utilization. In some FMS installations, the positioning and regivtrution requirements at the individual workstations are satisfied by the primary work handling system. In these cases, the secondary handling system is not included, The primary handling system is sometimes supported by an automated storage system (Section: 1.4). An example of storage in an fMS is illustrated in Figure 16.6. The FMS is integrated with an automated storage/retrieval system (AS/RS), and the SiRmachine serves the

work handling funcuon for the workstations as well as delivering parts to and from the storage racks,

FMS Lavout Configurations.The material handling system establishes the FMS layout. Most layout configurations found in today's FMSs can he divided into five categories:

(1) in-line layout,
(2) loop hl)'OU1,
(3) ladder layout.
(4) open field layout, and
(5) robot-cemered cell.

In the in-line layout, the machines and handling system are arranged in a straight line, as illustrated in Figure, 16.6 and 16.7. In its simplest form.the parts progress from one workstation to the next in a well-defined sequence, with work always moving in one direction and no back flow, as in Figure 16.7(a). The operation of this type of system is sirntlar to a transfer lin., (Chapter 18). except that a variety of workparts are processed in the



FMS that incorporates an automated storage and retrieval system for handling and storing parts. Key: *ASjRS*= automated storage/retrieval system, *SIR* = storage/retrieval machine
(also known as a stacker crane),

CNC == computer numerical control.

system. Since all work units follow the same TOuting sequence, even though the processing varies at each station, this system is classified as type III A in our manufacturing systems classification system. For in-line systems requiring greater routing flexibility, a linear transfer system that permits movement in two directions can be installed. One possible arrangement for doing this is shown in Figure 16.7(b), in which a secondary work handling system is provided at each workstation to separate most of the parts from the primary line. Becau .s.e of the variations in routings, this is II type II A manufacturing system. In the loop layout, the workstations are organized in II loop that is served by II part handling system in the same shape, as shown in Figure 16.8(a). Parts usually flow in one direction around the loop, with the capability to stop and be transferred to any station. A sec

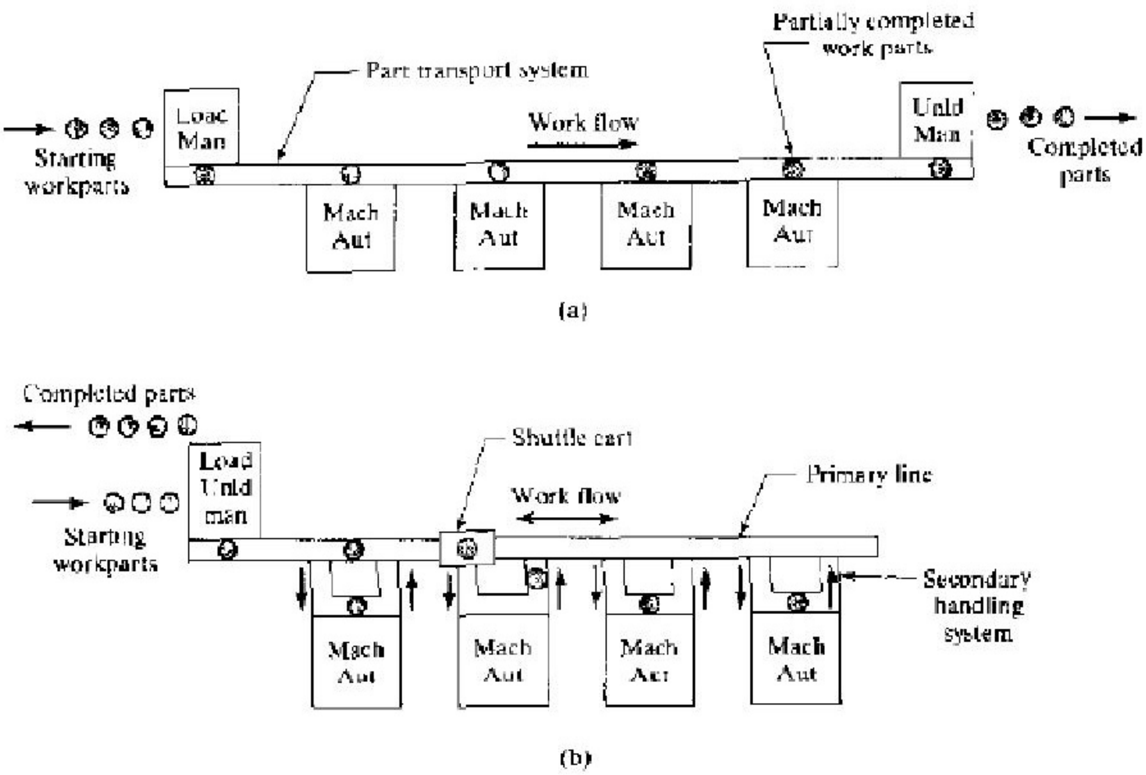


Figure 16.7 In-line FMS layouts: (a) one direction flow similar to a transfer line and (b) linear transfer system with secondary part handling system at each station to Iacilrtate flow in two directions. Key' Load = parts loading station. UnLd = parts unloading station.
Mach = machining station. Man = manuaL station, Aut = automated station.
secondary handling system is shown at each workstation to permit parts to move without obstruction around the loop. The load/unload stanonfs) are typically located at one end of the loop. An alternative form of loop layout is the rectangular layout. As shown in Figure
16.8(b), this arrangement might be used to return pallets to the starting position in a straight line machine arrangement. The ladder layout consists of a loop with rungs between the straight sections of the
loop, on which workstations are located, as shown in Figure 16.9.The rungs increase the possible ways of getting from one machine to the next, and obviate the need for a secondary handling system. This reduces average travel distance and minimizes congestion in the handling system, thereby reducing transport time between workstations.

The open ftcid layout consists of multiple loops and ladders and may include sidings as well as illustrated in Figure 16.m This layout type is generally appropriate for processing a large family of parts. The number of different machine types may be limited, and parts are routed to different workstations depending on which one becomes available first.

The robot-centered cell (Figure l ei.L] uses one or more robots as the material handling system. Industrial robots can be equipped with grippers that make them well suited for the handling of rotational parts, and robot-centered FMS layouts are often used to process cylindrical or disk-shaped parts

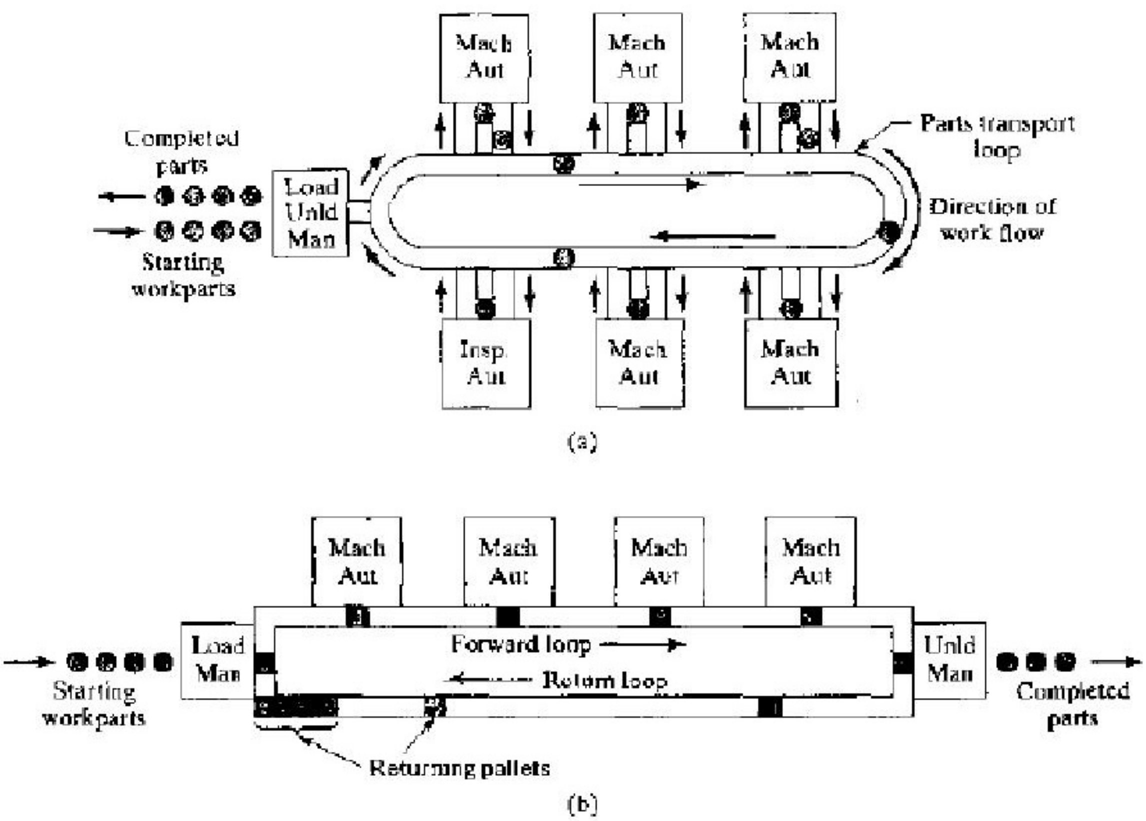


Figure 16.8 (a) FMS loop layout with secondary part handling system at each station to allow unobstructed flow on loop and (b) rectangular layout for recirculation of pallets to the first workstation in the sequence. Key: Lced> parts loading station, UnLd = parts unloading station, Mach = machining station, Man = manual station, Aut '" automated station

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. Functions performed by the FMS computer control system can be grouped into the following categories:

1. 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.

2. 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 DNe functions.

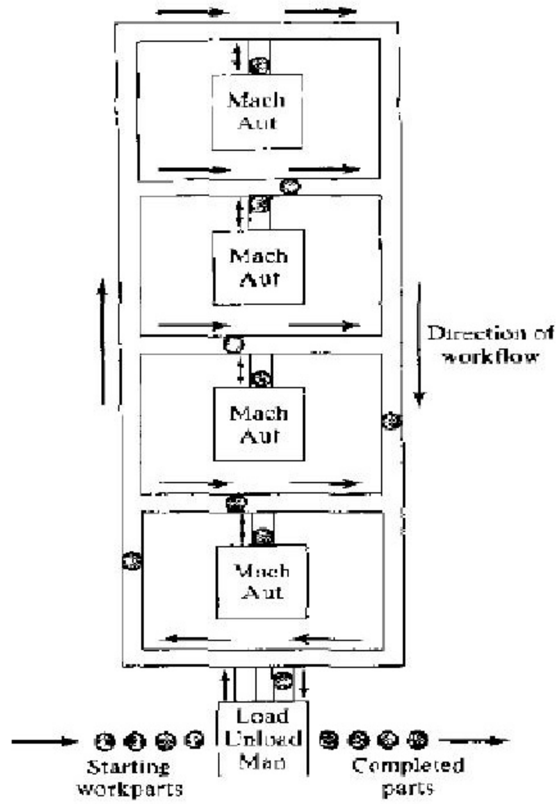


Figure 16.9 FMS ladder layout. Key: Load = parts loading station, UnLd == parts unloading station. Mach == machining station, Man = manual station, Aut = automated station.

3. 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 workpart.

4. 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 tool transfer locations, and moving pallets to load/unload stations.

5. 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, 'The lenr. *applicablepallel*refers 10 a pallet that is fixtured 10 accept a workpart of lhe desired type

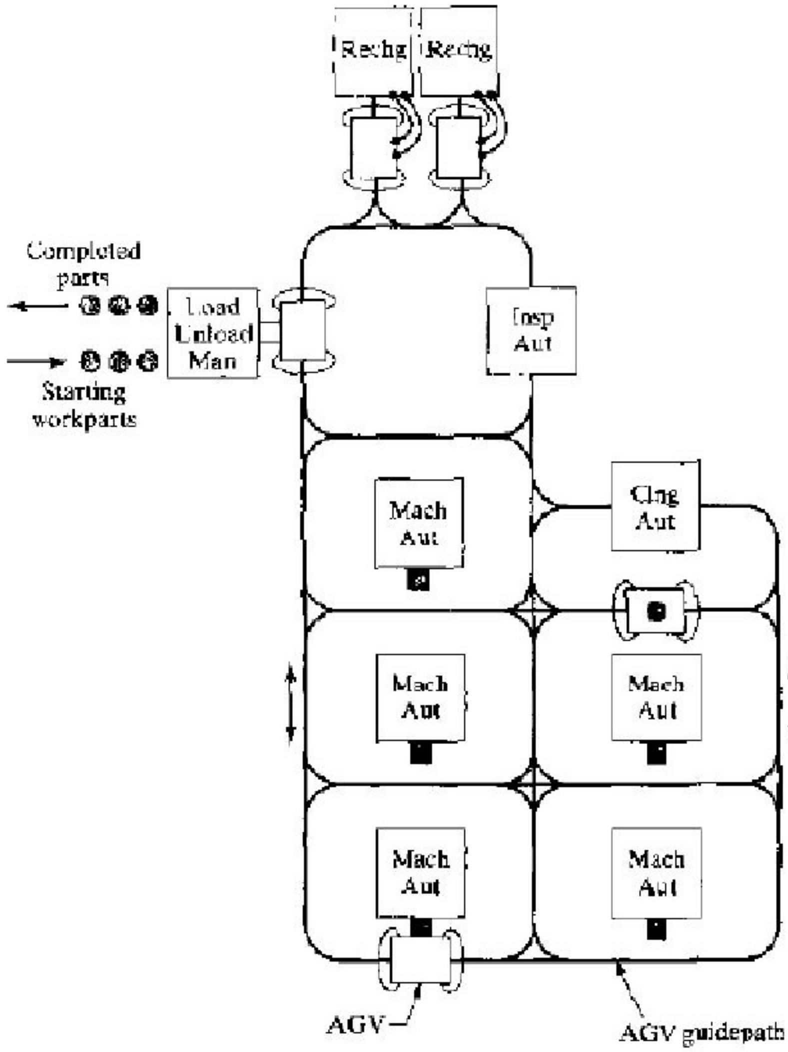


Figure 16.10 Open field FMS layout. Key: Load = parts loading, UnLd ,; parts unloading, Mach = machining, Clog = cleaning, lnsp "' inspection, Man = manual, Aut = automated,AGV = automated guided vehicle. Rechg = battery recharging station for AGVs.

6. Workpiece monitoring. The computer must monitor the status of each cart andlor pallet in the primary and secondary handling systems as well as the status of each of the various workpiece types.

7. 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). computer for each cutting too! ltl the F\tIS.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 replacementis needed.

K *Performance monitoring and reponing.*The computer control ~ystem i, programmedto 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 16.6

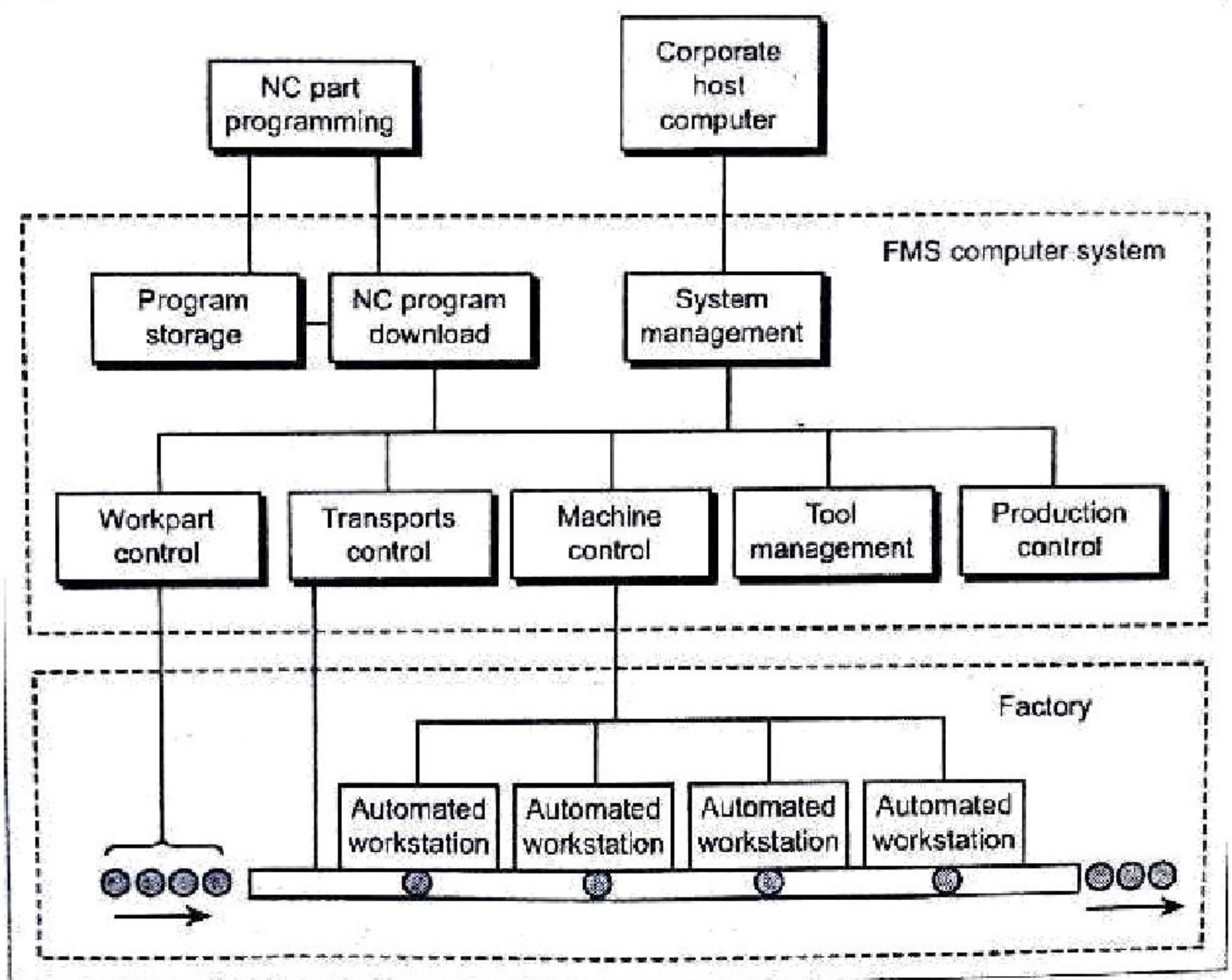
Y. *Diagnostics.* This function is available to a greater or lesser degree on many manufacturing systems to indicate the probable source of the problem when a malfunction occurs. It can also be used to plan preventive maintenance iu the system and to identify Impending failures. The purpose of the diagnostics 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 16.11. It should be noted that an FMS possesses the characteristic architecture or a DNC sy~tem_As in other ONe systems. two-way communication is used. Data and commands an: sent from the central computer to the individual machines and other hardware components, dnd data Ull execution and performance are transmitted from the components hack up to the centra] computer. In addition, an uplink from the FMS to the corporate host computer is provided

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



FMS APPLICATION S AND BENEFITS

In this section, we explore the applications of FMSs and the benefits that result from these applications. Many of the findings from the industrial survey on cellular manufacturing (reported in Section 15.5.2) are pertinent to FMSs, and we refer the reader to that report.

FMS Applications

- **Forging**
- **Plastic injection moulding**
- **Welding**
- **Textile machinery manufacture**
- **Semiconductor component manufacture**

The concept of flexible automation is applicable to a variety of manufacturing operations. **In** this section, some of the important FMS applications are reviewed. FMS technology i~ most widely applied in machining operations. Other applications include sheet metal press working, forging, and assembly. Here some of the applications are examined using case study examples to illustrate.

Flexible Machining Systems. Historically most of the applications of flexible machining systems have been in milling and drilling type operations (nonrotational parts), using NC and subsequently CNC machining centers. FMS applications for turning (rotational parts) were much less common until recently, and the systems that are installed tend to consist of fewer machines. For example, single machine cells consisting of parts storage units, part loading robots, and CNC turning centers are widely used today, although not always in a flexible mode. Let us explore some of the issues behind this anomaly in the development of flexible machining systems.

By contrast with rotational parts, nonrotational parts are often too heavy for a human operator to easily and quickly load into the machine tool. Accordingly, pallet fixtures were developed so that these parts could be loaded onto the pallet off-line and then the part-on. pallet could be moved into position in front of the machine tool spindle. Non rcrarlonal pans also tend to be more expensive than rotational parts, and the manufacturing lead times tend to be longer. These factors provide a strong incentive to produce them as efficiently as possible, using advanced technologies such as FMSs. For these reasons, the technology for FMS milling and drilling applications is more mature today than for FMS turning applications

F\1S at Ingersoll-Rand in Roanoke, Virginia One of the first FMS installations in the United States was at the Roanoke, Virgln. a.ptant of the Tool and Hoist Division of Ingersoll-Rand Corp. The system was installed by Sundstrand in the late 1960&It consists of two five-axis machining centers, two four-axis machining centers, and two four-axis drilling machines. The machines are each equipped with 6O-tool storage drums and automatic 1001 changers and pallet changers. A powered roller conveyor system is used for the primary and secondary workpart handling systems. Three operators plus one foreman run the system three shifts. Up to 140 part numbers are machined on the system. The parts begin as cast iron and aluminum castings and are machined into motor cases, hoist casings, and so on. Part size capability ranges up to a 0.9 m cube (36.0 in).