SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT 1 SPR1605-FLEXIBLE MANUFACTURING SYSTEM

UNIT 1

Introduction

A flexible manufacturing system refers to a production method designed to adjust to deviations in the product quantity and type being manufactured. The system aims to lower the production cost of a company by enhancing efficiency. The method can serve as a key factor of a make-to-order approach that lets customers tailor the products they want. The system may involve an outline of interconnected processing workstations with computer terminals. It processes the end-to-end manufacturing of products from the loading function to storing data processing.

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.

Development of manufacturing system

In a model driven development scenario, the models of parts, processes and resources themselves are the carriers of information which is used and refined throughout the work processes.

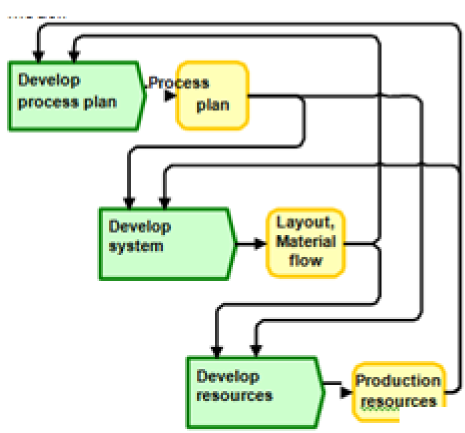


Fig 1.1 Basic machining operations

The fundamental principle of this model driven approach is to clearly describe how the value of the manufacturing system is growing throughout the activities of the development process. Rather than describing a development process in stages with declared gates and results such as “project description” or “requirement document”, the purpose is to model each activity as a function with a description of which manufacturing system information it requires and generates. This way the generic development model can be adapted to different companies by selecting activities relevant to the needs. Moreover, since the model is independent of the business process, it can be adapted to any company’s selected business process model.

The traditional studies on the manufacturing system have mainly focused on the factory or firm level These have primarily centered on strategic or operational decisions on plant, equipment, production planning and control, labor and staffing, product design and engineering, and organization and management at a firm/factory level .Those optimization decisions are normally centered on the firm/plant level to achieve higher productivity and cost efficiency of the factory operations.

With the fast pace of globalization in the last three decades, the vast majority of manufacturing in large companies is carried out in dispersed locations , as a result, the studies on the manufacturing system have been extended to a network level. For example, the international manufacturing network, which is a factory network consisting of geographically dispersed but interdependently coordinated factories/plants; and supply network, which is an integrated network of key supply units. These studies are more focused on the integration and coordination issues of the dispersed factory networks, especially the choice of location and number of factories, and role of each factory. In contrast to a manufacturing network which has dispersed factories, a supply network can be defined as a network with dispersed suppliers based on their supply relations, which is also different from the concept of a supply chain, as this describes the flow of goods and services from original sources to end customers. In other words, a supply network can be defined as sets of supply chains.

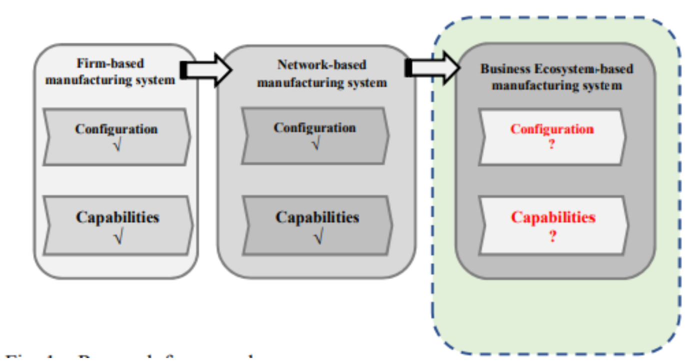


Fig.1.2 Research framework

One of the key differences is the focus of these three manufacturing systems. The firm-based manufacturing system is more focused on a plant's managerial optimization for efficiency and productivity. Network-based systems focus on process integration and coordination among dispersed plants or suppliers. While the ecosystem-based manufacturing system focuses on collaborative relations between a ranges of stakeholders in the business ecosystem.

Benefits of flexible manufacturing system

Fig 1.3 Advantages of FMS

1. Large variety of same products

Flexible Manufacturing System (FMS) can produce a large variety of the same type (homogeneous) of products.

2. 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.

3. Requires limited inventory

FMS requires limited inventories compared to other production systems.

4. 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.

5. 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.

6. Speedy production

The products can be produced very quickly because the materials are loaded, unloaded and transferred from one machine to another by robots.

Major elements of flexible manufacturing system

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

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 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 (Section 14.3.3): 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) (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 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 (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 level

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 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-parts. The handling system must include locations for load/unload stations.

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), inline 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 primary handling system establishes the basic layout of the FMS and is responsible for moving work-parts between stations in the system. The types of material handling equipment typically utilized for FMS layouts are summarized in Table 1.1

Table 1.1 FMS layout

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)

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 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 S/R machine serves the work handling function for the workstations as well as delivering parts to and from the storage racks

FMS Layout Configurations.

The material handling system establishes the FMS layout. Most layout configurations found in today's FMSs can he divided into five categories: (1) inline layout, (2) loop hl)'OU1, (3) ladder layout. (4) open field layout, and (5) robot-centered cell.

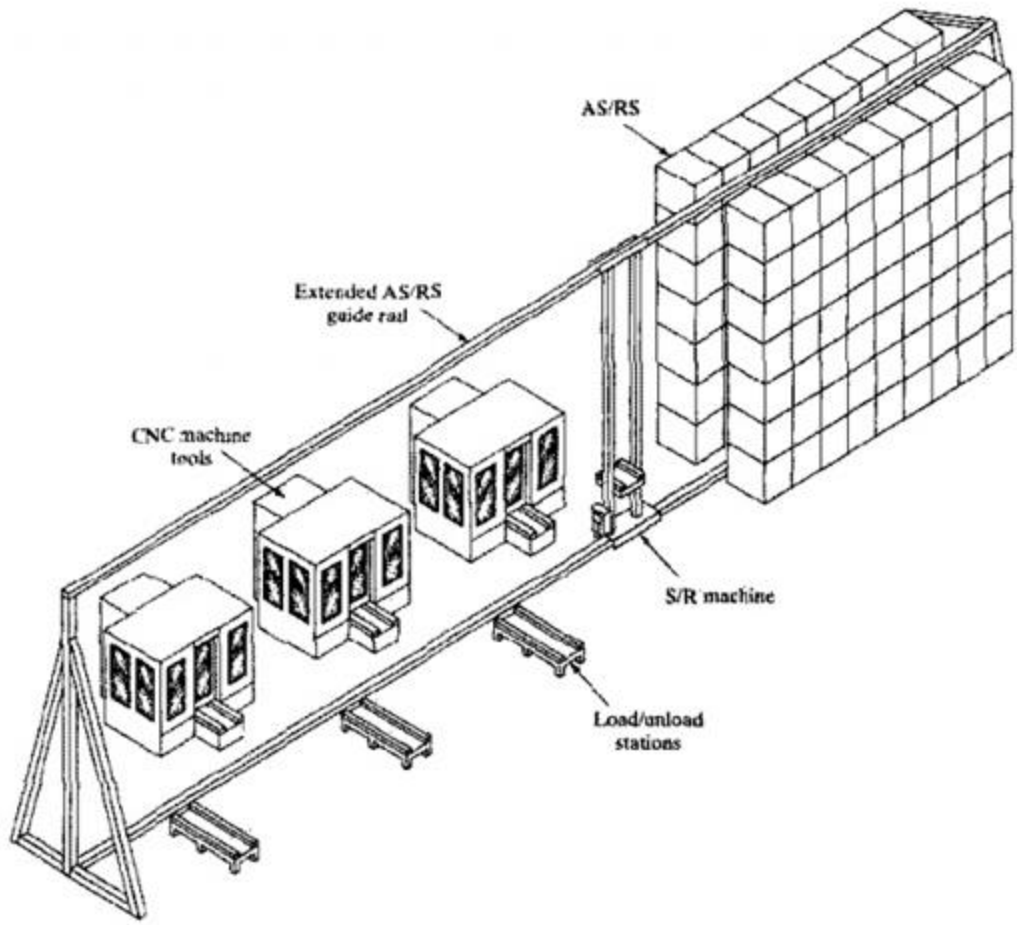


Fig 1.4 Layout configuration

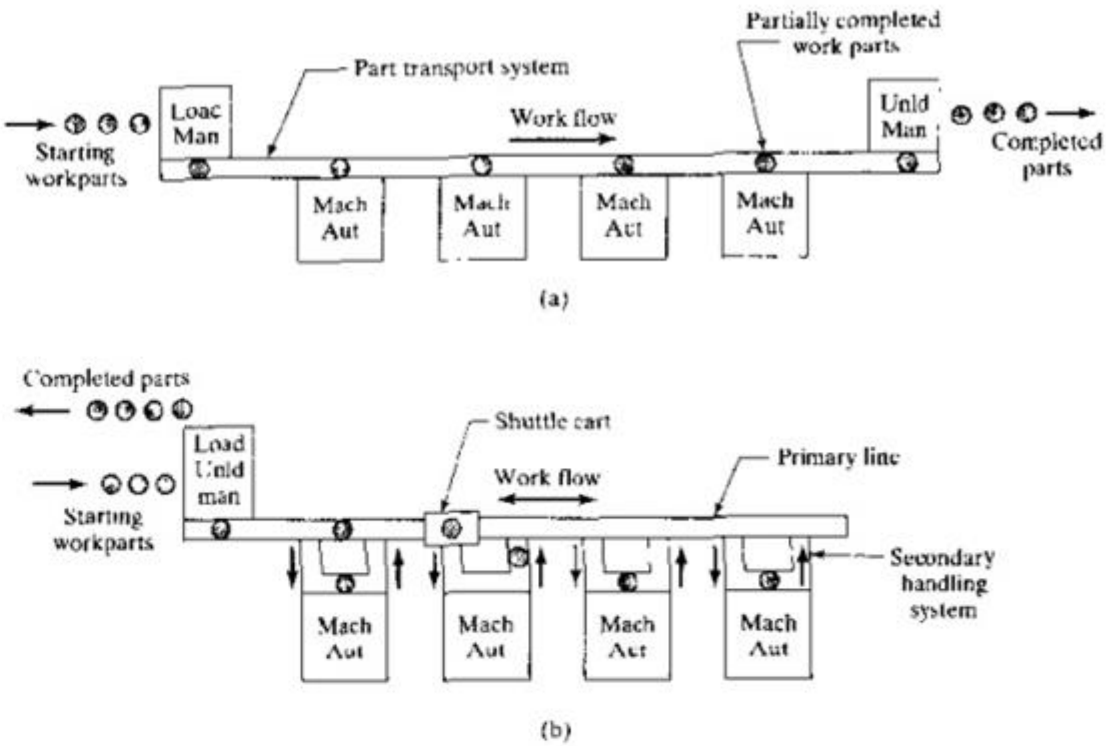


Fig 1.4 Inline FMS layout

In the inline layout, the machines and handling system are arranged in a straight line, as illustrated in Figure, 16.6 and 16.7. 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). Since all work units follow the same routing sequence, even though the processing varies at each station, this system is classified as type III A in our manufacturing systems classification system. For inline 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. Because of the variations in routings, this is II type II A manufacturing system.

In the loop layout, the workstations are organized in a 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 secondaryhandling system is shown at each workstation to permit parts to move without obstruction around the loop. The load/unload station(s) arc 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 field 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 16.1) 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

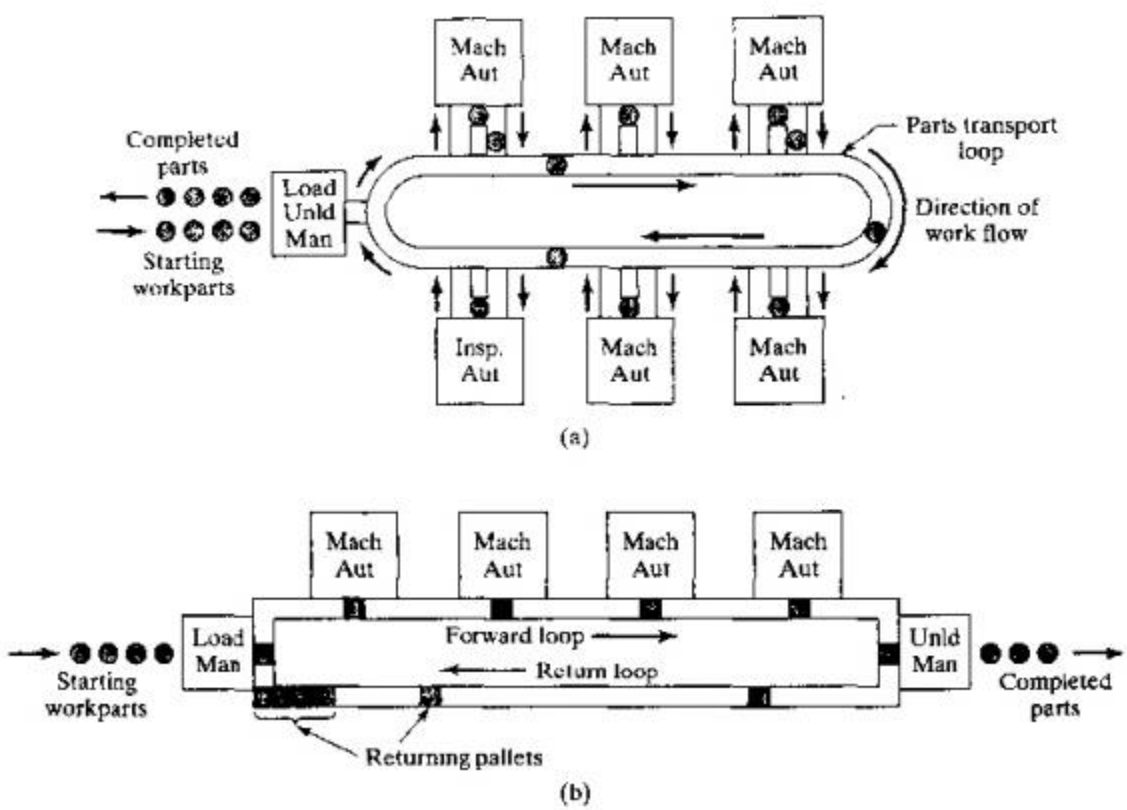


Fig 1.5 Loop layout

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:

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

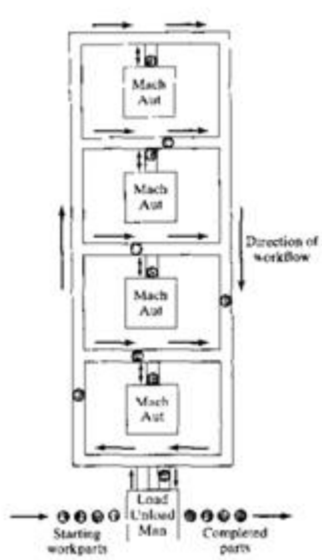


Fig 1.6 Ladder layout

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 tool transfer locations, and 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,

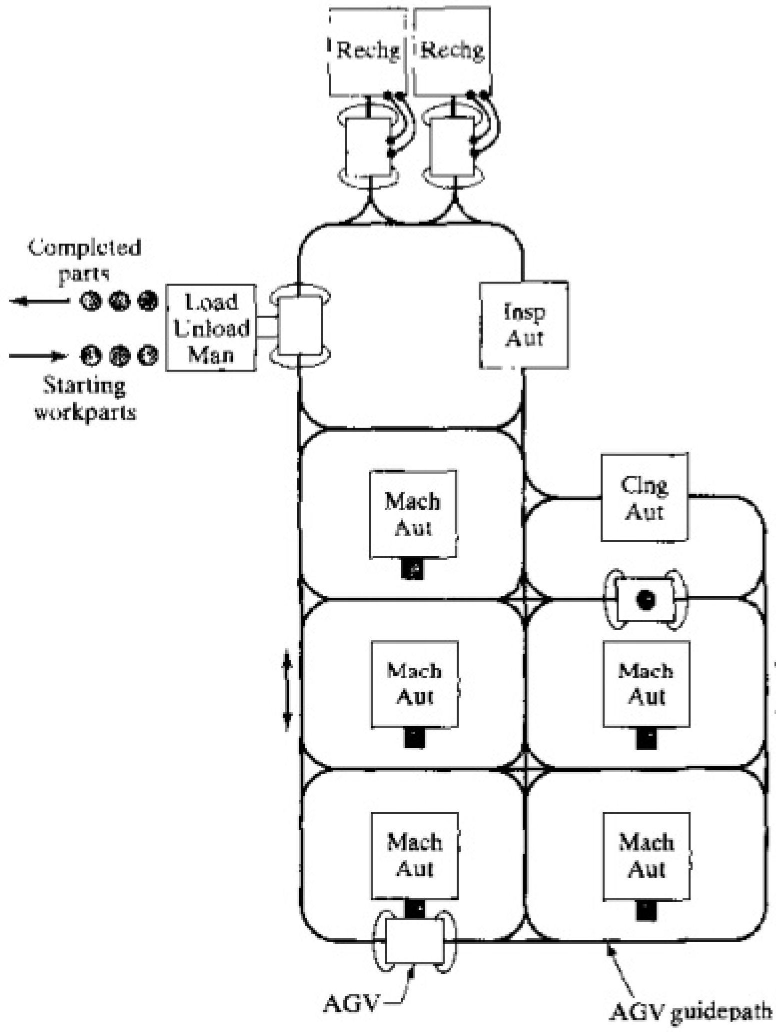


Fig 1.7 Open field FMS layout

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.1.nthis 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.

K 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 1.2

Table 1.2 Typical FMS performance report

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.

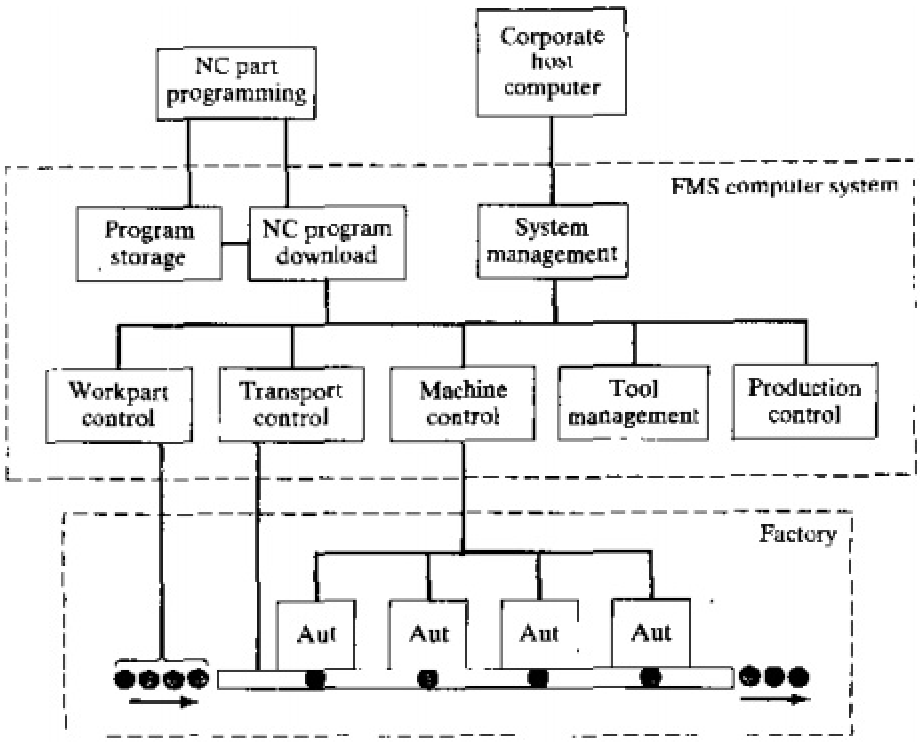


Fig 1.8 FMS structure

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.

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

FLEXIBILITY AND ITS TYPES

Flexibility is an attribute that allows a mixed model manufacturing system to cope up with a certain level of variations in part or product style, without having any interruption in production due to changeovers between models. Flexibility measures the ability to adapt "to a wide range of possible environment".

To be flexible, a manufacturing system must posses the following capabilities:

- Identification of the different production units to perform the correct operation
- Quick changeover of operating instructions to the computer controlled production machines Quick changeover of physical setups of fixtures, tools and other working units

These capabilities are often difficult to engineer through manually operated manufacturing systems. So, an automated system assisted with sensor system is required to accomplish the needs and requirements of contemporary business milieu. Flexible manufacturing system has come up as a viable mean to achieve these prerequisites.

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 different types of flexibility that are exhibited by manufacturing systems are given below:

1. 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

2. 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

3. 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

4. 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

5. 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

6. 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

7. 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.

Part selection problems in flexible manufacturing system

The integrated part type selection problem and machine loading problem that are considered as NP-hard problems in production planning of flexible manufacturing system (FMS) and strongly determine the system's efficiency and productivity. The integrated problems are modelled and solved simultaneously by using Variable Neighbourhood Search (VNS). A new neighbourhood structure is designed to enable the VNS produces near optimum solutions in a reasonable amount of time. The proposed VNS improves the FMS performance by considering two objectives, maximizing system throughput and maintaining the balance of the system.

The overall stages in FMS environment are depicted in Fig. 1. Problems addressed in this paper are shown in grey areas. The scheduling and assembly operations problems can be solved after solutions of the part type selection and machine loading problems are obtained.

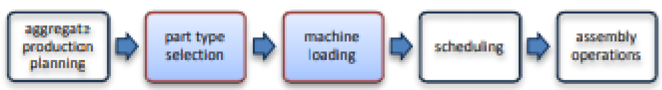


Fig 1.9 Manufacturing process

Even if the part type selection and machine loading problems can be solved hierarchically in separated stages, solving them simultaneously will produce better solutions that are indicated by higher throughput and balance machines' workload . Moreover, a solution produced by the part type selection in the previous stage may become infeasible for the machine loading the next stage . Thus, this paper focuses on the integrated part type selection and machine loading problems.

The part type selection problem and the machine loading problem are strongly related problems and exist in most FMS environments. The problems also heavily determine the system's efficiency . Higher throughput and efficient allocation of production resources of the FMS will be achieved by simultaneously solving part type selection and machine loading problems .

The part type selection and machine loading problems are considered as strongly NP-hard problems with a very large search space and the optimum solution may not be obtained by exact methods or complete enumeration in a reasonable amount of time . For a medium size problem with 36 part types and the average possible machining routes of 5, the total number of possible solutions for the integrated part type selection and machine loading problems is about 5.4*10^66.

For this kind of problem, a branch-andbound method run on personal computer equipped with Intel® Core™ i3-380 processor required more than 150 hours to get the optimum solution . This computational time cannot be accepted for daily operation of FMS. Thus, a good approach to achieve near optimum solutions on reasonable amount of time is required. While Mahmudy, et al. proved that their real-coded genetic algorithm (RCGA) could effectively exploring a huge search space of the problems, a series of experiments was required to obtain the best parameters of the approach. In this paper, an efficient variable neighbourhood search (VNS) is proposed. Variable neighbourhood search (VNS) is meta-heuristic technique that manages a local search (LS) technique. Here, the LS is systematically iterated to explore larger neighbourhood until termination condition is achieved. The neighbourhood structure is designed to enable the LS exploring the search space from new starting points . Thus, these properties enable the VNS to escape from local optimal areas and obtain optimum or near optimum solution. As a simple and effective method, the VNS have been successfully implemented to solve a various combinatorial problems such as maximum satisfiabilityproblem , job scheduling , location routing problem with capacitated depots [16], transportation and distribution.

A simple problem set is developed as an example of the problem formulation. The FMS have 3 different machines which have tool slot capacity of 15, 20 and 25 respectively. The machines have length of scheduling period (Lm) equal to 2500. Here, overloading of the machines is permitted. Moreover, there are 10 different tool types and each tool type has several instances (copies) and occupies a number of tool slots on machines' magazine as shown in Table 2. A production orders that consist seven part types are arrived. Each part type has specific production requirements as shown in Table 3. For example, part type 3 has 3 operations. Operation 1 can be executed on machines 2 or 3. Machine 2 needs 30 unit times for processing and requires tool types 6, 7 and 8. Different processing times and tool types are required if machine 3 is chosen. In this case, machine 3 needs 40 unit times and requires tool types 8, 9 and 10. Thus, it shows the occurrence of machine and tool flexibility in the production planning problem.

Table 1.3 Availability of tool types

THE AVAILABILITY OF TOOL TYPES

tool type	1	2	3	4	5	6	7	8	9	10
availability	2	3	2	3	2	3	2	3	2	3
number of slot needed	3	3	4	4	5	5	5	3	3	3

TABLE III
PRODUCTION REQUIREMENT OF PART TYPES

part type	batch size	value $	op	mac	time	tools		
1	20	5	1	2	20	2	3	5
			2	1	30	4	5	
			3	2	30	3	4	
				3	30	5		
2	20	3	1	1	30	1	3	
			2	2	20	3	4	
			3	2	30	4	6	7
3	40	2	1	2	30	6	7	8
				3	40	8	9	10
			2	2	20	1	10	
				3	40	2	10	
			3	1	20	1	2	

Knowledge based scheduling system

Research in the field of scheduling problems has applied the techniques of artificial intelligence (AI) to real-time soheduling in job shop production.

MODEL STRUCTURE

The structure of an expert system (ES) generally contains three components: knowledge database, inference engine, and control. The collection of rules whioh represents the expert's knowledge is called a knowledge database, where semantic networks are used as the knowledge representation of an ES/FMS scheduling. An inference engine is a program which uses the knowledge database to produce an expert recommendation with complete and incomplete information. The most common struoture of the inference engine is a series of "if-then" statements. Control is the reasoning deduction performance of an inference engine. Two approaches, forward chaining and backward chaining, are employed by the inference engine for reasoning deduction

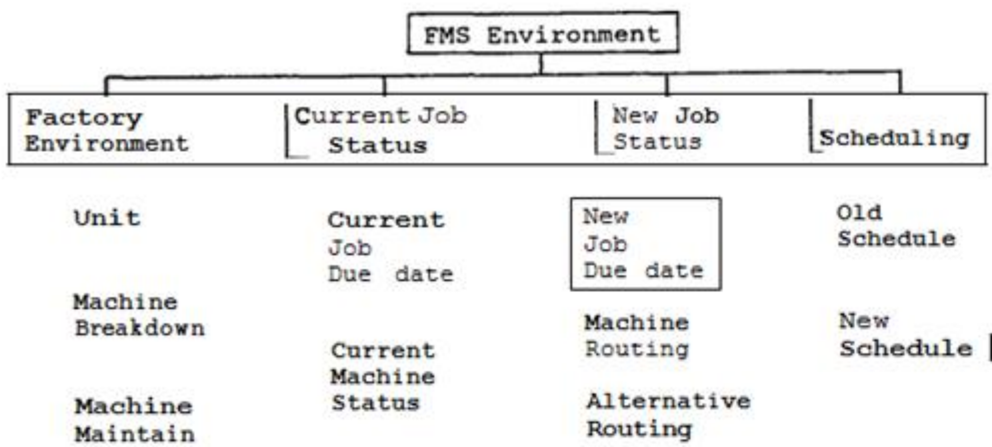


Fig 1.10 Networks

This model has five key assumptions:

(1)Pre-emption is allowed only for rescheduling

(2)Due dates are fixed.

3)Each job operation has alternatives to be machined on different machines

(4)Different job operations can be machined on the same machine

(5)Process time, setup time, and transportation time are deterministic

This model uses the Followlng notations:

Di	:	the due date of job i.
sst	:	the search spaoe at state t.
Jij	:	the jth operation of job i.
PTijkt	:	the process time oF Tij on machine k at state t.
Nk	:	the machine k.
CTiikt	:	the time at whioh Tlj 1s completed on machine k at state t.
STljkt	:	the starting time at which Tij oan be maohined on maohine k at state t.
MTkt	:	the time' at which machine k oan be assigned to complète an operation during backward constraint searoh at state t.
BETk	:	the time at which maohine k completes maintenance, or the end oF break down.
BSTk	:	the time at which machine k starts malntenanoe or breaks down.

The term "state" in the notation is defined as the situation in which only one of the schedulable oper at I ons can be scheduled . Floreo ver., the "sear ch g pane" i s tne set oJ schedul abl e oper at ions at the speci Iic state .. Each sche dul able job/oper at ion i s a node i n the sear ch s pace , and i ts data struct ure is

Jij	Mk	PTijkt	CTijkt	STijkt

METHODOLOGY

The overall methodology structure is shown in Figure 1.11. Once the knowledge representation of an FMS environment is developed, the inFerenoe en8ine conducts Fourdispatohing rules to generate, at most, Four near-optimal schedules. The AHP system determines the best schedule, even though there is no Feasible solution generated by the lnference engine. The knowledge representation structure is based on the hlerarchical planning which decomposes an FMS environment into four oomponents: factory environment, current joD status, new job status, and scheduling. Each component is desorbed by several predicates, as follows:

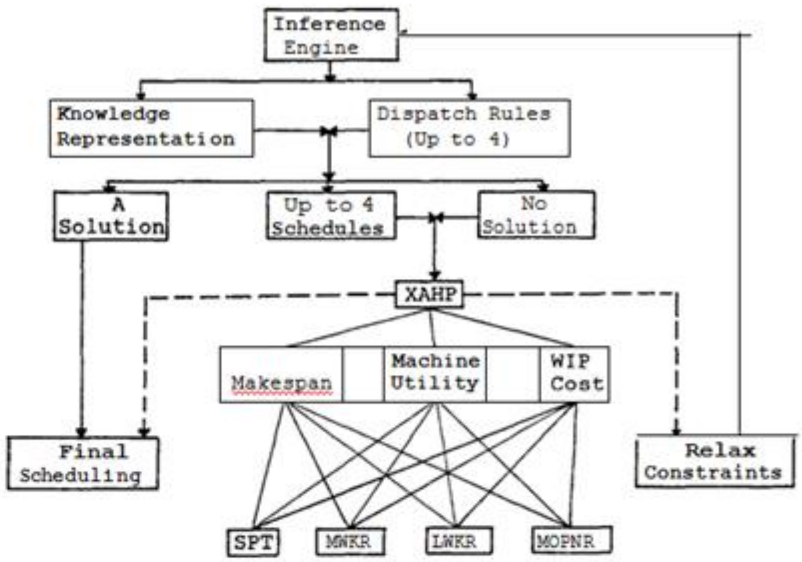


Fig 1.11 knowledge representation of an FMS environment

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT II SPR1605-FLEXIBLE MANUFACTURING SYSTEM

UNIT 2

INTRODUCTION

F.M.S. is system where a high degree of flexibility in the machining process is achieved by an integration of the hardware and software components. The flexibility in F.M.S. is achieved with the help of software controlling the hardware. The first step in the production of any component is scheduling the production. The flexibility in F.M.S. is achieved by proper scheduling of the production process. This is achieved with the help of the production scheduling software.

A variety of computer-based scheduling methods can be used in production. In order to prepare an ideal scheduling process, certain inputs are required by the software. These data include Part Data, Pallet Data, Program Data and Machine Data. It selects the optimal method based on the production objectives, available resources and the economic considerations to select the batch size. It determines the allocation of part to machines depending upon the operation to be performed, the availability of the machines and priority.

Once the scheduling operation is complete, the process planning software takes over. It determines the type of manufacturing processes that the workpiece has to undergo to be converted into a finished product. It does so by retrieving specific information from the central database, and considering machine tool capabilities and tooling. After the type of machining operation to be performed on a work-piece is decided, the tool management software selects the appropriate tool to be supplied to the machining centres. It does so by taking into consideration the tooling status and inventory records and a tool replacement strategy. Proper interfacing should be provided between these three software.

Once the scheduling and process planning stages are completed, the manufacturing of the work-piece actually starts. The raw work-piece is first fixed on the pallet and placed in the pallet store. The Robotic arm then picks up the required pallet and loads it on the guided vehicles (G.V.). The G.V. transports the pallet to the appropriate machining centre according to the scheduling program. If the machining centre is busy, the pallet is kept in centre’s buffer station.

The buffer stations are provided so that work is always available for the machining centre. The tool management software selects the tool from the tool room and supplies it to the machining centres through the tool transport system. The machine performs the metal cutting operation according to the part program it receives from the D.N.C.

The acts as the single-point supplier of part programs as required by the various machining centres. After the machining is completed on one machine a G.V. takes it to the next machining centre, if required, for the further processing of the work-piece. In this way the G.V.s transport the work-piece from machine to machine till it is transformed in to the finished product. At regular interval intervals of time, the machining operation stops, allowing probes to come out and measure the dimensions of the work-piece being operated on.

This product is taken to the washing centre for cleaning and then to the inspection station for checking the product. At the end of the work process, the work-piece is unloaded with the help of a Robotic arm. One of the characteristics of an F.M.S. is that a machine tool can work in various modes depending upon the requirements of the user. These are:

• Automatic mode: - this is the normal mode of operation of the machine tool when part of the system.

• D.N.C. mode: - In this mode any operation can be initiated at N.C.'s panel without being watched by the host.

• Maintenance mode: - This mode is used when maintenance is planned for a machine. The machine is also put in this mode when it is expected to be out of operation for a long period.

• Stand-alone mode: - This mode can be used to test the part program of a new piece part before introducing it in the system.

The machine is unsynchronised by the host in this mode. All the processes carried out by the hardware are being monitored in real-time by the various intrinsic software(s) loaded on to the Host Computer. Thus the Host Computer controls the whole system. Production Control software selects the suitable work-piece to be machined and monitors its progress through the machining centres and inspection stations according to the production schedule.

Production monitoring and reporting software collects the various data related to product management like number of completed parts, inspections results, tool change data etc and provides standard and custom reports for managing the F.M.S. resources. It also monitors the utilisation of the different units and the current status of machining operation. If any problems arise they are promptly reported to avoid delay in taking corrective measures and maximising machine utilisation.

The Machine/Process control is the lowest level in the communication hierarchy. It operates at the machine level and provides both control and monitoring functions. It monitors tool status and provides tool replacement strategies. It can also adapt to variation in process variables in real-time.

Machine Diagnostic software detects and can predict malfunctions, the probable reasons for the malfunctions and offers solutions for the same. In case of a failure, it can switch control of the failed unit to a back-up system. For the optimum performance of the system, it is necessary to carry out maintenance operations on a regular basis. In case of a failure, corrective measures have to adopted by the maintenance personnel.

A Maintenance Planning software performs the auxiliary functions required for the actual maintenance of the F.M.S. This includes activities like scheduling maintenance activities, issuing maintenance reports, supporting real-time supervision of machine components etc. It should also be able to track the status of maintenance and determine crew assignments.

Simulation is an important tool to test the part program of a new workpiece that is to be introduced or to check any alterations made in the part program of an existing work-piece and identify any bottlenecks. It is also used to compare alternative design and performing work scheduling and job sequencing. Examples of some simulation software are SIMAN, SLAM II etc.

CAD software is used to design the product and represent it in a solid model. While a CAM software is used to convert this solid model into part programs incorporating all the information about the machining operations to be performed on the work-piece.

The information based on which the whole system performs its functions is accessed from the central database system. The software is supplied Artificial Intelligence capability to be able to take decisions based on the actions of the system performed till now.

The program development should be menu-driven and have a user-friendly software. The concept of Blueprint Programming is widely used in the system, which involves the use of data for cutting parameters. Thus the various components of the F.M.S. work in co-ordination with each other to create a super machine of a versatile character.

COMPOSITION OF FMS

Components of a F.M.S. can be broadly classified into two categories.

- Hardware
- Software

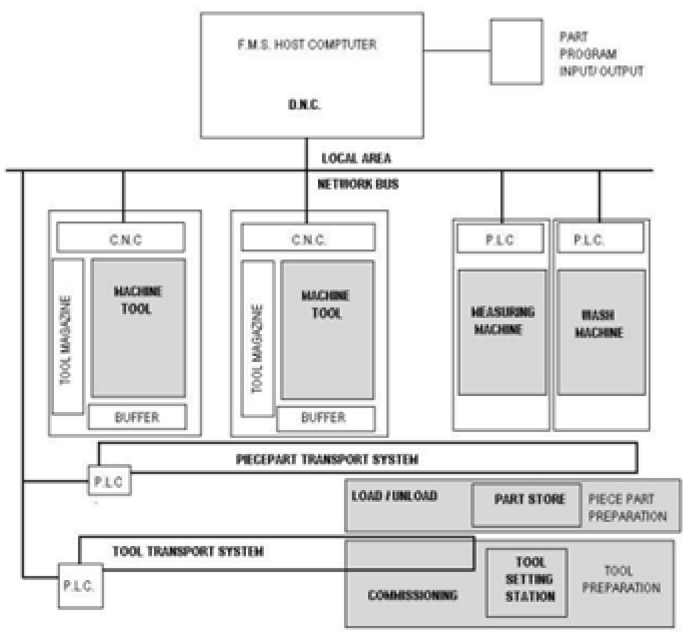


Fig 2.1 Generalized block diagram

Hardware: -

The Hardware component (Figure 3) basically consists of Machine Tools and Handling systems. It incorporates the following equipments• Machine Tools e.g., Universal Machining Centres, Turning Centres, Drilling Machines etc• Host Computer. • Load/ Unload station • Guided Vehicles e.g., wire-guided trolley, shuttle, over-head conveyor etc• Robots• Washing station • Tool Room •Swarf Disposal System • Inspection Hardware (C.M.M. facilities) • Programmable Logic Controllers (P.L.C.)

Software: -

Software for F.M.S. can be divided into 2 broad categories – extrinsic functions and intrinsic functions (Figure 4). Software for the extrinsic functions is used to plan and control the functions that take place outside the physical boundaries of the F.M.S.2 Software for the intrinsic functions is used to load and control the components within the physical boundaries of the F.M.S.

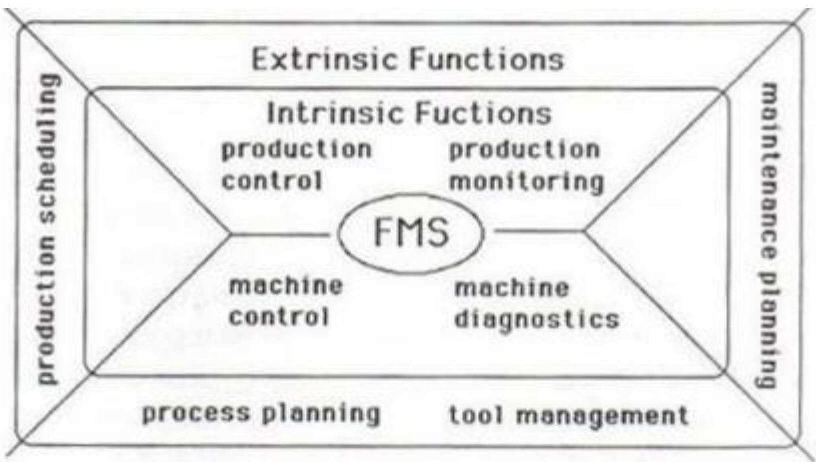


Fig 2.2 Functions

Extrinsic Functions incorporate the following operations: - • Production Scheduling • Process Planning • Tool Management • Maintenance Planning

Intrinsic Functions incorporate the following operations: - • Production Control • Production Monitoring/ Reporting • Machine/ Process Control • Machine Diagnostic

HIERARCHY OF COMPUTER CONTROL

One of the early applications of a digital computer in an industrial facility was for plant monitoring and supervisory control, as documented by Garrett and McHenry (1981). Figure 3 shows an evolution of the use of digital computers in industrial processes. As illustrated in Figure 3, Dupont-Gatelmand (1981) documented that the next step in evolution after the supervisory control is the computer numerical control (CNC) of the machines followed by direct digital control (DDC) for a group of multiple numerical control (NC) machines.

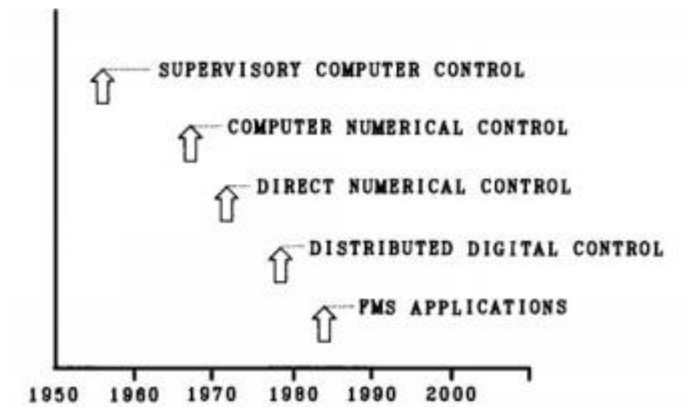


Fig 2.3 evolution of the use of digital computers in industrial processes

In the DDC, as written by Lukas (1986), a computer reads and directly processes measurements,, calculates the proper control outputs, and sends the control commands to the activation devices. In the initial implementations of DDC, backup analog control systems were used to avoid the ill effects of computer failures. In spite of the early computer hardware reliability problems, DDC demonstrated many advantages over analog control systems. They included the use of complex logic to calculate more accurately the control command values, ease of data logging, data trending, alarming, and so on. It also avoided the common problem of set-point drifts associated with analog devices. Several different system architectures evolved for the DDC systems in the late 1970s.

However, a central computer was a dominant feature of all the variations of these architectures. The single largest disadvantage of these architectures, as pointed out before, was the single-point failure of the central computer, which could shut down the process. It necessitated the expense of a second computer as backup. Another disadvantage was that the software for the central computer was very complex and required a team of software/hardware experts to change and maintain the software. It also had limited expansion capability and, when the expansions were made, they were very expensive.

In the mid 1960s the distributed control system architecture was brought forward as a viable option. The technology to implement the DDC in a costeffective manner was not available until the early 1970s.

The price of computers decreased significantly and personal computers could be used economically on the factory floor. A number of production lines with distributed control systems have begun to emerge since the late 1970s.

In the mid 1960s the distributed control system architecture was brought forward as a viable option. The technology to implement the DDC in a cost effective manner was not available until the early 1970s. The price of computers decreased significantly and personal computers could be used economically on the factory floor. A number of production lines with distributed control systems have begun to emerge since the late 1970s.

As shown in Figure 1, every work center has a dedicated control computer. The work center computer is responsible for making production happen in its work center. It communicates with each tool and robot and downloads the programs, resulting in appropriate commands for all equipment. It is also responsible for ascertaining the health of all the components in the work center. The next level in the hierarchy of computer control is the subassembly/main assembly line computer. In general, this computer coordinates and controls the manufacturing activities within a section of the manufacturing facility. This computer communicates to each work-center computer the type of product to be made and all the appropriate commands. It also serves as a backup to any one of the failed work-center computers in its jurisdiction.

As shown in Figure 1, the supervisory computer is at the highest level in the hierarchy of computer control. This computer does overall production planning and scheduling and communicates with the subassembly/main assembly line computers (Koren, 1983). In the event of the failure of any of the subassembly/main assembly computers, the supervisory computer takes over the tasks of the failed computer. The key for producing economically different products or part numbers from the automated line shown in Figure 1 is the flexibility provided by the computer control. Simple software changes can dictate the automated manufacturing line to produce different part numbers by changing the number of subassemblies, the manufacturing process in designated work centers, and the logistics flow of the parts.

COMPUTER CONTROL OFWORK CENTER

The task of controlling total production in an FMS plant is the management of a complex set of machines interconnected with the automated parts transfer mechanisms. To control a real-time process, the computer must do the following,

1. Process Control Commands: The control computer must have the software capability to direct the hardware devices to do their tasks. The hardware includes the actual machines that perform the manufacturing operations and the logistics mechanisms.

2. Process-Initiated Interrupts: The control computer must receive and respond to the signals received from the process. Depending upon the importance of the signal, the computer may have to abort its current operation and perform a priority task.

3. Periodic Time-Initiated Events: The control computer must periodically collect management and status information. This is important for creating a history base and performing trend analyses.

4. System and Program-Initiated Events: The work-center computer is connected to subassembly/main assembly control computer. Therefore, it must handle communication and data transfer with the higher level computers. Figure 3 shows a set of control functions the work-center control computer must perform, A brief description of each of these control functions is given in the remainder of this section.

Fig 2.4 Work center computer control functions

5. Programmable Device Support: The control computer is responsible for downloading the part programs to the devices in the work center that have their own control computers. The downloading is coordinate to the work-center production schedule.

6. Tool Management: This control function includes management of all reusable resources such as drills, bits, gauges, and so on, with the work center. It should keep the inventory of all tools and monitor tool wear.

7. Maintenance: The work-center control computer must keep track of the health of each piece of equipment within the work center. This includes keeping a maintenance history and creating preventive maintenance schedules. The maintenance function is directly related to the availability of the work center for production.

8. Material Handling: The control computer is responsible for the flow of material into the work center, movement of material within it, and the flow of material exiting it. As shown in Figure 1, the devices used for material handling are the conveyors, robots, AGVs, and so on.

9. Statistical Process Control: In a completely automated FMS plant, it is necessary to perform a statistical check within the work center to a predefined statistical norm. The control computer must perform such checks periodically and take appropriate actions to correct any variations in the manufacturing process within the work center.

10. Communication: The control computer must communicate with every device within the work center. It must also communicate with the subassembly/main assembly computer. Orderly and accurate

communication is needed to avoid costly waste. The exact product schedule will be communicated to the work-center computer by the subassembly/main assembly computer.

11. Monitoring: The control computer serves as an alert and indefatigable supervisor. The most important monitoring task is that of process monitoring. This usually requires that the control computer establishes the status of the instruments and the process variables, the status of the equipment within the work center, and the status of the product itself. The control computer can also monitor indirect measurements, as shown by Savas (1985). These measurements are a function of several directly monitored process attributes. The computer supervision is an important function in producing a defect-free product in a work center.

12. Data Logging and Alarming: The work-center control computer must collect and store the information about all the devices in the work center and the significant events that take place in it. These data will be used to create preventive maintenance schedules and keep the processing capabilities of the devices current. The data can be uploaded to the subassembly/main assembly computer for trend analysis. The data can be used for the alarm management function.

COMPUTER CONTROL IN SUBASSEMBLY/ MAIN ASSEMBLY LINES

The control computer in a manufacturing line communicates with the workcenter control computers and ensures scheduled production through its line. The subassembly/main assembly line control computer receives its production schedule from the FMS supervisory computer. The primary functions of the subassembly/main assembly line control computers are as follows.

1. Monitor Production Performance: The subassembly/main assembly line control computer must monitor the production performance of each work-center control computer in its jurisdiction. If the work-center control computer fails, the subassembly/main assembly line control computer has the responsibility to function as a backup control computer. Therefore, it must be capable of performing the control functions of the workcenter control computer given in Section IV.

2. Database Management: The subassembly/main assembly line control computer receives and stores all the process and device-related data in its database, as pointed out by (Meister, 1987). It manipulates these data and uploads them to the FMS supervisory control computer for generating production plans.

3. Production Scheduling: The subassembly/main assembly line control computer receives primary production and two backup production schedules each day from the FMS supervisory control computer. This process is described in Section VI. The subassembly/main assembly control computer utilizes the backup production schedule in the anomalous operating conditions. It communicates such operating conditions to workcenter computers as well as to the FMS supervisory control computer.

4. Alarm Management Section: The subassembly/main assembly line control computer is responsible for the alarm management system. The control computer must keep log of the reasons for all the alarms in all the work centers in its jurisdiction.

FMS SUPERVISORY COMPUTER CONTROL – TYPES OF SOFTWARESPECIFICATION AND SELECTION – TRENDS.

As the name implies, the supervisory computer supervises and controls production throughout the entire manufacturing facility. This is the highest and most important level in the hierarchy of computer control. At this level, the demands for various parts are analyzed.

Knowing the process involved in the manufacture of each product and the capacity of each of the equipment, a production schedule is created. Simulations are run to understand the capacity pinch-point operations. An overview of the important control functions of the supervisory computer are presented.

1. Production Planning: Production planning necessarily begins with the analysis of firm demands for each product and the forecast of future sales. The supervisory computer database necessarily contains the description of the production process for each product and the tool capacity in each subassembly/main assembly line. A preliminary production plan for the facility is created for the rolling day that will accommodate the firm and projected demands.

2. Simulation: The demands for each product within the production plan should be simulated to understand the pinch-point resources and the intricate subtleties for the product changeover requirements. "What if" scenarios should also be simulated to create alternative production plans. They should include tool failures, part shortages, or quality problems. The data used should be based upon the historical data stored in the supervisory computer. The simulation effort may be very complex since a product may be able to take alternative routes made possible by the FMS. Buzacolt (1983) described a basic philosophy to develop models to estimate performance and key technical issues of FMS. If the preliminary production plan does not appear feasible, the production planning step described above may have to be repeated.

3. Master Production Schedule: A detailed production schedule for each day within the rolling week is created for the preliminary production plan, as well as two backup production plans using the "what if" analysis. The details of the master production schedule include the sampling/verification plan for each subassembly and for the final assembly for quality. Fox (1982) gave an overview of the FMS software control functions for variable missions and scheduling procedures. The master production schedule must be accurate. It will be downloaded each day to the subassembly/main assembly computers and it dictates the total production operations within the FMS.

4. Capacity Analysis: The supervisory computer must determine the unused capacity in each subassembly area. This unused capacity may be utilized to produce spare parts such as field replaceable units (FRUs). Also, the supervisory computer must schedule preventive maintenance consistent with the utilization of the equipment. Kumar and Vannelli (1986) presented a flexible decision process to help balance the capacity of work centers.

5. Communication: A supervisory computer requires constant communication with the subassembly/main assembly computers to be aware of the status of the equipment as well as the

production. It can then compare the status with the simulation results to predict the problem and sound appropriate alarms. In a completely automated FMS, the role of the supervisory computer is very important. It can help to fully utilize FMS hardware and therefore help to manufacture costcompetitive products.

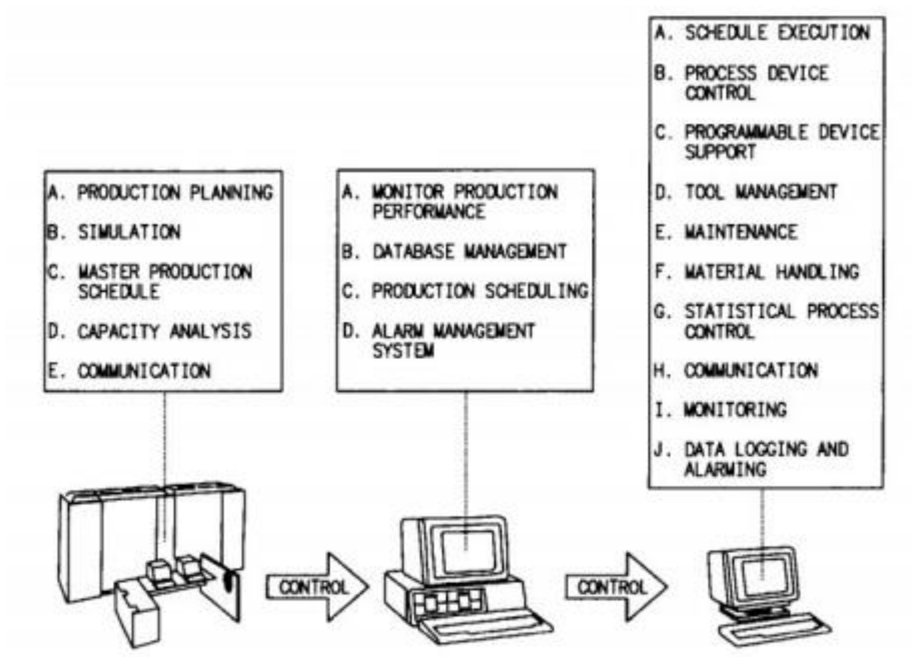


Fig 2.5 Computer control functions

TYPES OF SOFTWARE SPECIFICATION AND SELECTION

SYSTEM COMPONENTS: The typical components that become the building blocks of the FMS used for material removal can be summarized as follows: • Machine tools—machining centers, multiple-spindle machines, turning centers, and specialpurpose machines. • Material handling systems—industrial robots, tow-line carts, AGVs, conveyors, shuttle systems • Computer(s)/controller(s)—minis, micros, PLCs • Coordinate measuring machines (off-line quality assurance) • Automatic gaging/compensation stations (online quality control) • Automatic part wash stations

TYPES OF SOFTWARE:

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 are displayed in Figure 2. 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.

OBJECT-ORIENTED CONTROL ARCHITECTURE

In response to foreign competition and rapidly changing customer demands, domestic manufacturers in many industrial sectors have developed a strong interest in flexible automation. Decreased costs and improved capabilities in robotics and computer-integrated systems have increased the feasibility of such systems, particularly for small to medium-sized companies.

Their primary benefit is relaxation of the restrictions on the range of manufacturable products associated with 'hard' automation systems. In concert with the 'just in time' (JIT) manufacturing philosophy, companies are seeking to move from large volume/low product mix production capabilities towards reduced lot sizes. Ideally, systems should provide the ability to produce a significant set of parts, in lot sizes as small as one, without consuming appreciable time in setting up or adjusting production equipment for part changeovers.

Flexible automation is a vehicle for the reduction of both manufacturing lead times and lot size. Additional goals of flexible automation are the reduction of direct labor costs, improved quality and faster delivery. However, experience has shown that the implementation of full-blown flexible manufacturing systems has not, in general, provided the anticipated rewards.

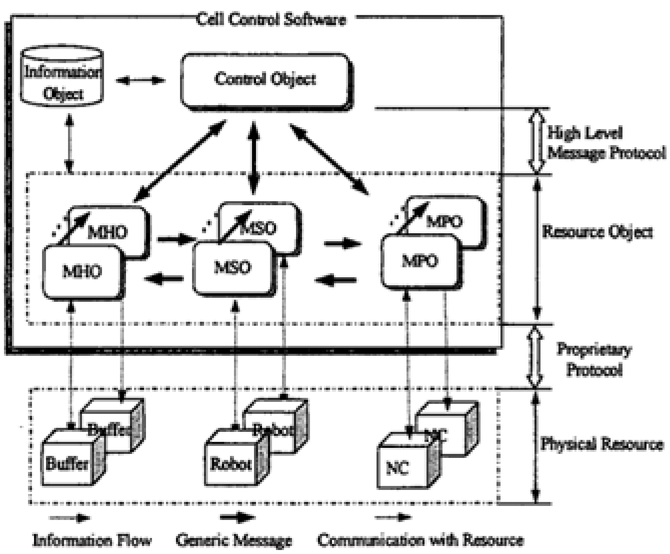


Fig 2.6 Object oriented control, architecture

Consequently, many companies have pursued the use of flexible cells as a means to learn and gain necessary experience in flexible automation (O'Grady, 1989). One critical task in the successful implementation of flexible cells is the development of the cell control system. To achieve its potential, flexible automation must have robust control software which can run on a number of hardware platforms and provide the following capabilities.

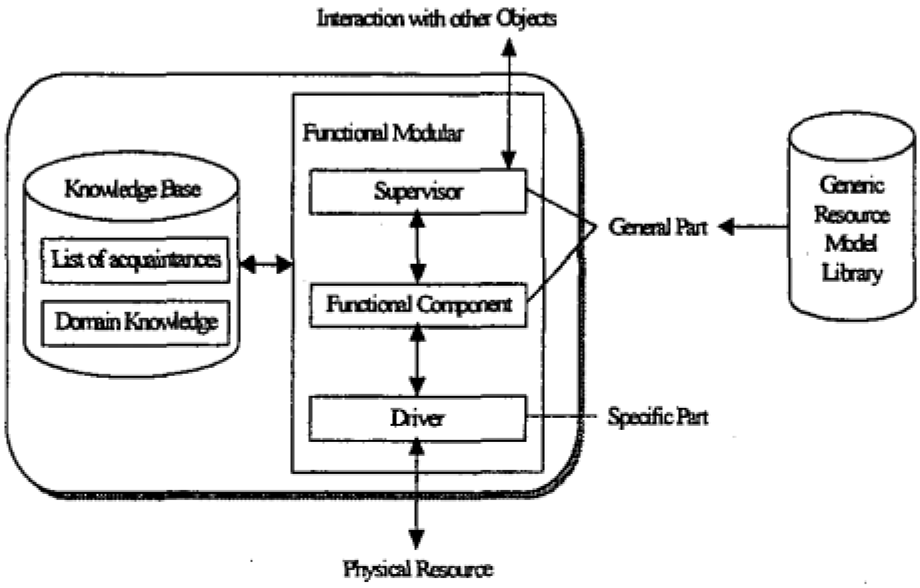


Fig 2.7 Generic resource library

1. The software must be able to communicate with all devices in the cell and control cell action, minimizing delays between signals and corresponding actions. 2. Errors in the system must be detected and handled within strict time limits. 3. The cell control software must easily adapt to different cell configurations. 4. The software must be extensible to accommodate the addition of new components (machinery) to the cell. A scheduling module should also be included in this software specification unless scheduling will be handled by a separate, but interfacing, program at the 'shop level' of the manufacturing system control hierarchy as described by Weber and Moodie (1989). In this chapter, a cell control system is presented which embodies the concepts of object-oriented design and programming and therefore has the following characteristics: • data encapsulation and information hiding; • structured, hierarchical knowledge representation; • inheritance of values; and, • flexible and reusable code. To provide context, a review of the recent literature discussing current approaches to cell control and modeling is provided. Then a generalized model for cell control is developed using the concepts of object-oriented design and programming. This model is further refined into a generic cell control architecture and class hierarchy. The architecture is then applied to a flexible manufacturing cell for furniture part production (FFMC) as described by Culbreth, King and Sanii (1989).

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT III SPR1605-FLEXIBLE MANUFACTURING SYSTEM

UNIT 3

MANUFACTURING DATA SYSTEMS

Product life cycles are getting shorter and customers want variations. Production system flexibility is the key factor and systems are getting more complex

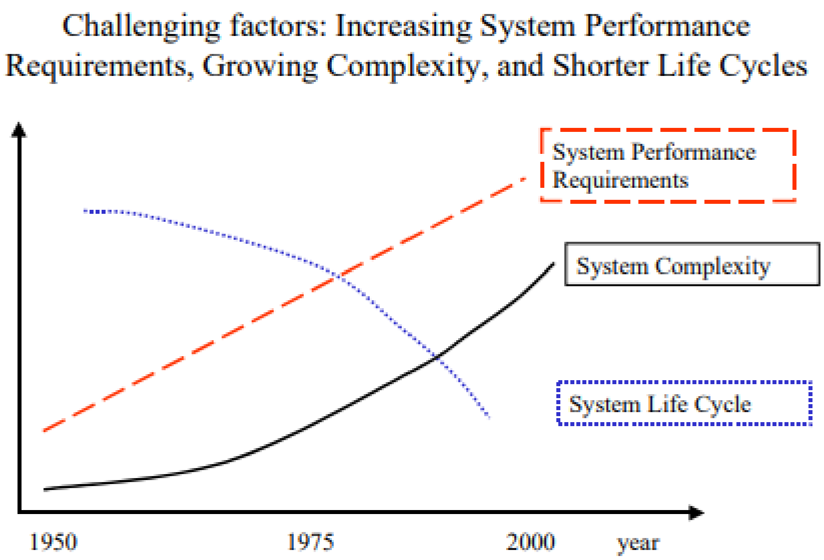


Fig 3.1 Challenging factors

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.

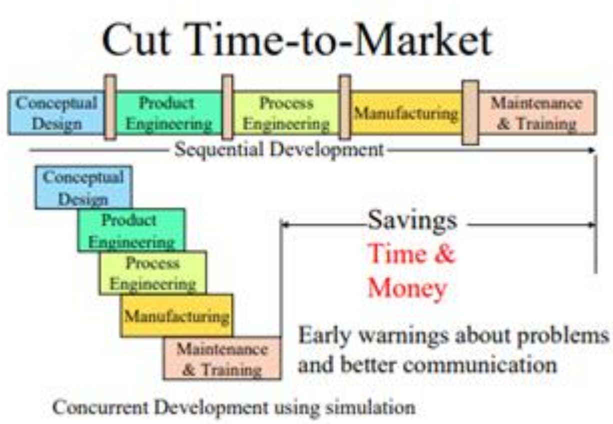


Fig 3.2 Digital manufacturing tools

Manufacturing system design involves a number of interrelated subjects, e.g., tooling strategy, material-handling 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.

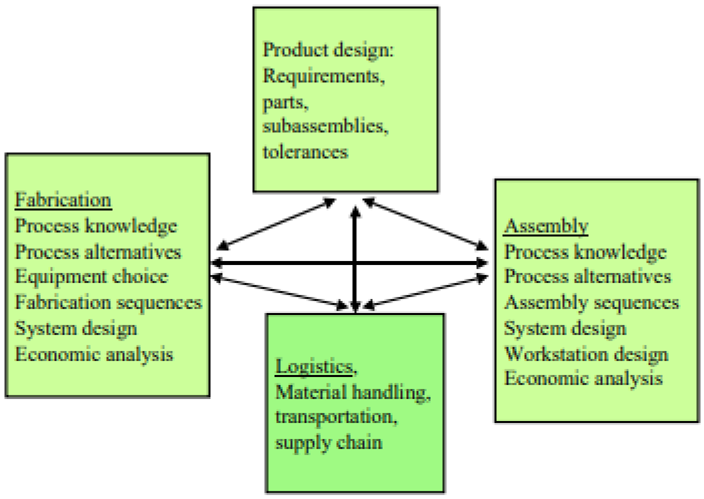


Fig 3.3 Connections between product design, fabrication, assembly and logistics system

Time-to-customer, punctuality and throughput time, are important competition factors in make-to-order 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.

APPLICATUION OF SIMULATION

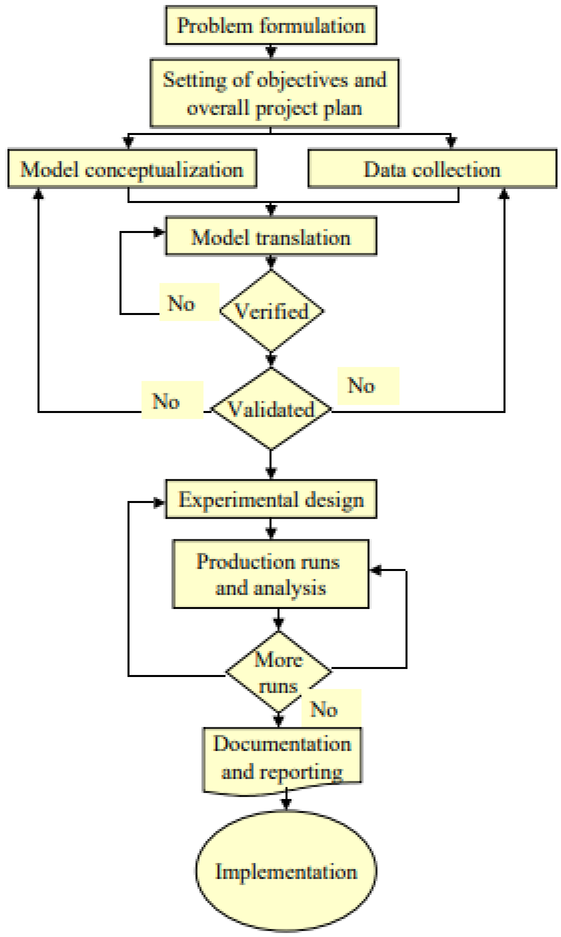


Fig 3.4 Simulation project

A simulation project is described in Figure, Set of steps guide a model builder in a thorough and sound simulation study. Following steps should be present in any simulation study

1. Problem Definition

Clearly defining the goals of the study so that we know the purpose, i.e. why are we studying this problem and what questions do we hope to answer?

2. Project Planning

Being sure that we have sufficient and appropriate personnel, management support, computer hardware and software resources to do the job.

3. System Definition

Determining the boundaries and restrictions to be used in defining the system (or process) and investigating how the system works.

4. Conceptual Model Formulation

Developing a preliminary model either graphically (e.g. block diagram or process flow chart) or in pseudo-code to define the components, descriptive variables, and interactions (logic) that constitute the system.

5. Preliminary Experimental Design

Selecting the measures of effectiveness to be used, the factors to be varied, and the levels of those factors to be Enterprise Scalable solution Factory Line Cell Machine Production simulation is useful in different levels of planning, from process planning to material flow analysis Human Product data and process data management CAD, PDM, ERP, etc.. Factory Line Cell Machine Enterprise Resources and process: database or file structure Simulation model is a re-usable document Figure

6. Simulation in all levels of manufacturing

AS 116.140 10 JuhaniHeilala 1999 investigated, i.e. what data need to be gathered from the model, in what form, and to what extent. 6. Input Data preparation. Identifying and collecting the input data needed by the model.

7. Model Translation

Formulating the model in an appropriate simulation language.

8. Verification and Validation

Confirming that the model operates the way the analyst intended (debugging) and that the output of the model is believable and representative of the output of the real system.

9. Final Experimental Design

Designing an experiment that will yield the desired information and determining how each of the test runs specified in the experimental design is to be executed (length of simulation run, warm-up periods, number of replications)

10. Experimentation

Executing the simulation to generate the desired data and to perform sensitivity analysis.

11. Analysis and Interpretation

Drawing inferences from the data generated by the simulation runs.

12. Implementation and Documentation.

Reporting the results, putting the results to use, recording the findings, and documenting the model and its use.

Many Uses of Simulation

In the manufacturing system life cycle following steps can be found: concept creation, layout planning, production simulation, software development, operator training and potentially operational use of the simulation model in decision support for managers. The use of simulation model can shorten the sales cycle of production system.

• Layout and concept creation (3D, animation)

• visualization, communication Design flow Product structure, BOM, process Production plans, mix, volume Process and material flow, tasks cycle times equipment cycle times, control/routing improvements to selected solution layout concepts, number and type of workstations, buffers Evaluation and selection of alternatives Figure 8. System design flow, simulation is the analysis tools for evaluating AS 116.140 13 JuhaniHeilala 1999

• cell, lines, factories

• Production simulation (data, analysis, reports)

• control principles, routing, buffer sizes, capacity, utilization, throughputtime, bottlenecks, etc

• Software development (emulation, system integration)

• Training of operators (emulation, VR)

• Operational use of simulation (Data, speed, integration)

Layout Planning And Concept Creation

3D visualization tools are needed to improve communication in concurrent engineering teams. In this step the facility floor space needs and production principle is verified. Logistic solutions can be evaluated also. Quick modeling is a benefit here.

Production Simulation

The aims usually are to test and verify plans, check the material flow routing and control principle, verify the buffer size and location and search for bottlenecks. The data should be real production data if available, or data from similar products or variants in the same product family. This is an iterative analysis, the engineers should return back to cell level studies, if some parameters need some more detail study, for example cycle time need to be shorter. One of the main requirements here is validated simulation model. Flexible, parametric model building is advantage.

Software Development

The simulation model can emulate the real system. With emulation the lower level software, i.e. PLC code can be tested and also upper level MES (Manufacturing Execution System) software. The real programs that will be used in the real system can be tested with real data if available. The virtual system, simulation model replaces in this case the planned system before anything is build to the factory floor. One of the main requirements here is validated simulation model and integration of software.

4.4.4 Training Of Operators

The emulation and simulation model is great tool for training of operators; the system parameters can be studied with simulation model. The software training with the real data can be done and this speeds up the ramp-up phase. If the control software has been integrated with the simulation model. The operators have the same user interface as in the real life and the simulation gives a holistic view to the manufacturing system.

Operational Use

While some models are used to plan and design, other models are used in the day-to-day operation of manufacturing facilities. These "as built"' models provide manufacturers with the ability to evaluate the capacity of the system for new orders, unforeseen events such as equipment downtime, and changes in operations. Some operations models also provide schedules that manufacturers can use to run their facilities. Simulation can complement other planning and scheduling systems to validate plans and confirm schedules.

Before taking a new order from a customer, a simulation model can show when the order will be completed and how taking the new order will affect other orders in the facility. Simulation can be used to augment the tasks of planners and schedulers to run the operation with better efficiency. Some of the operational uses of simulation models are [Thomson, 1993]: • Emulation of real time control systems • Real time display • Real time forecasting • Scheduling.

SIMULATION SOFTWARE

Simulation models can be build with general programming language such as FORTRAN or C/C++. Some routines can be found from the literature [Law and Kelton, 1991] Currently there are several commercial simulation tools available. These tools can be divided into three basic classes: general-purpose simulation language, simulation front-ends and simulators. The general-purpose simulation language requires the user to be a proficient programmer as well as competent simulationist. The simulation front-ends are essentially interface programs between the user and the simulation language being used. The simulators of today utilize constructs and terminology common to the manufacturing community, and offer graphical presentation and animation.

The discrete event simulators are well suited for the simulation of a manufacturing system. Simulators can reduce the time required to develop a simulation model and they may exceed the capabilities of the average manufacturing engineer, thus requiring a dedicated programmer/analyst.

There are often specialized situations and scenarios that are outside the available set of modeling constructs (i.e., objects), where the user must often resort to more intensive programming to complete the model. Recent development in simulator packages, especially in the ability to define submodels (reusable model segments), provide them with the flexibility to meet the needs of the development effort.

The newest versions of simulator packages have a graphical user interface (GUI), and the use of a mouse in model building is an advantage. The computer platform is usually PC Windows/NT or a graphical Unix workstation. Information about some simulators can be found from the following web addresses, note that there are also other simulators or simulation languages on the market:

Automod / Autosched	http://www.autosim.com
Promodel	http://www.promodel.com
Areena	http://www.sm.com
Factor/AIM	http://www.pritsker.com http://www.symix.com
Witness	http://www.lanner.com
TaylorII	http://www.taylorii.com
TaylorED	http://www.taylor-ed.com
Micro Saint	http://www.madboulder.com
Quest	http://www.deneb.com, http://www.tdm.fi,
Simple ++	http://www.aesop.de http://www.tecnomatix.com
Extend	http://www.imaginethatinc.com/
MODSIM III	http://www.modsim.com/

LIMITATIONS OF SIMULATION

Simulation modeling has become an essential tool for many types of industrial systems; for analyzing anticipated performance, for validating a design, for demonstrating and visualization the operation, for testing hypotheses, and many other uses. A question that is often overlooked should be asked: Is the simulation modeling the right tool for the problem?

Here are 10 rules for determining when the technique is not appropriate or may not lead to a successful outcome [Banks J. 1998].

1. The problem can be solved using commonsense analysis

2. The problem can be solved analytically

3. It easier to change or perform direct experiments on the real system

4. The cost of the simulation exceeds possible savings

5. Proper resources are not available for the project

6. There isn't enough time for the model results to be useful

7. There are no data – not even estimates

8. The model cannot be verified or validated

9. Project expectations cannot be met

10. System behavior is too complex or cannot be defined

MANUFACTURING DATA FLOW

Modeling of manufacturing system requires an understanding of the types of manufacturing systems that exits and the objectives and issues associated with each type of system. Types of manufacturing systems as defined by Harrell and Tumay (1995) include, but are not limited to:

1. Project shop

2. Job shop

3. Cellular manufacturing

4. Flexible manufacturing systems

5. Batch flow shop

6. Line flow systems (production and assembly lines, transfer lines)

Tab 3.1 Characteristics of a manufacturing system model

Manufacturing System parameters	
Physical layout	Product • Product flow, routing and resources needed • Bill of materials

Labor
• Shift schedules
• Job duties and certifications
	Production schedules
	• Make-to-stock
	• Make-to-order
	  • Customer order
	  • Line items and quantities

Equipment
• Rates and capacities
• Breakdowns
  • Time to failure, MTTF
  • Time to repair, MTTR
  • Resources needed for repair
	Production control
	• Assignment of jobs to work areas
	• Task selection of workcenters
	• Routing decisions

Maintenance • PM schedule • Time and resource required • Tooling and fixtures	Suppliers • Ordering • Receipt and storage • Delivery to workcenters
Workcenters • Processing • Assembly • Disassembly	Storage • Suppliers • Spare parts • Work-in-process (WIP)
	Final goods • Packing and shipping • Order consolidation • Paperwork • Loading trailers

Manufacturing and material handling systems can be arbitrarily complex and difficult to understand. Some of the characteristics needed for modeling are listed in Table 1 and 2. The number of possible combinations of input variables can be overwhelming when trying to perform experimentation. Other methods of analysis, such as spreadsheet models or linear programs, may not capture all the intricacies of process interaction, downtime, queuing, and other phenomena observed in the actual system.

Tab 3.2 Characteristics of a material handling model

Material Handling parameters	
Conveyors • Accumulating • Non-accumulating • Indexing and other special purpose • Fixed window or random spacing • Power and free	Storage systems • Pallet storage • Case storage • Small part storage • Oversize items • Rack storage or block stacked • Automated storage and retrieval systems (AS/RS) with storage -retrieval machines
Transporters • Unconstrained vehicles, Fork Lifts • Guided vehicles, AGV • Bridge cranes and other overhead lifts	

FMS DATA BASE SYSTEMS

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).

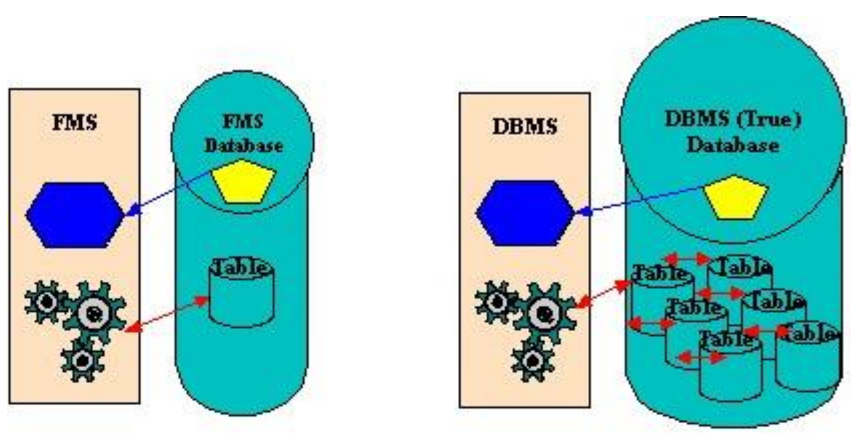


Fig 3.5 Comparison of FMS vs DBMS

Tab 3.3 File management systems

Advantages	Disadvantages
Simpler to use	Typically does not support multi-user access
Less expensive	Limited to smaller databases
Fits the needs of many small businesses and home users	Limited functionality (i.e. no support for complicated transactions, recovery, etc.)
Popular FMS's are packaged along with the operating systems of personal computers (i.e. Microsoft Cardfile and Microsoft Works)	Decentralization of data
Good for database solutions for hand held devices such as Palm Pilot	Redundancy and Integrity issues

Typically, File Management Systems provide the following advantages and disadvantages:

The goals of a File Management System can be summarized as follows (Calleri, 2001):

- *Data Management.* An FMS should provide data management services to the application.
- *Generality with respect to storage devices*. The FMS data abstractions and access methods should remain unchanged irrespective of the devices involved in data storage.
- *Validity*. An FMS should guarantee that at any given moment the stored data reflect the operations performed on them.
- *Protection*. Illegal or potentially dangerous operations on the data should be controlled by the

FMS.

- *Concurrency*. In multiprogramming systems, concurrent access to the data should be allowed with minimal differences.
- *Performance*. Compromise data access speed and data transfer rate with functionality.

From the point of view of an end user (or application) an FMS typically provides the following functionalities

- File creation, modification and deletion.
- Ownership of files and access control on the basis of ownership permissions.
- Facilities to structure data within files (predefined record formats, etc).
- Facilities for maintaining data redundancies against technical failure (back-ups, disk mirroring, etc.).
- Logical identification and structuring of the data, via file names and hierarchical directory structures

Database Management Systems

Tab 3.4 Database Management Systems advantages and disadvantages:

Advantages	Disadvantages
Greater flexibility	Difficult to learn
Good for larger databases	Packaged separately from the operating system (i.e. Oracle, Microsoft Access, Lotus/IBM Approach, Borland Paradox, Claris FileMaker Pro)
Greater processing power	Slower processing speeds
Fits the needs of many medium to large-sized organizations	Requires skilled administrators
Storage for all relevant data	Expensive
Provides user views relevant to tasks performed	
Ensures data integrity by managing transactions (ACID test = atomicity, consistency, isolation, durability)	
Supports simultaneous access	
Enforces design criteria in relation to data format and structure	
Provides backup and recovery controls	
Advanced security	

PREDICTIVE CONTROL OF FLEXIBLE MANUFACTURING SYSTEMS

Flexible manufacturing systems (FMS) are one of the key ingredients of modern flexible production systems where small batches of specialized products are produced to satisfy the specific demands of specific customers. To deliver high quality products with short response times has become a key factor for competitiveness. Short response times to fluctuating demands can always be achieved by large spare capacities in the production process.

The high investment which is necessary to install flexible highly automated manufacturing systems however renders this solution unacceptable. Thus scheduling policies are necessary which make sure that under the constraint of a high average load of the system, the due dates of the production jobs are met. The optimal allocation of the resources of complex manufacturing systems to a large number of competing jobs exceeds the capacities of humans using simple decision aids as pen and paper, wall charts etc. The implementation of similar tools on a computer which is only used for the graphical representation of the actual state of the decision process, as it is frequently offered by the vendors of computer-based factory control systems does not remove this bottleneck. Scheduling should be done on-line, i.e. depending on the actual situation in the production process, by suitable algorithms and only be controlled and eventually modified by the dispatchers.

The resource allocation problem in manufacturing systems of the jobshop type is known to be NP-hard. This means that the computational effort to find the optimal solution grows exponentially with the number of operations and the number of machines considered, and a trueoptimization becomes unfeasible on-line even for very small systems. The standard solution to the scheduling problem in practice is to generate suboptimal schedules using priority rules for the individual queues. Most priority rules are computationally extremely simple and can be implemented easily. For a test problem described in detail in section 2, we present the results of a detailed study on the performance of all usual priority rules in section 4. Observations of the scheduling errors caused by the known priority rules motivated the introduction of a new rule, the WLS (weighted loss of slack) rule.

This new rule is described and compared with the conventional rules in section 5. To overcome the deficiencies of priority rules in general, we then investigated predictive strategies for multimachine problems. Our approach is based on the idea of predictive control as it has emerged in the context of standard continuous control problems (Richalet et al., 1978; Clarke et al., 1987; Garcia et al., 1989). The basic idea of predictive control is: assume the present state of a system and a model of its dynamics are known, and a desired trajectory of some variables (outputs) is prescribed.

Then, at a given instant of time, the effect of all possible control inputs on the future evolution of the system can be evaluated, and the input sequence which yields the best fit to the desired trajectory can be determined. As both disturbances and changes of the desired trajectory may occur, this process is iterated, and only the first or the first few control inputs are used. In the control of standard continuous-time or discrete-time dynamical systems with continuous variables, the computation of the optimal input which minimizes a given cost function over a finite or infinite horizon is relatively simple in many cases, e.g. for quadratic cost functions. In our case, due to the discrete nature of the problem, an analytical solution of the optimization problem is not possible and the computational effort increases exponentially with the length of the horizon which is considered. The key factor for the applicability and the performance of predictive scheduling algorithms is an adequate restriction of the search problem to critical decisions and/or promising candidate control sequences.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT IV SPR1605-FLEXIBLE MANUFACTURING SYSTEM

UNIT 4

GROUP TECHNOLOGY AND JUSTIFICATION OF FMS

GROUP TECHNOLOGY

Group technology is a manufacturing technique and philosophy to increase production efficiency by exploiting the "underlying sameness" of component shape, dimensions, process route, etc.

WHY GROUP TECHNOLOGY?

1. Average lot size decreasing

2. part variety increasing

3. increased variety of materials

4. with diverse properties

5. requirements for closer

6. Tolerances PART FAMILIES (Similarity groupings are called Part Families)

• A part family is a collection of parts that are similar either because of geometric shape and size or because similar processing steps are required in their manufacture.

• The parts within a family are different, but their similarities are close enough to merit their inclusion as members of the part family.

GROUPING PART FAMILIES 0

• There are three general methods for solving part families grouping. All the three are time consuming and involve the analysis of much of data by properly trained personnel.

• The three methods are:

• Visual inspection.

• Parts classification and coding.

• Production flow analysis.

1- Visual Inspection Method The visual inspection method is the least sophisticated and least expensive method. It involves the classification of parts into families by looking at either the physical parts or their photographs and arranging them into groups having similar features.

2- Parts classification and Coding

• In parts classification and coding, similarities among parts are identified, and these similarities are related in a coding system.

• Two categories of part similarities can be distinguished:

1. Design attributes, which concerned with part characteristics such as geometry, size and material.

2. Manufacturing attributes, which consider the sequence of processing steps required to make a part.

• Reasons for using a classification and coding system:

• Design retrieval. A designer faced with the task of developing a new part can use a design retrieval system to determine if a similar part already exist. A simple change in an existing part would take much less time than designing a whole new part from scratch.

• Automated process planning. The part code for a new part can be used to search for process plans for existing parts with identical or similar codes.

• Machine cell design. The part codes can be used to design machine cells capable of producing all members of a particular part family, using the composite part concept.

• A part coding system consists of a sequence of symbols that identify the part's design and/or manufacturing attributes.

• The symbols are usually alphanumeric, although most systems use only numbers.

• The three basic coding structures are:

1. Chain-type structure, also known as a polycode, in which the interpretation of each symbol in the sequence is always the same, it does not depend on the value of the preceding symbols.

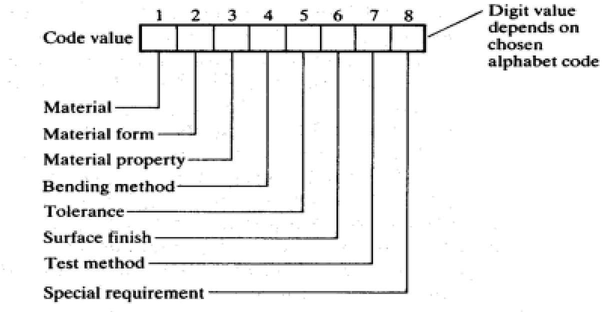


Fig 4.1 Chain type structure

2. Hierarchical structure, also known as a mono code, in which the interpretation of each successive symbol depends on the value of the preceding symbols.

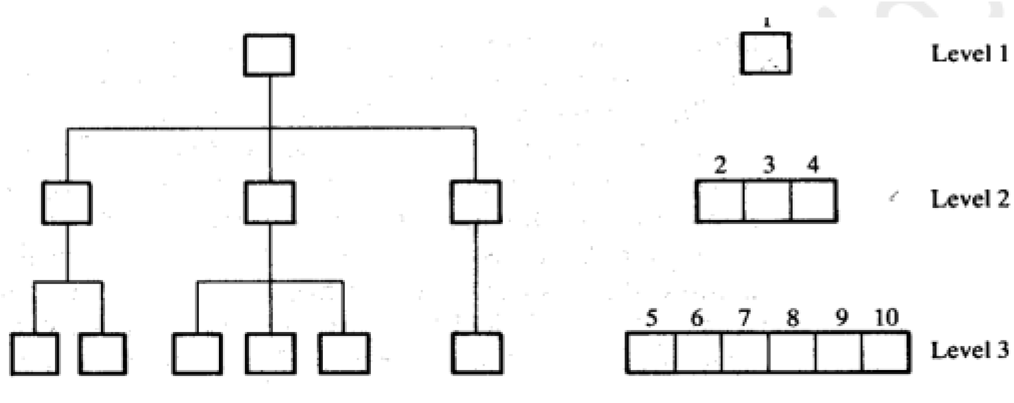


Fig 4.2 Hierarchical structure

MATHEMATICAL MODELING

Mathematical modeling is the art of translating problems from an application area into tractable mathematical formulations whose theoretical and numerical analysis provides insight, answers, and guidance useful for the originating application.

Mathematical modeling

- is indispensable in many applications
- is successful in many further applications
- gives precision and direction for problem solution
- enables a thorough understanding of the system modeled
- prepares the way for better design or control of a system
- allows the efficient use of modern computing capabilities

Learning about mathematical modeling is an important step from a theoretical mathematical training to an application-oriented mathematical expertise, and makes the student fit for mastering the challenges of our modern technological culture.

Graphic-Analytical Model of FMS

Manufacturing flexibility expresses the capacity of the system to produce not only a typological diversity of products but also unpredictability and instability, reduced time delivery, small batch manufacturing, rapid response to changing market conditions, change in structure-insensitive manufacturing pregnancy, rapid reconfiguration of the system to change production volumes, and geometric configuration of the piece.

Flexible manufacturing systems (FMS) are oriented, open, deterministic, and complex systems.

The study of such a system means to know the evolution in time of inputs/outputs and of the transfer of information. This is done using mathematical models. Developing a mathematical model consists in developing a system block diagram representation and of defining the analytical part, the graphic-analytical model developed for FMS. A system is generally defined as the set of components grouped by organizational rules which have a lot of functional relationships. The system is defined as consisting of three components: external environment (EE), composition (CS), and structure (ST). The FMS graphic processing part revolution will be designed by highlighting the physical meaning of different types of variables involved in the system:

a. Exogenous variables are variables for which behavior is dictated by external phenomena and events, variables through which the system can communicate with the external environment:

• Input variables (command) define inputs to the system (for which the values are given, known, and estimated).

• Output variables define the outputs from the system (resulting from processing).

• Disturbance variables external environmental influences on the system. The functional relationship (linked) between input and output variables can be expressed mathematically in the form of algebraic equations (inequalities), differential equations, integral equations, etc.

b. Endogenous variables are those in which the behavior is dictated by the interior system phenomena and events and that describe its dynamics.

There are two such types of variables: state variables, defining the state of the system, and interaction variables (between subsystems), defining the links between subsystems.

In the external environment (outside the system EEo—exomedium), many outlets, objective functions—performance indicators (imposed, real parameters that are available) chosen from the sensitivity indicators—are found. At the output of the manufacturing system, products with determined configurations and properties, and auxiliary materials and waste are found. The energy consumed within the system during the process is released into the environment as heat. If the output size-power is considered as the default in the study of manufacturing systems, the output size-information, instead, has a special importance for the production management by expressing the real state of the system during the process evolution on which real-time and real-environment operative manufacturing management decisions are based. Summarizing the above, it appears that the general function of a manufacturing system consists in transferring the information flow (IF) into a material flow (MF), using an energy flow (EF), so that the information creates an emerging property on input FM, transforming it into an output finished product (Pf) that can be sold on the market.

Knowing the overall system function, one can determine its structure, and their connecting and relating elements within the structure. For this, a time evolution analysis of the material, energy, and information flow on the transfer that is transferred is transformed in the manufacturing system from input to output. Finally, the overall structure of the flexible manufacturing system will be determined by allocating partial functions to some physical elements—FMS component subsystems such as machine tools, transmission, transformation and processing systems, handling, transport and storage elements, transmission and distribution of energy, and its transformation, etc. Then, the necessary links between them are established in order to achieve the overall system operation. Input Dates and Variables The complexity of a system is given by the number of components, the number and type of interactions, the set of system state, the nonlinearities type, and the number of inputs and outputs. During design, system decomposition S should be made in a minimum number (strictly necessary) of subsystems, so that each sub-model is globally optimal solvable. Process management subsystem (PrM) has the function of couplings coordinator between subsystems and of sharing the subsystem objectives. Coordination of interactions at the same hierarchical level is made by establishing relationships of priority between subsystems for which the number should be minimal. The processing subsystem (PrSb) has priority over other subsystems, followed by industrial logistics subsystem (ILSb) and the stocking/storage subsystem (STSb), then the measurement/control subsystem (MCSb), and ancillary subsystems (ASb). The analyzed system is characterized by inputs (i) and outputs (o) and, therefore, by input data, output data, and information links. The system links with the external environment represent the so-called “external coupling” or “entourage”. External couplings can be found on the input, in the input external environment (EEe) and on the output, and in the output external environment (EMo). The input EEe contains “resources”, and the output EEo contains the system “target”. The dependency relations between external environment EEe (“resources”)–the system composition SC (“middle”)–external environment EEo (“target”) are shown in the figure above. For the studied case, the graphic-analytical model from Figure 1 was elaborated.

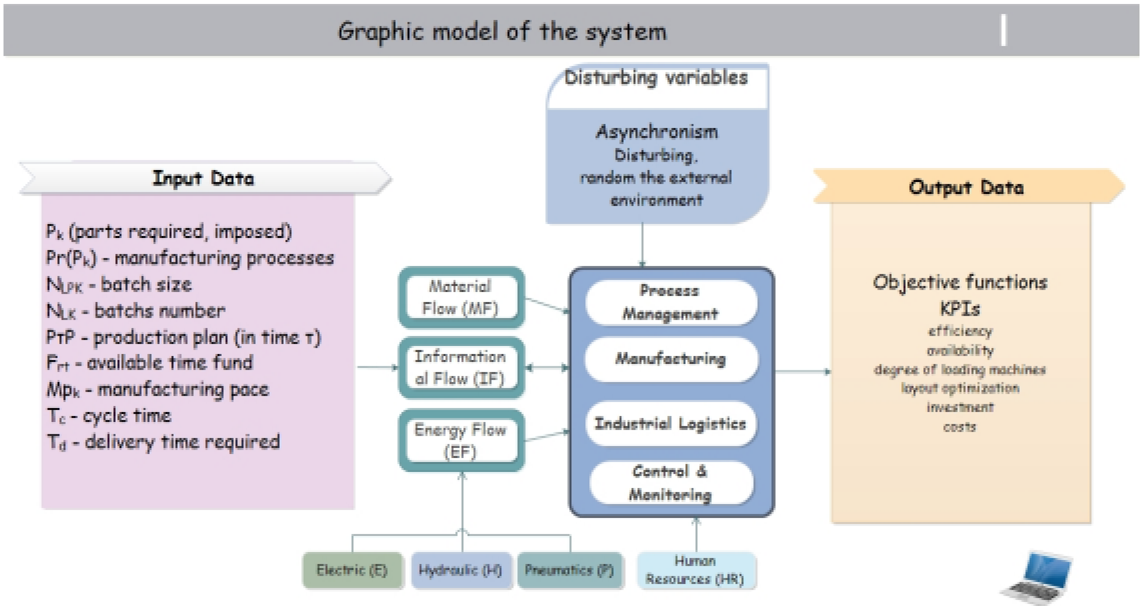


Fig 4.3 Graphic model of the system

Inputs in a flexible manufacturing system that are found in the input external-environment (EEe) are the following: material flow (MF), informational flow (IF), energy flow (EF), and manpower (MP). Outputs from the manufacturing system represent the output external environment (EEo) containing the following output flows: finished goods flow (strategic finished product for the company and finished parts for third parties); knowledge flow (know-how); waste flow (recoverable waste and residues); and secondary energy flow, formed by secondary recoverable energy and secondary dissipated energy. A major influence on the evolution of the system in time has the appearance of random variables in the system, such as bottlenecks. They are unpredictable and require a probabilistic analysis. By simulation, they can be easily identified; then, by applying the optimization model, they can be eliminated, ensuring continuous flow operation and reducing losses on the manufacturing line.

Knowledge-Based Scheduling System

Numerical algorithms have traditionally been used for solving scheduling problems. The approach presented in this section involves not only algorithms but also declarative and procedural knowledge and an inference engine, all implemented as a knowledge-based scheduling system (KBSS). The KBSS performs the following two basic functions: Selects an algorithm for the problem considered• Controls the schedule generation procedure of the algorithm selected•

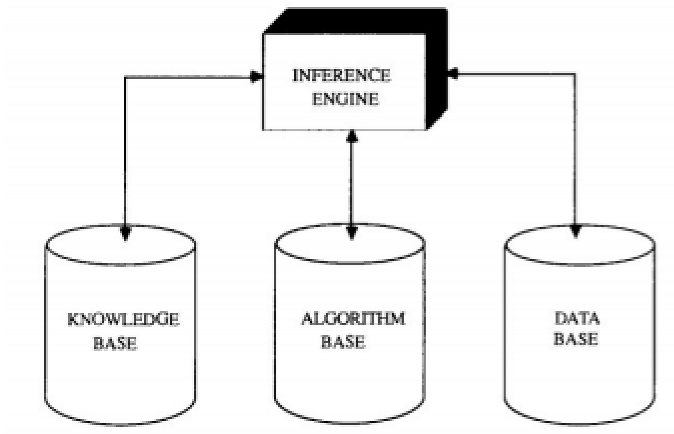


Figure Structure of the knowledge-based scheduling system (KBSS).

Fig 4.4 Knowledge-Based Scheduling System

The knowledge-based system is built using the tandem architecture proposed in Kusiak (1987). The basic components of the KBSS is shown in Figure 26. (Full details of KBSS and computational results are presented in Kusiak, 1990.) As shown in Figure 26, the scheduling system KBSS involves • Knowledge base • Algorithm base • Data base • Inference engine

Knowledge Base

Knowledge in KBSS has been acquired from experts as well as the scheduling literature. Frames are used to represent the declarative knowledge related to the description of scheduling problems, parts and operations, and the schedules generated. Four sample frames for a scheduling problem, part, operation, and the schedule generated are presented below.

Frame 1

```
(Problem_number (Problem_type (e.g., flow shop))
  (Problem_features
       (Number_of_parts,
        Number_of_operations,
        Number_of_precedence_constraints)))
```

Frame 2

```
(Part_number (Due_date (value))
             (Number_of_operations (value))
             (Number_of_process_plans (value))
             (Process_plan_0 ( operation_number,
                         processing_time,
                         machine_number,
                         tool_number,
                         pallet_fixture_number,
                         material_handling_carrier_number))
            .
            .
            .
```

```
(Process_plan_p ( operation_number,
                  processing_time,
                  machine_number,
                  tool_number,
                  pallet_fixture_number
                  material_handling_carrier
                  _number)))
```

Frame 3

```
(Operation_number (Belongs to (part_number))
    ((Preceding_op (op_1, op_2, ..., op_a))
     (Successive_op (op_a+1,op_ a+2, . . . ,
     op_b))))
```

Frame 4

```
(Schedule_of_problem (Problem_number)
        (Generated_by (algorithm_number))
        (Idle_time (machine_1, machine_2, ...,
        machine_m))
        (Completion_time (part_, part_2, ..., part
        _n))
        (Average_utilization_rate ( machine,
                                    tool,
                                    pallet_fixture,
                                    material_handling
                                    _carrier))
```

Economic justification

Economic justification of projects requires knowledge of costs and benefits attributable to the project. The costs and benefits included in a justification procedure depend on the accuracy required. This depends on whether the study is preliminary or final. In order to make the proper investment decision on a flexible manufacturing system, the data requirements of the procedure should be addressed and the costs and benefits of the FMS should be identified. As described by Choobineh, ~ benefits ofa FMS are broken down to two classes: strategic, as described above and listed in Table 1; and tactical, which are measurable and more easily evaluated by current engineering economy procedures and are listed in Table 2.

Table 4.1 Strategic benefits of FMS

1. Improvement in ROE
2. Better competitive advantage
3. Ability to adjust to varied product life cycles
4. Development of engineering and management expertise
5. Lower exposure to labor unrest
6. Being viewed as the leader in the use of new technologies
7. Ability to introduce some products faster to the market

Tab 4.2 Typical benefits of FMS

1. Lower work-in-process inventories
2. Reduced setup time
3. Reduced throughput time
4. Reduced throughput time variability
5. Lower fixtures and jigs costs
6. Improved manufacturing control
7. Improved quality
8. Reduced scrap rate
9. Reduction of floor space used
10. Reduced labor costs
11. Reduced tooling costs
12. Reduced rework
13. Better status monitor of machines, tools, and material handling devices
14. Improved data management
15. Improved control of operations
16. Improved control of parts
17. Improved response time to demand variations
18. Improved ability to adjust to machine breakdowns
19. Improved working conditions
20. Improved ability to respond to design or process change over

Justification Procedures

The cost elements of Table 3 and the benefits shown in Table 2 should be estimated. The effort put into quantifying the costs and benefits depends on the degree of accuracy required.

Table 3
Cost Elements for Economic Evaluation of a MS

1. System design
2. Machine tool and material handling capital
3. Installation and training
4. Tooling
5. Fixture and jig
6. Programming
7. Maintenance
8. Computers and communication network
9. Inspection
10. Labor and supervision
11. Rework and scrap
12. Burden
13. Energy
14. Floor space
15. Raw material inventory
16. Work-in-process inventory
17. Finished parts inventory
18. Estimates of equipment working life
19. Estimates of the salvage value of the equipment
20. Demand pattern of the parts over the working life of the equipment

The payback period, rate of return and net present value are popular engineering economy methods for tactical type investment decisions. Payback period is the most popular due to its ease of use. 4 Unfortunately, payback period does not account for the time value of money, and therefore the validity of the payback period as an economic justification method is suspect. The net present value method is recommended for the economic analysis of the alternatives. In particular, the incre- mental method for maximizing the net worth of the portfolio of alternatives is suggested. Strategic benefits are used to develop strategic factors. A strategic analysis of the alternatives will justify the selection of the FMS project. Choobineh 2 advocates the use of a scoring method. Weights are assigned to attributes to represent the importance of each. This method takes into account each strategic factor by assigning a score (from 1 to 1,000) for that factor for each alternative. Each score is multiplied by its respective weight and the weighted scores of the factors for each alternative are summed, The author believes this technique has short- comings. In particular, one cannot be sure the function is linearly additive and judgements cannot be measured for consistency.

Measuring flexibility and performance

Flexible manufacturing system (FMS) is a highly integrated manufacturing system. Therelation between its components is very complex. The mathematical programming approaches arevery difficult to solve for very complex system so the simulation of FMS is widely used to analyze itsperformance measures. Also the FMS components are very sophisticated and costly. If FMS has tobe implemented then it is better to analyze its results using simulation which involves no loss ofmoney, resource and labor time. As a typical discrete event system FMS have been studied in suchaspects as modeling and performance analysis.

The optimal design of FMS is a critical issue and it is acomplex problem. There are various modeling techniques forFMS; the most common one are based on mathematical pro-gramming. FMS is a highly integrated manufacturing systemand the inter-relationships between its various componentsare not well understood for a very complex system. Due to thiscomplexity, it is difficult to accurately calculate the perfor-mance measures of the FMS which leads to its design throughmathematical techniques. Therefore, computer simulation isan extensively used numeric modeling technique for the analy-sis of highly complex flexible manufacturing systems.

Petri nets

Petri nets as a mathematical tools possess several properties.These properties, when construed in the context of modeledsystem allow the system designer to identify the presence or ab-sence of the application domain specific functional propertiesof the system under design. There are two types of propertiesfor Petri nets: behavioral and structural. The behavioral prop-erties are those which depend on initial state or marking ofPetri nets while the structure properties do not depend uponthe initial state but on the topology or net structure. Someof the behavioral properties are reachability, boundedness,conservativeness, etc

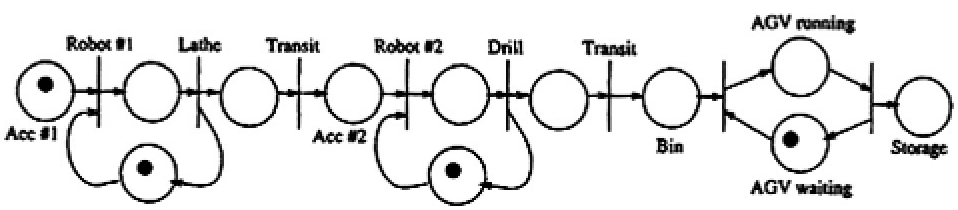


Fig 4.4 Petri net model

Boundedness

A Petri net (N,M0) is said to be bounded if the number of to-kens in each place does not exceed a finite numberkfor anymarking reachable fromM0, i.e.M(p)6kfor every placepand every markingMeR(Mo). Places are frequently used torepresent product and tool storage areas in manufacturing sys-tems, etc. In manufacturing systems, attempts to store more tools, for instance, in the tool storage area may result in theequipment damage. The Petri net property which helps to iden-tify in the modeled system the existence of overflows is the con-cept of boundedness.

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE

www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT V SPR1605-FLEXIBLE MANUFACTURING SYSTEM

UNIT 5

APPLICATIONS OF FMS AND FACTORY OF THE FUTURE

INTRODUCTION

This FMS was developed as a result of the combined efforts of GD and the Air Force Wright Aeronautical Laboratories/Materials Laboratory (AFWAL/ML). As this FMS is a part of a overall computer integrated manufacturing (CIM) architecture or strategy, it cannot be labeled as an island of automation. Also, this FMS is important because it is both a commercial and a research and development venture. One of the goals of this FMS was to advance the American machine tool and factory automation industries. Westinghouse Automation Division was the main supplier.

PHYSICAL CONFIGURATION

DeVlieg Machine Co. supplied the machine tools for this FMS, which is comprised of six, five-axis DeVlieg 430R machining centers. The pallet changers at the front of each machine automatically perform pallet exchanges between the AGV, pallet queueing stations, and the machine bed. A second pallet changer at the rear of the machine tool is used to exchange tool carousel pallets with the AGV. Part dimensions are inspected on LK Tool horizontal-arm coordinate measuring machines (CMM), which are fully integrated with the FMS to provide for unattended operations. Cutting tools are stored in a central tool crib. Required tools are manually loaded on a tool pallet carousel. When these tools are loaded, a pallet changer in the tool crib automatically loads the tool pallet onto an AGV for delivery to the appropriate machine. At the machine, a GMF robot loads these tools into the tool magazine and unloads dull or unneeded tools to be returned to the tool crib. The entire basic FMS is controlled by a cell control system based on artificial intelligence (AI) and distributed processing technology. Automated scheduling and control has been achieved. The FMS control system is linked with plant-level control systems to achieve integration of FMS operations in the overall factory.

OPERATIONAL DESCRIPTION Parts are loaded to fixtures at one of two load/unload stands. Fixtures are permanently mounted to tooling cube tombstones, which in turn are mounted on part pallets. The fixture/cube/pallet assemblies are stored in a pallet storage area. This assembly is retrieved by the tracked automatic pallet changer (APC) and delivered to one of the two load/unload stands. At this place it is picked up by an AGV

MACHINING CENTERS The DeVlieg machines used in this FMS are unique as they have several built-in features to facilitate unmanned or unattended operations. These CNC machines have five-axis capability and are equipped with an automatic tool changer.

INTEGRATED INSPECTION EQUIPMENT This FMS uses CMM manufactured by LK Tools. Inspection is considered an important part of FMS operations and thus is fully integrated in FMS. The CMM has several special features to achieve integration. The FMS parts are machined on a horizontal spindle machining center and remain on the same fixture for inspection. To utilize the same horizontal fixture, the CMM is designed with a horizontal arm. This is a deviation from conventional practice of vertically oriented, gantry robot-type CMMs. The standard CMM rotary table is modified so that the DeVlieg pallet changer can automatically perform load and unload operations. Additional flexibility has been achieved by using an automatic probe changer. This is necessary as a large variety of FMS parts cannot be inspected using only a single stylus probe or sensor. Conventional touch type and the recent laser probes are both used in the system. Inspection data collected by CMM are transferred to the FMS controller. At the FMS controller, statistical analysis is performed. The data are subsequently passed to plant-level quality assurance systems.

MATERIAL HANDLING SYSTEM The system is comprised of two battery-operated AGVs and pallet changers. The AGV was supplied by Control Engineering, a subsidiary of Jervis B. Webb Company. The pallet changers were supplied by DeVlieg, the supplier of machine tools. The AGVs can automatically charge batteries through contact plates mounted on the floor at two system locations; as batteries can be charged any time the vehicles are idle. This method is known as "opportunity" charging. This has enabled the FMS to operate with only two AGVs. Standard DeVlieg pallet receiving tables are installed on top of the table lifting mechanism of the AGV, which is completely passive during the pallet changing operation. A pallet changer does all the work of sliding a pallet onto the AGV or removing the pallet from it. The AGVs are used to transport both part pallets and tool pallets in the FMS. The pallet with tools or parts appears exactly the same to the AGV. Fixtures are permanently set up on pallets. They are changed only for repair or modifications.

CONTROL SYSTEM The control system essentially determines the performance level of the complete FMS. This control system also integrates FMS operation within the plant. The system has been designed to optimize the performance of the FMS and at the same time achieve integration with the rest of the plant. The system architecture is shown in Figure 1. The control system software and hardware are described in the following sections.

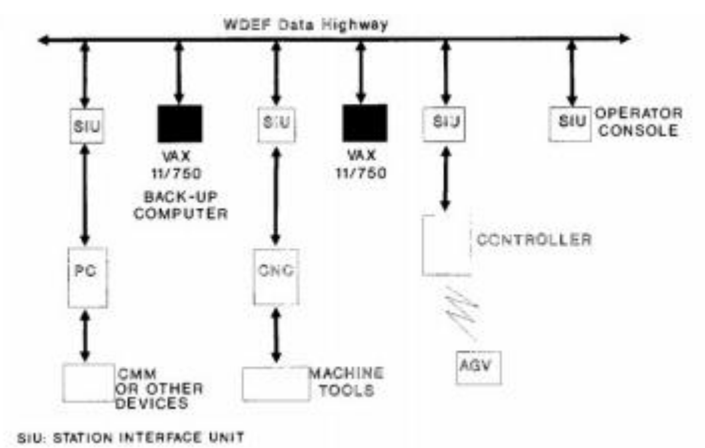


Fig 5.1 FMS in aerospace application

FMS application in sheet metal fabrication:

This is one of the pioneering applications of FMS technology to sheet metal fabrication. By producing over 300 parts, a true flexibility of production has been achieved. Parts produced are rather simple as compared to parts produced in the FMSs for aerospace application described previously. This indicates that cost-effective application of FMS technology does not depend on the complexity of the parts.

PHYSICAL CONFIGURATION A schematic of the FMS physical configuration is given in Figure 2. The FMS can be divided into the following parts: CI shearing center, line 1, line 2, line 3, line 4, and material handling system.

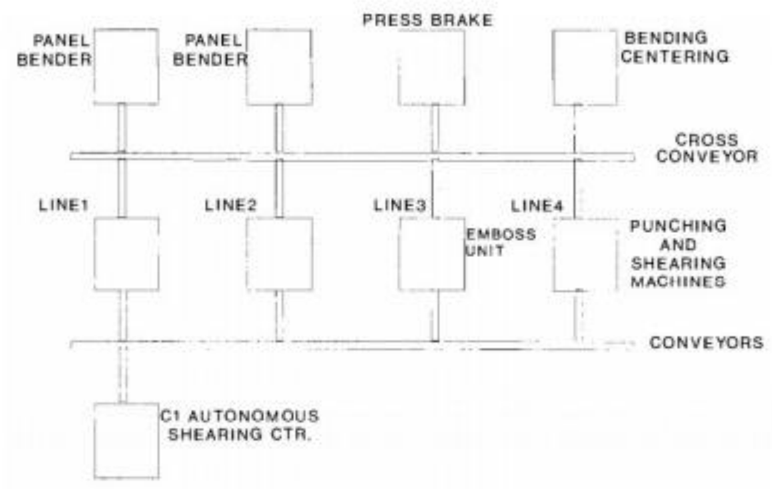


Fig 5.2 FMS application in sheet metal fabrication

1. CI Shearing Center This is an entry point for all the incoming sheet metal stock. The shearing center receives a daily production schedule. The sheets are loaded onto the loading tables and the large sheets are then cut into smaller sheets and transferred through a magnetic conveyor system and stacked onto a roller surface until the shear has completed packing requirements. After the stack has been completed, it is transferred to the required line. An ink jet system is used to trace the sheets. The pack distribution system consists of seven stackers or scissor tables. The stackers lift and traverse by using roller surfaces fixed to the ground. Other roller surfaces are used as buffers between the shear and individual lines.

2. Line One As mentioned above, sheet metal stock is stacked and transferred to individual lines. A magnetic destacker is used to transfer one sheet at a time from the pack to the line. The following machines are in each line: punching and shearing machine, panel bending machine, and embossing station. An embossing operation is required on only a few parts and hence the embossing station either performs the operation or simply transfer parts to the exit conveyor.

3. Line Two Line two is quite similar to line one. This line has only two machines: punching and shearing, and bending. The difference between the punching operation in line one and line two is that the

punching head in line two uses a special head to draw holes or both holes and knockouts. A vertical storage unit is used as a buffer between the punching and bending operations. After a final forming operation on the bending machine, sheets are transferred to the exit conveyor.

4. Line Three Line three is used to produce many small parts with an overall volume of over 1 million per year. The shearing machine in this line is similar to the shearing machine in line two, and in addition there are five embossing units. This line has significantly more job-routing flexibility as some parts are processed through the punching machine only, while others can be processed through all three machines. Smaller parts are transferred by an underground conveyor to a bin system that automatically sorts the parts for use in the final assembly. Some parts that require a bending operation are transferred between the lines on a cross conveyor to line two. The system also has the flexibility to transfer parts to a programmable press brake.

5. Line Four The configuration of the punching machine is identical to that of other lines. Five double embossing units are added to the punching line. This line also includes a 100-metric-ton hydraulic press which can bend up to 32 different parts automatically.

6. Material Handling System An automated conveyor-based elaborate system is used for material handling. These conveyors link each machine together. As described above, machines within each line are interconnected. A cross conveyor connects all four lines. The cross conveyor is used when it is necessary to transfer sheets between the lines. The cross transfer facility has increased flexibility of the system and ensured cost-effective utilization of the machinery. Scrap removal is an integrated part of this system. Scrap removal conveyors run under all punching machines. At the shearing center there are two large scrap containers. Scrap is automatically separated into mild steel and galvanized and is stored separately into two containers.

FMS development towards factories of the future

The increasing importance of information flow planning and development is shown in Figure 1. It is likely that in a few years half of the work involved with FMS projects as a whole will be taken up with this aspect. This is in line with findings by the consultancy company, McKinsey, which forecasts a 50% software component in FMS, making this sector the decisive market segment in factory automation of the 1990s.

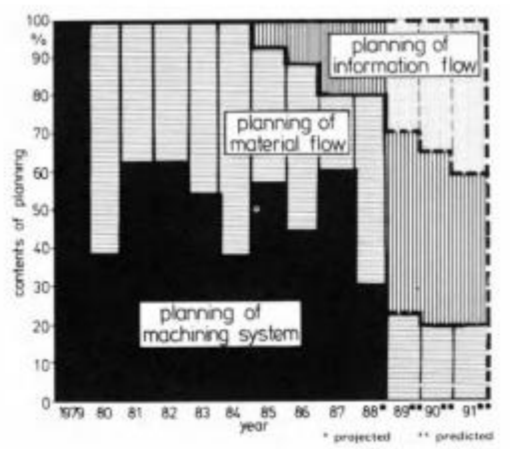


Fig 5.3 FMS development towards factories of the future

The demand for development resources aimed at FMS elements will not decrease in the future. Many FMS components are commercially available now, so that one might expect the main task of an FMS project to consist of the accurate planning and arrangement of known components. More and more development tasks for FMS are still arising, however.

The implementation of software in particular remains a major problem. Standardization of interfaces is one way of reducing the expense for adaptation. The main task, however, is the reduction of the number of interfaces. It is not only parts, and possibly tools, which need to be transported in flexible manufacturing systems. The automated clearance and disposal of chips from machining is a task which did not occur on working schedules previously and which was often left out of consideration until the automation stage. Here many detail problems have to be solved.

A single chip at the wrong spot can disrupt automated machining and material flow and can bring the whole system to a standstill. Attention to supposedly unimportant things such as chip flow and the provision of suitable technical and organizational measures to deal with them may be key factors for the failure-free operation and running of the material flow in future FMS.

Not only the project contents but also the products to be manufactured in FMS have changed. Since 1980, development efforts have been aimed at the design of FMS for turning, welding, and sheet metal working (Figure 2). The special problems of sheet metal working with regard to flexible manufacturing have resulted in an average difference of one generation between part manufacturing and sheet metal working. There is thus a great potential for improvement.

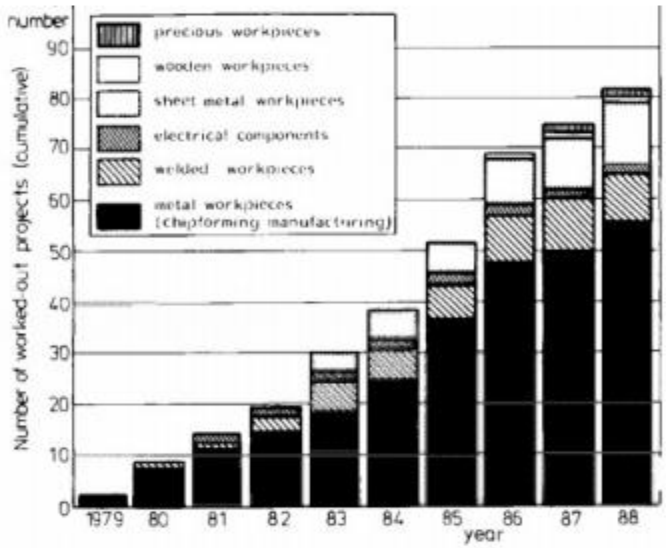


Fig 5.4 Types of workpieces in FMS project

ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS IN FMS:

COMPUTER-AIDED PLANNING AS A CENTRAL PLANNING AREA

Since essential tasks in the conceptual and operative phases of the manufacturing system are the responsibility of operations planning, considerable interaction can be noted, especially between process planning and the economical introduction of flexible manufacturing systems. Thus operations planning determine the investment costs for processing and material flow facilities, as well as manufacturing system operating costs (Roth et al., 1988). During the planning and configuring of flexible manufacturing systems, work plans are important for analysis of the current status and the future work piece spectrum. As such they form the basis for new manufacturing concepts (Figure 9). In addition to the representative workpiece spectrum, the process plans must be prepared in the initiation phase for all work pieces to be processed in the flexible manufacturing system. Also, a multitude of special requirements must be considered in respect of the manageable complexity of work pieces or machine tool process reliability, with low staffing levels. A process plan update is often carried out during adaptation of construction or process times on new manufacturing concepts with higher productivity

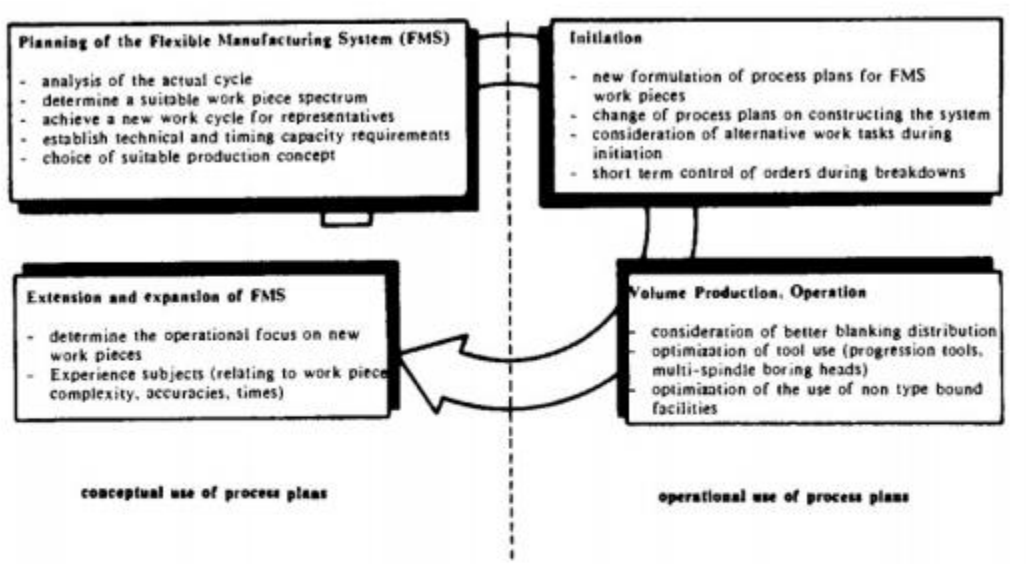


Fig 5.5 Use of process plans in the different phases of FMS

A fundamental consideration of changed chucking situations or of a changed tool requirement occurs in very few cases. In the course of planning activities for a flexible manufacturing system, as the long-term task of operations planning, it is necessary to retain detailed knowledge obtained about manufacturing possibilities.

BASIC TASKS AND METHODS OF PROCESS PLANNING

Within the production development process, operations planning represent the link between product definition in design and product realization in manufacture. Computer aids can be classified into the following four basic types: 1. Repeat planning: The simplest type of process planning, slight or form changes on plans already existing. However, no new planning data prepared. 2. Variation planning: Already existing standard process plans are used as a basis for planning work pieces within corresponding part families and planned from the resulting geometry or quantity variations. 3. Similar planning: By means of the plan of a work piece with similar geometry and manufacturing technology, planning takes place by change and adaption of individual process operations.

INTEGRATION INTO THE INTERNAL INFORMATION FLOW CONCEPT

The efficiency of a manufacturing area, and particularly the means of manufacture, has increased considerably in recent years. By contrast, the immediately adjacent areas have been largely excluded from this development despite the considerable contribution they make to the overall costs. In this respect, it would appear that too much emphasis has been placed on rationalization and automation of production as a way of optimizing the manufacturing process as a whole. While CAD systems and databanks with subject characteristics are well established, computer-assisted process planning is still in its infancy.

KNOWLEDGE-BASED PLANNING AIDS

1. Decision Table Systems

Decision table systems represent a preliminary stage in the direction of automatic systems for process plan preparation. As an aid, they offer procedures from manual dialog-oriented plan preparation, through semiautomatic functions, to fully automatic process plan generation. By means of decision table technology, intelligent dialog can be achieved with reduced input expense. Above all, however, projection of the process plan logic contributes to raw material operations, machine and processing stock determination, and time study. Furthermore, the required hierarchical construction of the system contributes considerably to the systemization of planning activities. With the aid of decision table generating and interpreting programs, the tables can be generated and modified relatively easily.

2. Expert Systems

In comparison to conventional systems and as an extension of decision table systems, expert systems make it possible to process planning knowledge in the form of rules and facts. Knowledge is no longer in firmly programmed or tabular form, but given to the knowledge base without a rigid structure. The finishing of this planning knowledge takes place through a so-called inference component, which deduces results for a specific application from the user's input. In recent years, process plan preparation has been tackled intensively with the help of expert systems, especially by universities. However, at this point only a few implementable formulations are known. They are nevertheless promising, particularly in the area of rotational workpieces. Expert systems are ideal for planning tasks in particular, not least as a result of the planner's method of working, which involves breaking down a problem initially into a number of subtasks and devising partial solutions for each of these tasks. When all the alternatives are considered together, a large number of combinations present themselves. All-purpose software aids are incapable of handling this profusion of concepts, and planners are obliged to resort to knowledgebase problem-solving techniques. From the planner's procedures in new planning, a model can be defined consisting of five planning steps (Figure 10). This is valid for planning the total part spectrum, with individual work pieces run through repeatedly.

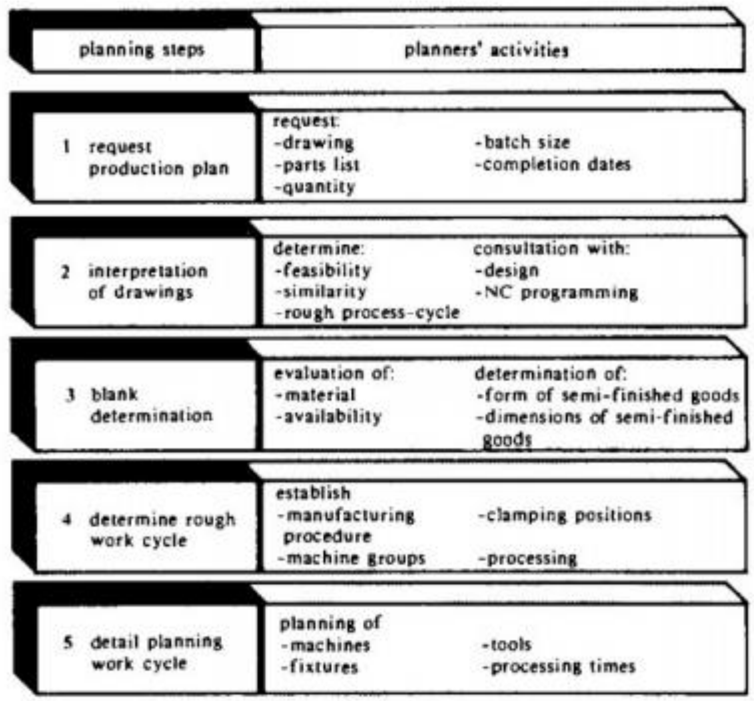


Fig 5.6 Planning procedure phases in the preparation of process plan

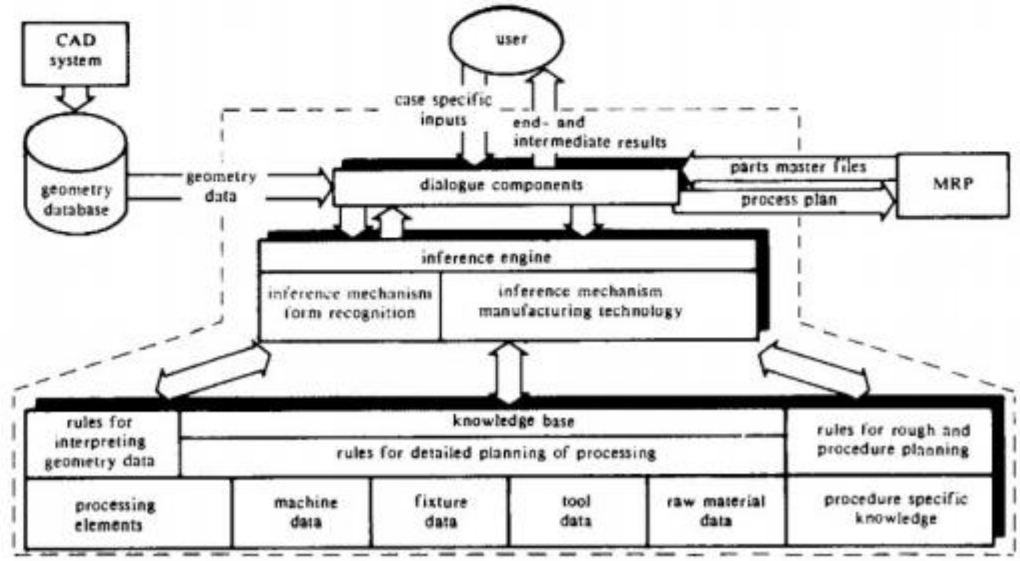


Fig 5.7 Structure of an expert system for process planning

Construction of the expert system, itself composed of dialog and inference components and a knowledge base, is identified through the tie-up to the CAD system and the knowledge base divided up in different modules (Figure 11). The dialog component represents the interface to the user not only in the actual course of planning, but supports the user as an aid in form recognition. This calls for an intrinsic and discriminating inference process in the planning segment.

DESIGN PHILOSOPHY AND CHARACTERISTICS FOR FUTURE:

MACHINE TOOLS IN FLEXIBLE MANUFACTURING SYSTEMS

What will be the main characteristics of flexible manufacturing systems in the 1990s? A survey recently carried out by the Fraunhofer Institute for Manufacturing Engineering and Automation on FMSs already partially installed, planned in detail, or designed conceptually for the 1990s showed that an impressive range of all kinds and sizes of FMS is planned in Germany in the coming years (Figure 13). Although lathes and machine centers will still remain the kind of machine tools used most frequently in future FMSs, one-third also involve grinding machines and nearly one-half contain other machine tools (Figure 14). Looking at additional operations to be included into FMS, Figure 15 shows that there is a great need for "system machines of the next generation" which should also be available for non-chip-forming operations and adaptable to the material flow and information flow interfaces within FMS. Efforts are being made in the development of system to further automate tool handling in FMS (Figure 16).

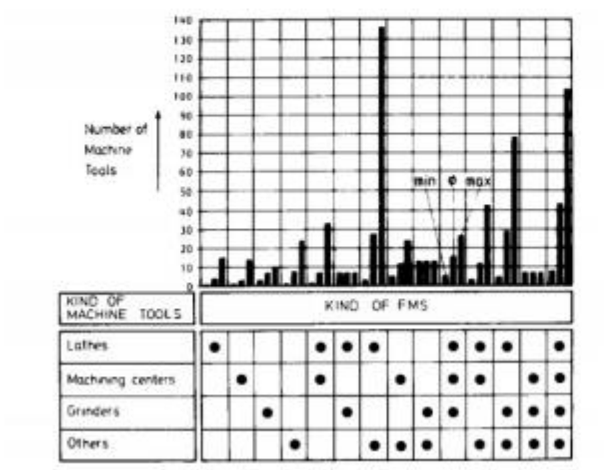
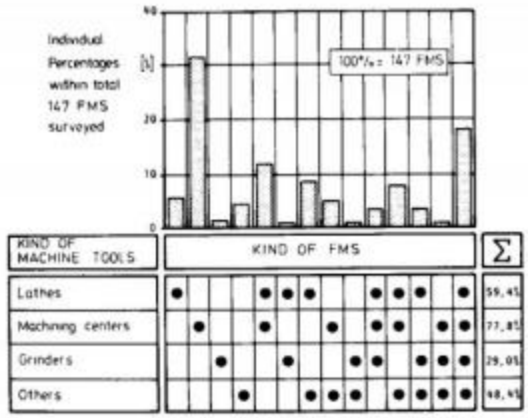


Fig 5.8 FMS in Germany : number of machines



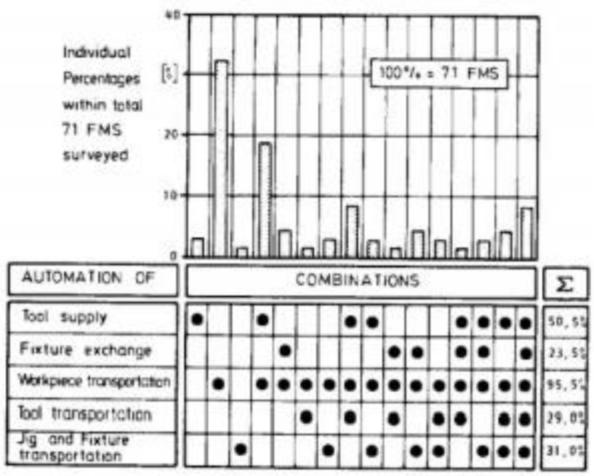


Fig 5.9 FMS in Germany : Variety of machines, material flow

Even now the technology exists to deliver tools within the FMS using mobile robots and AG Vs. Sensor technology and related algorithms will progress. Thus it will be possible to predict tool wear and tool breakage more accurately. Inspection of work pieces will also be a target for FMS suppliers as links between coordinate measuring machines and FMS control are refined and fully exploited. Some experts predict breakthroughs allowing more inspection to be performed on the machine tools themselves. Advances in adaptive control will continue. Automated compensation at the machine tool for drive axis error and the effect of misalignment forces, work piece weight, temperature, and machine component wear will also improve. The link between CAD and CAM will be increasingly exploited. Designers will create families of parts designed specifically for efficient machining using FMS technology. The future will also bring new sophistication in FMS operating software. Start-up procedures will be easier and less time-consuming.

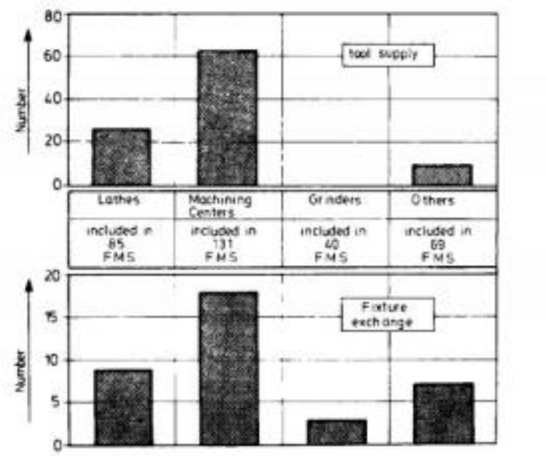


Fig 5.10 FMS in Germany : tool supply and fixture change

Much work will be done to automate fixture storage and retrieval systems to lessen the work of setup and tear-down. Further advances will emerge in serialization. Every tool, fixture, pallet, cart, or other transportable element of an FMS can be identified and tracked for improved overall system control (Figure 17). Application of bar-code scanners and other identification technologies will increase. To date, most machine tools and their peripherals have not been prepared for these purposes. For this reason, presently FMSs contain a multitude of different work piece and tool carriers, pallets, and other handling devices which considerably complicate investment to a hardly affordable amount. "System machines of the next generation" should therefore use common standards and interfaces not only for material flow, but also, and not less important, for information flow.

MODULAR DESIGN OF FLEXIBLE MANUFACTURING SYSTEM CONTROL SOFTWARE The key to flexibility is software. Controls and software can represent as much as one-third to one-half of the total investment of a complex system. Because of this, and to provide a "learning by-doing" possibility in a step-by step approach from automation islands to integrated systems, modular design of software packages will be absolutely indispensable. These packages will be assembled in different combinations, according to different individual applications and needs. Figure 18 shows the main goals stated in the survey mentioned above and the resulting requirements for FMS control.

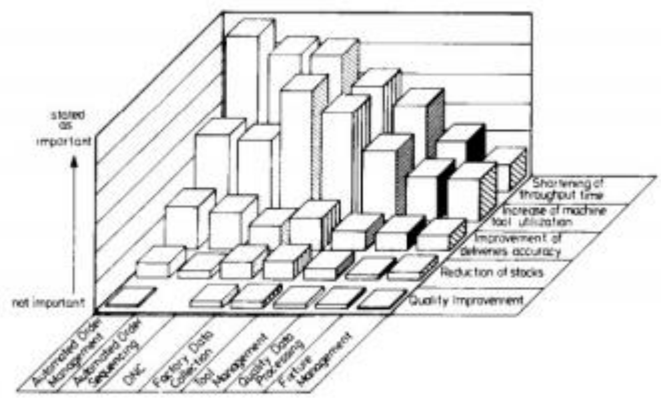


Fig 5.11 FMS in Germany : main goals and requirements for FMS control

Furthermore, FMS controls and software have to be compatible with business information systems, so that they can successfully interact with the overall system using a common database for design, manufacturing, and all other tasks within the entire operation, thus becoming a step toward and a part of computer integrated manufacturing (CIM) in the automated factory of the future.

FUTURE COOPERATION IN THE FACTORY AUTOMATION MARKET

The most frequently asked question is, "What kind of general supplier should one turn to for an overall factory automation concept?" The manufacturer of existing commercial data processing systems? The CNC and DNC machine tool supplier? Or an independent systems and software house? The choice is not easy—the leap from hitherto isolated computer applications to CIM is as great as that from a company car to a company plane, something which would certainly not be ordered from the former car supplier (although there are companies who make both cars and planes!). The question will probably stay unanswered in the next decade. It might be important, however, to remember that there are two essential prerequisites for successful extending right down to the factory floor: a sophisticated software concept and the skilled knowledge of production procedures within the company and on the shop floor itself. The latter at least should be provided by the usercompany at the planning stage, no matter whether a general supplier for the integrated overall solution or various component manufacturers are involved in the project. This entails familiarity with all specific components, especially with "system machines of the next generation," which in spite of all CIM discussions will continue to play an important role in the success of manufacturing companies.