UNIT 6 FLEXIBLE MANUFACTURING SYSTEM

6.1 INTRODUCTION

Globalization, fickling market requirements and modern lifestyle trends have put up tremendous challenge to manufacturing industries. In the current business scenario the competitiveness of any manufacturing industry is determined by its ability to respond quickly to the rapidly changing market and to produce high quality products at low costs. However, the product cost is no longer the predominant factor affecting the manufacturers' perception. Other competitive factors such as flexibility, quality, efficient delivery and customer satisfaction are drawing the equal attention. Manufacturing industries are striving to achieve these capabilities through automation, robotics and other innovative concepts such as just-in-time (JIT), Production planning and control (PPC), enterprise resource planning (ERP) etc. Flexible manufacturing is a concept that allows manufacturing systems to be built under high customized production requirements. The issues such as reduction of inventories and market-response time to meet customer demands, flexibility to adapt to changes in the market, reducing the cost of products and services to grab more market shares, etc have made it almost obligatory to many firms to switch over to flexible manufacturing systems (FMSs) as a viable means to accomplish the above requirements while producing consistently good quality and cost effective products. FMS is actually an automated set of numerically controlled machine tools and material handling systems, capable of performing a wide range manufacturing operations with quick tooling and instruction changeovers.

6.2 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, or

new 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.

SAQ

1. Define flexibility. Discuss various types of flexibility?
2. Describe the essentiality of flexibility in shop floor environment?

6.3 FMS AND ITS RULE IN CIM ENVIRONMENT

As discussed in above section, FMS ensures quality product at lowest cost while maintaining small lead-time. So, firms adopt FMS as a means of meeting burgeoning requirements of customized production. Main purpose of FMS is to achieve efficiency of well-balanced transfer line while retaining the flexibility of the job shop (Stecke, 1983, 1985). A flexible manufacturing system (FMS) has four or more processing workstations connected mechanically by a common part handling system and electronically by a distributed computer system. It covers a wide spectrum of manufacturing activities such as machining, sheet metal working, welding, fabricating, scheduling and assembly. Advantages of processes involved in flexible manufacturing system over the convectional methods are:

Item	Flexible	Conventional
Set-up	Defined	Varies
Volume	Low-Medium	Medium-High
WIP (work-in-process)	Low	High
Flexibility	High	Low
Scrap	Low	Unpredictable
Labor	Low	High
Equipment cost	High (short term)	Low (short term)
Equipment ROI	Low	High
Plant ROI	High	Low
Queuing	Low	High
Automation	High level	Low level
Future	Lead to integration	Dead end
Quality	Controlled	Varies
Inspection	Automatic tie-in	Doesn’t flow
Tooling and fixturing	Flexible	Rigid
Market changes	Flexible	Rigid

Equipment utilization	Optimized	Low
Production control	Predictable	Unpredictable
Lead time	Low	High
Engineering changes	Easier	Equipment and time constraints

Source: Modern machine shop, September 1984.

Table 6.1. Comparison between attributes of flexible and conventional manufacturing systems

Another strategic advantage of FMS is that it is able to handle the risk caused by uncertainty about the future. It can be done through planning in a way that maintains flexibility of the environment. Although it is impossible to predict the future, one can make estimates of probabilities and proceed in ways to accord with the future. The simple decision tree in figure 6.1 illustrates the decision-making in case of FMSs governing the choices among three different options depending upon the nature of the market.

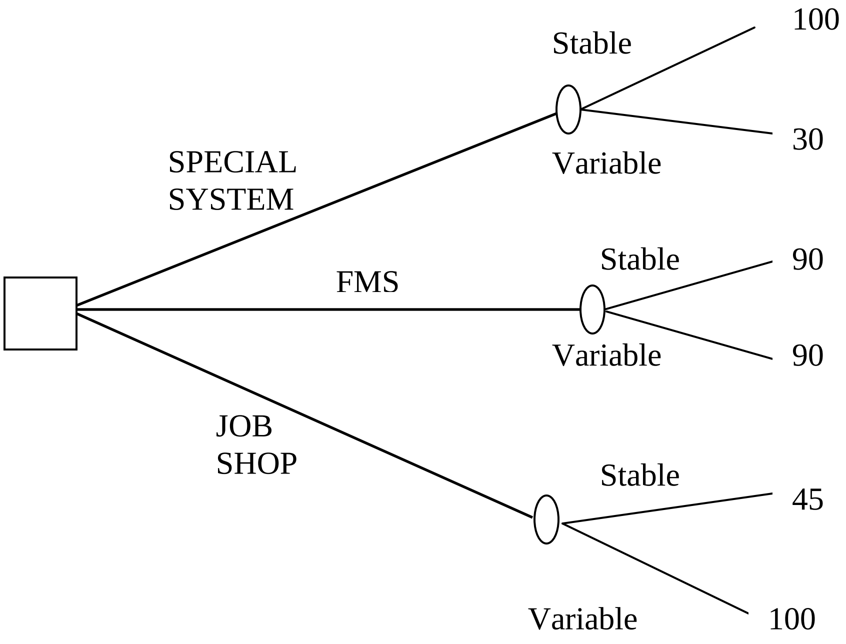

Figure 6.1 Simple Decision Tree

The first option is a specialized manufacturing system that performs well in stable market (payoff = 100) but will perform poorly (payoff = 30) if the market is variable. The second option, the FMS, will perform fairly well (payoff = 90) regardless of the type of market. The third option is the job shop that will perform well in variable (payoff = 100). From the example it is clear that an FMS performs less well then a specific option in specific market but proves to be a fairly good performer when the nature of market is not defined.

As a conclusion, FMS technology can be termed as an evolutionary step beyond transfer lines that enables the industries to accommodate the growing costumer demand and maintain the quick delivery of customized products. It is the newest wave in attaining greater productivity with instant positive response to both adversities and new opportunities.

TYPES OF FMS:

Flexible manufacturing systems can be divided into various types depending upon their features. They all are discussed below:

1. DEPENDING UPON KINDS OF OPERATION-

Flexible manufacturing system can be distinguished depending upon the kinds of operation they perform:

I. **Processing operation.** Such operation transforms a work material from one state to another moving towards the final desired part or product. It adds value by changing the geometry, properties or appearance of the starting materials.

II. **Assembly operation.** It involves joining of two or more component to create a new entity which is called an assembly/subassembly. Permanent joining processes include welding, brazing, soldering , adhesive bonding, rivets, press fitting, and expansion fits.

2. DEPENDING UPON NUMBER OF MACHINES –

The following are typical categories of FMS according to the number of machines in the system:

I. **single machine cell (SMC).** It consist of a fully automated machine capable of unattended operations for a time period longer than one machine cycle. It is capable of processing different part styles, responding to changes in production schedule, and accepting new part introductions. In this case processing is sequential not simultaneous.

II. **Flexible manufacturing cell (FMC).** It consists of two or three processing workstation and a part handling system. The part handling system is connected to a load/unload station. It is capable of simultaneous production of different parts.

III. **A Flexible Manufacturing System (FMS).** It has four or more processing work stations (typically CNC machining centers or turning centers) connected mechanically by a common part handling system and automatically by a distributed computer system. It also includes non-processing work stations that support production but do not directly participate in it. e.g. part / pallet washing stations, co-ordinate measuring machines. These features significantly differentiate it from Flexible manufacturing cell (FMC).

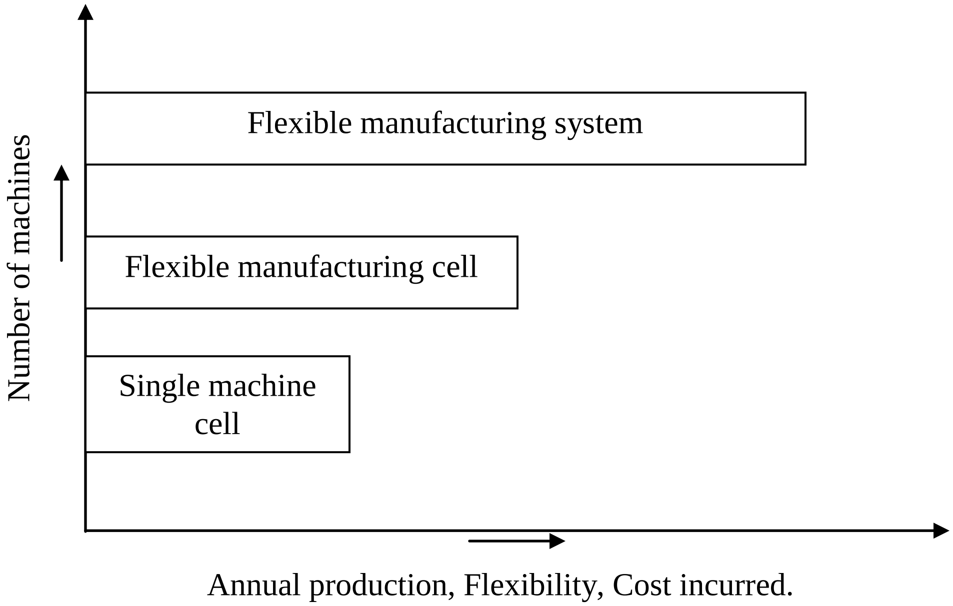

Figure 6.2 Comparison for three categories of FMS

3. DEPENDING UPON LEVEL OF FLEXIBILITY–

Another classification of FMS is made according to the level of flexibility associated with the system. Two categories are distinguished here:

I. **Dedicated FMS.** It is designed to produce a particular variety of part styles. The product design is considered fixed. So, the system can be designed with a certain amount of process specialization to make the operation more efficient.

II. **Random order FMS.** It is able to handle the substantial variations in part configurations. To accommodate these variations, a random order FMS must be more flexible than the dedicated FMS. A random order FMS is capable of processing parts that have a higher degree of complexity. Thus, to deal with these kinds of complexity, sophisticated computer control system is used for this FMS type.

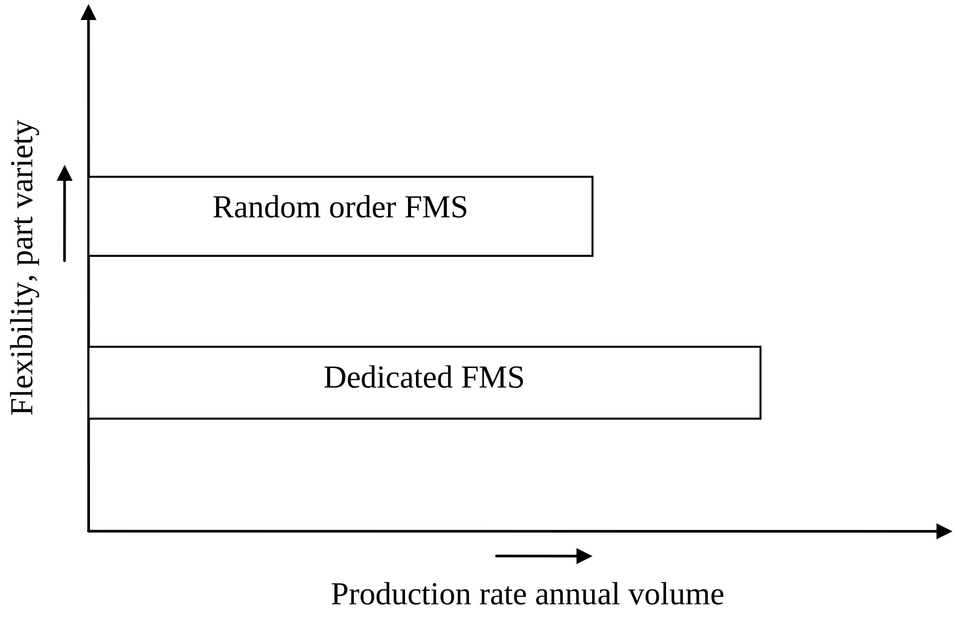

Figure 6.3 differences between dedicated and random-order FMS types

As indicated in our definition, there are several basic components of an FMS. In the following segment, a framework for understanding the components of an FMS is presented. A flexible manufacturing system consists of two subsystems:

- Physical subsystem
- Control subsystem

Physical subsystem includes the following elements:

1. **Workstations**. It consists of NC machines, machine-tools, inspection equipments, loading and unloading operation, and machining area.
2. **Storage-retrieval systems.** It acts as a buffer during WIP (work-in-processes) and holds devices such as carousels used to store parts temporarily between work stations or operations.
3. **Material handling systems.** It consists of power vehicles, conveyers, automated guided vehicles (AGVs), and other systems to carry parts between workstations.

Control subsystem comprises of following elements:

1. **Control hardware.** It consists of mini and micro computers, programmable logic controllers, communication networks, switching devices and others peripheral devices such as printers and mass storage memory equipments to enhance the working capability of the FMS systems.
2. **Control software.** It is a set of files and programs that are used to control the physical subsystems. The efficiency of FMS totally depends upon the compatibility of control hardware and control software.

Basic features of the physical components of an FMS are discussed below:

1. Numerical control machine tools.

Machine tools are considered to be the major building blocks of an FMS as they determine the degree of flexibility and capabilities of the FMS. Some of the features of machine tools are described below;

- The majority of FMSs use horizontal and vertical spindle machines. However, machining centers with vertical spindle machines have lesser flexibility than horizontal machining centers.
- Machining centers have numerical control on movements made in all directions e.g. spindle movement in x, y, and z directions, rotation of tables, tilting of table etc to ensure the high flexibility.
- The machining centers are able to perform a wide variety of operations e.g. turning, drilling, contouring etc. They consist of the pallet exchangers

interfacing with material handling devices that carry the pallets within and between machining centers as well as automated storage and retrieval systems.

2. Work holding and tooling considerations.

It includes pallets/fixtures, tool changers, tool identification systems, coolant, and chip removal systems. It has the following features:

- Before machining is started on the parts, they are mounted on fixtures. So, fixtures must be designed in a way, to minimize part-handling time. Modular fixturing has come up as an attractive method to fixture a variety of parts quickly.
- The use of automated storage and retrieval system (AS/RS) and material handling systems such as AGVs, lead to high usage of fixtures.
- All the machining centers are well equipped with tool storage systems called tool magazines. Duplication of the most often used tools in the tool magazines is allowed to ensure the least non-operational time. Moreover, employment of quick tool changers, tool regrinders and provision of spares also help for the same.

3. Material-Handling Equipments

The material-handling equipments used in flexible manufacturing systems include robots, conveyers, automated guided vehicle systems, monorails and other rail guided vehicles, and other specially designed vehicles. There important features are:

- They are integrated with the machine centers and the storage and retrieval systems.
- For prismatic part material handling systems are accompanied with modular pallet fixtures. For rotational parts industrial robots are used to load/unload the turning machine and to move parts between stations.

- The handling system must be capable of being controlled directly by the computer system to direct it the various work station, load/unload stations and storage area.

4. Inspection equipment

It includes coordinate measuring machines (CMMs) used for offline inspection and programmed to measure dimensions, concentricity, perpendicularity, and flatness of surfaces. The distinguishing feature of this equipment is that it is well integrated with the machining centers.

5. Other components

It includes a central coolant and efficient chip separation system. Their features are:

- The system must be capable of recovering the coolant.
- The combination of parts, fixtures, and pallets must be cleaned properly to remove dirt and chips before operation and inspection.

SAQ

1. What do you understand by FMS? What are the components of FMS?
2. Describe the advantage of FMS over conventional manufacturing system?
3. Describe the physical sub-system of an FMS?

6.4 MACHINE LOADING

Operation management in an FMS is more intricate than that of the conventional manufacturing systems e.g. transfer line or job shop production system and depends largely upon how the decision problems is being tackled. This is primarily due to versatile machines, which are capable of performing a wide range manufacturing operations with quick tooling and instruction changeovers that result in many alternative routes for processing of part types. In most FMSs, the part to be machined has to be loaded on a pallet of some kind and after required operations; it is needed to be taken-off from the pallets. In other words, we can say that loading involves, taking a component delivered to the systems and preparing it for processing. After processing the component is brought back from its pallet to the load/unload area and it is placed on the floor to wait its disposal to assembly department or a storehouse. These actions come under unloading process.

Machine loading problem of a flexible manufacturing system is known for its complexity, which encompasses various types of flexibility aspects pertaining to part selection and operation assignments along with constraints ranging from simple algebraic to potentially complex and conditional one. Decision pertaining to machine loading problems has been considered as tactical level planning decision that acts as a tie between strategic and operating level decision in manufacturing. It receives the input from preceding decision levels, such as part mixes selection, resource grouping, aggregate planning, etc and transfer it to the succeeding decision levels of resources scheduling and dynamic operation planning and control. This is why the FMS loading problems have been rigorously pursued in the recent past.

In fact, Stecke (1983) studied machine loading problems in detail and described six main objectives:

1. Balancing the machine processing time;
2. Minimizing the number of movement;
3. Balancing the workload per machine for a system of groups of pooled machines of equal sizes;
4. Unbalancing the workload per machine for a system of groups of pooled machines of unequal sizes;
5. Filling the tool magazines as densely as possible;
6. Maximizing the sum of operations priorities.

KEY TERMINOLOGIES:

1. Essential operations are those operations that can be done only on specific machine using specific tool slots.

2. Optional operations are those operations that can be carried out on more than one machine. It is advisable to preserve the optional operations as long as possible while considering all possible routes. Flexibilities lie in the selection of a machine for processing the optional operations of the part.

3. System unbalance can be defined as sum of unutilized or over-utilized time on all machines available in the system. Maximization of machine utilization is same as minimization of system unbalance

4. Throughput refers to the units of part types produced.

The following are provided a numerical example to illustrate the machine loading problem clearly. Objective functions used while dealing with this problem are, the minimization of system unbalance and the maximization of throughput because:

1) It is concerned with minimization of system idle time leading to achieve higher machine utilizations.

2) The most important goal of any loading policy is concerned with enhancing total system output, which is nothing but throughput.

3) Kim and Yano (1997) have found that throughput maximization by balancing the workloads on the machine often results in limiting the tardiness.

SAQ

1. What do understand by machine loading?
2. What are the main objectives for machine loading?
3. Define the term 1) system unbalance 2) throughput 3) essential operation 4) optional operation?

6.5 NUMERICAL EXAMPLE

6.5.1 Problem Description

Let's consider an example of machine-loading problem of random FMS in which 8 part types are to be processed on four machines, each having five tool slots and different processing time for each operation. Each part type consists of essential and optional operations, which can be performed on any of the machine without altering the sequence of the operations. The adaptability of each machines and its potential to perform many different operations facilitate several operation assignments to be duplicated to generate alternative part routes. Thus, there can be fairly large number of combinations in which operations of the part type can be assigned on the different machines while satisfying all the technological and capacity constraints. Further consideration of flexibilities such as: tooling flexibilities, part movement flexibilities, etc along with the constraints of the system configuration and operational feasibility make the problem more complex.

To arrive at optimal or near optimal solution for the machine loading problem, combinations of machines and operations allocated are evaluated using two common performance measures: system unbalance, and throughput. It is necessary to explore each combinatorial allocation with respect to a given objective function (minimization of system unbalance and maximizing throughput), by simultaneously satisfying constraints. It is found that number of possible allocations to be explored, increases exponentially as size of the problem increases.

Part type	Operation no.	Batch size	Unit Processing time	Machine no.	Tool slot needed
1	1	8	18	3	1
2	1	9	25	1	1
			25	4	1
	2		24	4	1
	3		22	2	1
3	1	13	26	4	2
			26	1	2
	2		11	3	3
4	1	6	14	3	1

	2		19	4	1
5	1	9	22	2	2
			22	3	2
	2		25	2	1
6	1	10	16	4	1
	2		7	4	1
			7	2	1
			7	3	1
	3		21	2	1
			21	1	1
7	1	12	19	3	1
			19	2	1
			19	4	1
	2		2	1	1
			13	3	1
			13	1	1
	3		23	4	1
8	1	13	25	1	1
			25	2	1
			25	3	1
	2		7	2	1
			1	1	1
	3		24	1	3

Table 6.2 Description of problem no.1 (adopted from Shanker and Srinivasulu 1989)

Many researchers have solved machine loading problems by generating the pre-determined part sequencing based heuristics, but these techniques don’t guarantee optimal/near optimal solutions. Therefore, the application of local intelligent search techniques, such as genetic algorithm (GA), tabu search (TS), simulated annealing (SA), and CBGA (Constraint Based Genetic Algorithm) have been extensively used by researchers since 1992, to solve such a computationally complex optimization problem. These problems have been addressed considering following objective functions:

1) Minimization of system unbalance alone;
2) Maximization of throughput alone;
3) Minimization of system unbalance and maximization of throughput considered together;

Let us solve the above problem using an evolutionary heuristic known as Reallocation paradigm. An approach that ensures simultaneous allocations of an index of essential as well as optional operations on the machines based on the value "operations allocation priority index" has been pursued. The concept of "operation allocation priority index" (PI) has been evolved to include the effects of available and essential time and tool slots on the machines before and after the operation decision of a part type.

6.5.2 Solution Methodology

The procedure for determining the "operation allocation priority index" of a part type can be illustrated as follows: -

In machine loading problems, because of the availability of optional operations of part types, decisions are to be made for allocating operations on the machines. Following notations and definitions are to be introduced to explain the formulation of "operation allocation priority index" (hereafter termed as priority index "PI"):.

- Operation allocation: Operation allocation means the assignment of an operation of a part type on a machine.

O^{p}_{om}-operation "o" of part type "p" has been allocated to machine "m".

- Set of operations allocation: A set of operations allocation of a part type is defined as the collection of distinct operations allocations on the machines. The cardinality of this set is same as the total number of operations of that part type.

AS^p_q = q^{th} set of operations allocation of part type “p”

Where “q” is the index for set of operation allocation number, q=1,2,…….q_{max}.

- A set of operations allocation is represented as

$AS^p_q=\{O^p_{1m}, O^p_{2m}, O^p_{3m}, \ldots\ldots\ldots\ldots, O^p_{Op}m''\}$

$\forall$ m,m’,m’’,……,m’’’ ε {m}, where m =1 to M and m corresponds to o.

If a part type “p” contains o_p operations and if operation “o” can be allocated on q_{max} number of machines then the total number of set of operations allocation (q_{max}) is given by

$$q_{max} = \prod_{o=1}^{o_p} M \quad \forall m \text{ corresponds to k.}$$

For example, the part type “7” (table 6.2), contains 3 operations, where operation 1 can be allocated on 3 machines, operation 2 on 3 machines and operation 3 on 1 machine. Therefore, the total number of sets of operation allocation that can be formed is:

$$q_{max} = \prod_{p=1}^{o_p} m_{max} \quad \in m \text{ corresponds to o}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.1).$$

Where m_{max} is the maximum number of machine on which the operation of the part type can be allocated.

For o =1, m =2, 3, 4, m_{max} =3,

For o =2, m =1, 2, 3, m_{max} =3,

For o =3, m =1, m_{max} =1,

For o =1, m_{max} =3,

For o =2, m_{max} =3,

For o =3, m_{max} =1, and

O_p =3

$\therefore \quad n_{max} = 3\times3\times1= 9.$

The various set of operation allocation for this case are:-

$AS_1^7 = \{O_{12}^7, O_{21}^7, O_{34}^7\}$

$AS_2^7 = \{O_{13}^7, O_{21}^7, O_{34}^7\}$

$AS_3^7 = \{O_{14}^7, O_{21}^7, O_{34}^7\}$

…………………………………….

…………………………………….

$AS_9^7 = \{O_{14}^7, O_{23}^7, O_{34}^7\}$.

- B_p is the batch size of part type “p”
- t_{copm} is the unit processing time of operation “o” of part type “p” on machine m, ∀“o” corresponds to “m”.
- T_{copm} is the number of tool slots required for carrying out o^th^ operation of p^th^ part type on m^th^ machine, ∀ “o” corresponds to “m”.

- I_p is the position of part type p in the part type sequence, p = 1 to P and $I_{p=1}$ to I_P

- Machining time index: Corresponding to each operation_allocation of a part_type on machine, the machining time index takes into account the available time on the machine before allocation, essential time requirement of machine and available time on machine after allocation. It represented by

$$MTI\,[O_{om}^{P}] = (t_{ropm} - ET_{mp})/(t_{aopm} - ET_{mp}) \ldots\ldots\ldots\ldots\ldots\ldots..(6.2)$$

Where MTI $[O_{om}^{P}]$ represents the machining time index of the machine "m" after the allocation of operation "o" of part type "p" on machine "m" as per the nth set of operation allocation.

- **Tool Slot Index**: Corresponds to each operation allocation of part type on machine, the tool slot index takes into account the available tool slots on machine before allocation, essential tool slot requirement of machine and available tool slots on machine after allocation.

$$TSI\,[O_{om}^{P}] = (T_{ropm} - ES_{mp})/(T_{aopm} - ES_{mp}) \ldots\ldots\ldots\ldots\ldots\ldots..(6.3)$$

Where TSI $[O_{om}^{P}]$ represents the tool slot index of machine "m" after the allocation operation "o" of part type "p" on machine "m" as per the nth set of operation allocation.

- **Priority Index:** Priority index of set of operation allocation can be expressed as the product of average of machining time index and tool slots index of machine. It is represented by PI(AS_q^{P}) and expressed as:

$$PI(AS_q^{P}) = \{1/\,M \times \sum_{m=1}^{M} MTI_{mq}\,[O_{om}^{P}\,] \times [\,1/\,M \times \sum_{m=1}^{M} TSI\,[\,O_{om}^{P}]\} \ldots\ldots(6.4)$$

$$\text{If,}\quad TSI\,[\,O_{om}^{P}]\} \geq 0$$

= $\propto$(Infinity), otherwise.

Table 6.3 summarizes the different situation, which can arise during the evaluation of PI for a set of operation allocation..

Case	$MTI_{mq}[O_{om}{}^{p}]$	$TSI_{mp}[O_{om}{}^{p}]$	$PI(AS_q{}^p)$	Remarks
1	All positive	All positive	Positive	Set of operation allocation $AS^p{}_q$ is feasible.
2	Positive and negative	All positive	Positive and negative	Set of operation allocation $AS^p{}_q$ is feasible.
3	All positive	Negative	$\propto$	Set of operation allocation $AS^p{}_q$ is infeasible.
4	Positive and negative	Negative	$\propto$	Set of operation allocation $AS^p{}_q$ is infeasible.
5	Negative	Negative	$\propto$	Set of operation allocation $AS^p{}_q$ is infeasible.
6	Negative	All positive	Negative or Positive	Set of operation allocation $AS^p{}_q$ is feasible.
7	Positive and negative	Positive	$\propto$ T_{ropm} is Negative	Set of operation allocation $AS^p{}_q$ is

				infeasible.
8	Positive and negative	All positive	Positive (T_{ropm} is positive) but $T_{ropm6} < ES_{mp}$’ and $T_{aopm} < ES_{mp}$’	Set of operation allocation AS^p_q is feasible but given least priority irrespective of the value of PI(AS^p_q)

Decisions pertaining to set of operation allocation is to be made based on higher PI value. Some of the part types from the pool of part types remain unassigned due to violation of system constraints in the given planning horizon. According to the proposed methodology, part types are to be assigned on machines till various set of operation allocation observes tool slot constraints (till TSI [O_{om}^p] is positive) since overloading of machines are permitted. After all the part from the pool of part types have been assigned, the system unbalance indicates the termination of the throughput is to be evaluated. Positive system unbalance indicates the termination of assignment procedure of the part types. If the system unbalance is negative, then those part types are to be searched whose rejection can bring system unbalance to minimum positive value with minimum reduction in throughput. After searching such types and its subsequent rejection, the status of machines (available time and available tool slot) are to be updated. Updation of machine status implies addition of corresponding machining time and tool slots on the respective machines on which the rejected part type’s operations have allocated. If any part type has been rejected earlier on the ground of non-availability of tool slots ($PI = \propto$ for all AS_q^p), then the same is to be reallocated now and all other steps are repeated as practiced for unallocated part types.

Before any part types are to assigned on machines, it is essential to determine the sequence in which the given part types are to be allocated on the machines. Most of the researchers have practiced standard sequencing rules such as SPT, LPT, MOPR, FIFO etc for the determination part types sequences. Among the above sequencing rules, “SPT” has been claimed to work better on an average. But, the determination of part type sequence using above rules, have been viewed by several researchers as the weakness of solution methodology for machine loading problem. Therefore, in this research, attempts has been made to devise a part type sequencing criteria, which encompasses the several parameters such as batch size, total processing time etc. to suit the objectives of problem. As per the suggested criteria of part type sequencing, contribution of every part type to these parameters is determined. Part types are to be arranged in sequence based on the value of contribution (part types are arranged in descending order of contribution).

Contribution is to be evaluated based on the following expression:

$$\alpha_j = (W_1 \times \beta_p^1 + W_2 \times \beta_p^2)/(W_1 + W_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.5)$$

Where α_p = Total contribution of the part types “p”.

β_p^1 = Contribution of the part type “p” to the batch size,

$$= (b_p - [b_p]_{min})/([b_p]_{max} - [b_p]_{min}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.6)$$

β_p^2 = Contribution of the part type “p” to the total processing time,

$$= ([TPT_p]_{max} - TPT_p)/([TPT_p]_{max} - [TPT_p]_{min}) \ldots\ldots\ldots\ldots\ldots\ldots (6.7)$$

W_1= Weightage of batch size,

W_2 = weightage of total processing time,

TPT_p = Total processing time of part type p

$$= \sum_{o=1}^{o_p} b_p \times at_o^p \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6.8)$$

at_o^p = Average unit processing time of operation “o” of the part type “p”

$$= (1/M) \sum_{m=1}^{M} at_{om}^{p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6.9)$$

t_{copm} = Unit processing time of operation “o” of the part type “p” on machine “m”.

$W_1 = W_2 = 1$(For our case),

$0 <= \beta_p^1 <= 1$, $0 <= \beta_p^2 <= 1$, and $0 < = \alpha_p <= 1$.

The above-mentioned concepts and logic for solving the machine-loading problem have been summarized in the form of various steps of the exact proposed heuristic proposed in this work. These steps are listed as follows: -

6.5.3 Exact Heuristic Reallocation paradigm

Step 1 : (1) Input the total number of part types P.

(2) Input the total number of machines M.

(3) For p=1 to P, input o_p,

For o=1 to p_p.

For m=1 to M,

Input the value of t_{copm}, T_{copm} $\forall$ o corresponds to m.

Step 2: For p =1 to P, evaluate α_p using equation (6.5).

Step 3: Arrange part type p, where p=1 to P in decreasing order of the contribution α_p and generate the part type sequence.

Step 4: For p =1 to P , input the value of I_p from part type sequence.

Step 5: Input t_{aopm}, T_{aopm}, for m=1 to M.

Step 6: Determine ET_{mp}, ES_{mp} for m =1 to M.

ET_{mp} is the essential machining time requirement on machine "m" before the allocation of any essential operation of part type

ES_{mp} is the essential tool slot requirement on machine "m" before the allocation of any essential operation of the part type

Step 7: Initialize I_p=1.

Step 8: Determine AS_q^p, the set of operation allocation of part type “p”, for q = 1 to $q_{max.}$

Step 9: Determine ERM_m^*, ERT_m^*, $ATMm^*$, ATS_m^*.

Where $ERM_m^* = ET_{mp} - ET(O_{om}^p)$

$ERT_m^* = ES_{mp} - ES(O_{om}^p)$

$ATMm^* = t_{aopm} - t_{aopm}(O_{om}^p)$

$ATS_m^* = T_{aopm} - T_{aopm}(O_{om}^p)$.

Step 10: Initialize q =1.

Step 11: Determine t_{ropm}, T_{ropm} corresponding to AS_q^p.

Step 12: Evaluate PI (AS_q^p) using equation 6.4.

Step 13: If q< q_{max}, then q = q+1, go to step 11, Else go to step 14.

Step 14: If for AS_q^p, where q = q to q_{max}, PI = $\propto$(infinity),

then $p \in PU_{TSC}$. Hence reject the part due to tool slot constraints, $I_p = I_p + 1$,

go to step 8,

Else go to step 15.

Step 15: Select AS_p^p which has maximum $PI(AS_q^p)$ value. Allocate operation on machines as per the (AS_q^p) set of operation allocation.

Step 16: Update t_{aopm}, T_{aopm}, ET_{mp}, and ES_{mp} after allocation of part type "p".

[Set t_{ropm} to t_{aopm}, T_{ropm} to T_{aopm}, ES_{mp} to ES_{mp}' ,ES_{mp} to ES_{mp}']

Step 17: If $I_p < I_p$, increase I_p by 1 and go to step 8, Else go to step 18.

Step 18: Find system Unbalance "SU" and part throughput "TH".

$$SU = \sum_{m=1}^{M} t_{ropm} \text{ and } TH = \sum_{p=1}^{P} b_p \text{ where p does not } \in PU_{TSC} \text{ and } PU_{NSU.}$$

PU_{TSC} = Set of part types unassigned due to tool slot constraints.

PU_{NSU} = Set of part types unassigned due to negative system unbalance.

Step 19: If SU is negative, then go for reallocation, else output the final SU and TH.

Step 20: REALLOCATION

For p =1 to P, where p does not $\in PU_{TSC}$ and PU_{NSU}, do the following:

(A). Add TPT_p to SU and SU^* .

(B) Choose the minimum positive value of SU^* and get the corresponding

Throughput TH^* and go to step C. If SU is still negative, then add TPT_p to SU and get SU^{**}. Choose the minimum positive value of SU^{**} and Determine the corresponding TH^{**} and go to step C.

(C) Reject the part type “p” from the set of assigned part types. This part type is rejected due to negative system unbalance.

(D) Add corresponding machining time and tool slots of the part type “p” to the respective machines. Go to step G.

(E) Reject the part type p and p^* from the set of pool of assigned part types (due to part types)

(F) Add corresponding machining time and tool slots of the allocate operations of the part type p and p^* to m respective machines. Go to step G.

(G) Allocate part type p where $p \varepsilon PU_{TSC}$ and obtain SU and TH.

(H) If SU is negative for all part types of $PU_{TSC,}$ reject these part types and obtain the final SU and TH.

6.5.4 Numerical illustration

With the help of a numerical example (given in table 6.2), the details of solution methodology using the proposed exact heuristic to address the machine loading problem are explained in this section. For the above problem, a planning period of 8 hrs (= 480 mins) has been devised to test the computational performance of the proposed heuristic.

As a numerical illustration of the proposed heuristic, the various steps required for solving above problem given in table 6.2 are as follows:

Step 1: (1) Total number of part types P = 8.

(2) Total number of machines M = 4.

(3) For p=1, o_p = 1, for p=2, o_p = 3, p=3, o_p=2, p=4 o_p = 2,

p=5, o_p = 2, for p=6, o_p = 3, p=7, o_p =3, p=8 o_p = 3.

(4) t_{c113}= 18, s_{c113}= 1

t_{c121}= 25, t_{c124}=25, s_{c121}= 1, s_{c124}=1

And remaining values can be entered from Table 6.2.

Step 2: Using equation (6.5),

α_1= 0.64, α_2 = 0.285, α_3 = 0.71, α_4 = .453, α_5 = .47, α_6 = .53, α_7 = .508,α_8 = .50

Step 3: Part type sequence: [3-1-6-7-8-5-4-2].

Step 4: Form part type sequence, I_3 = 1, I_1= 2, I_6 = 3, I_7 = 4, I_8 = 5, I_5 = 6,I_4 = 7, I_2 = 8.

Step 5: $T_1 = T_2 = T_3 = T_4 = 480$,

$S_1 = S_2 = S_3 = S_4 = 5$.

Step 6: The values of ET_{mp} , ES_{mp} for m=1 to M are:

M	ET_{mp}	ES_{mp}
1	312	3
2	423	2
3	371	5

4	766	6

Step 7: $I_3 = 1$.

Step 8: The set of operation allocation of part type “3”, for q =1 to q_{max} are:

$AS_1^3 = \{ O_{11}^3, O_{23}^3\}$ and $AS_2^3 = \{ O_{14}^3, O_{23}^3\}$.

Step 9: The values of ATM_m^*, ATS_m^*, ERM_m^*, ERT_m^* , for m =1 to M are:

m	ATM_m^*	ATS_m^*	ERM_m^*	ERT_m^*
1	480	5	312	3
2	480	5	423	3
3	337	2	228	2
4	480	5	766	6

Step 10: Initialize q = 1.

Step 11: The values of t_{ropm},T_{ropm} corresponding to $AS_1^3 = \{ O_{11}^3, O_{23}^3\}$are:

m	t_{ropm}	T_{ropm}
1	142	3
2	480	5
3	337	2
4	480	5

Step 12: Using equation 6.4, PI (AS_1^3) = 0.373.

Step 13: q_{max} =2, q< $q_{max,}$ then q = q+1.

Step 11: The values of t_{ropm}, T_{ropm} corresponding to AS_2^3= {O_{14}^3, O_{23}^3}are:

M	t_{ropm}	T_{ropm}
1	480	5
2	480	5
3	337	2
4	142	3

Step 12: Using equation 6.4, PI (AS_2^3) = 1.295 but $T_{ropm6} < ES_{mp}{}'$ and $T_{aopm} < ES_{mp}'$

(Case 6 of Table 6.3).

Step 13: q = q_{max}.

Step 14: PI (AS_1^3) = .373 and PI (AS_2^3) = 1.295 (but $T_{ropm} < ES_{mp}{}'$).

Step 16: Updation

M	T_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	142	3	312	3
2	480	5	423	3
3	337	2	228	2

4	480	5	766	6

Step 17: $I_3 < I_2$ and $I_1 = 2$.

Step 8: $AS_1^1 = \{ O_{13}^1\}$

Step 9:

M	ATM_m^*	ATS_m^*	ERM_m^*	ERT_m^*
1	142	3	312	3
2	480	5	423	3
3	193	1	84	1
4	480	5	766	6

Step 10: q =1.

Step 11: $AS_1^1 = \{ O_{13}^1\}$

m	T_{ropm}	T_{ropm}
1	142	3
2	480	5
3	193	1
4	480	5

Step 13: $q = q_{max.}$

Step 15: Allocate $AS_1^1 = \{O_{13}^1\}$.

Step 16: Updation

m	T_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	142	3	312	3
2	580	5	423	3
3	193	1	84	1
4	480	5	766	1

Step 17: $I_6 = 3$.

Step 8: $AS_1^6 = \{O_{14}^6, O_{22}^6, O_{31}^6\}$.

$AS_2^6 = \{O_{14}^6, O_{23}^6, O_{31}^1\}$.

$AS_3^6 = \{O_{14}^6, O_{24}^6, O_{31}^6\}$.

$AS_4^6 = \{ O_{14}^6, O_{22}^6, O_{32}^6\}$.

$AS_5^6 = \{ O_{14}^6, O_{23}^6, O_{32}^6\}$, and

$AS_6^6 = \{ O_{14}^6, O_{24}^6, O_{32}^6\}$.

Step 9:

M	ATM_m^*	ATS_m^*	ERM_m^*	ERM_m^*
1	142	3	312	3
2	480	5	423	3
3	193	1	84	1
4	320	4	606	5

Step 10: q = 1.

Step 11: $AS_1^6 = \{O_{14}^6, O_{22}^6, O_{31}^6\}$,

m	T_{ropm}	T_{ropm}
1	-68	2
2	410	4
3	193	1
4	320	4

Step 12: PI $(AS_1^6) = \propto$ (infinity)

Step 13: q = 2.

Step 11: $AS_2^6 = \{O_{14}^6, O_{23}^6, O_{31}^1\}$,

m	T_{ropm}	T_{ropm}
1	-68	2
2	480	5
3	123	0
4	320	4

Step 12: PI $(AS_2^6) = \propto$ (infinity)

Step 13: q = 3.

Step 11: $AS_3^6 = \{O_{14}^6, O_{24}^6, O_{31}^6\}$,

m	T_{ropm}	T_{ropm}
1	-68	2
2	480	5
3	193	1
4	250	3

Step 12: PI (AS_3^6) = ∝ (infinity).

Step 13: q = 4.

Step 11: $AS_4^6 = \{ O_{14}^6, O_{22}^6, O_{32}^6\}$.

M	t_{ropm}	T_{ropm}
1	142	3
2	200	3
3	193	1
4	320	4

Step 12: PI(AS_4^6) = 0.413.

Step 13: q = 5.

Step 11: $AS_5^6 = \{ O_{14}^6,\ O_{23}^6, O_{32}^6\}$,

M	T_{ropm}	T_{ropm}
1	142	3

2	270	4
3	193	1
4	250	3

Step 12: PI (AS_5^6}= 1.725.

Step 13: q = 6.

Step 11: $AS_6^6 = \{ O_{14}^6, O_{24}^6, O_{32}^6 \}$.

M	t_{ropm}	T_{ropm}
1	142	3
2	270	4
3	193	1
4	250	3

Step12: PI (AS_6^6) = 1.665.

Step 13: $q = q_{max} = 6$.

Step 14: PI (AS_4^6) = .413, PI (AS_5^6) = 1.725, PI (AS_6^6) = 1.665.

Step 15: Select AS_5^6 as PI (AS_5^6) = 1.725.

Step 16: Updation.

m	t_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	142	3	312	3
2	270	4	423	3

3	123	0	84	1
4	320	4	606	5

Step 17: $I_7 = 4$.

Step 8: $AS_1^7 = \{ O_{12}^7, O_{21}^7, O_{34}^7\}$,

$AS_2^7 = \{ O_{12}^7, O_{22}^7, O_{34}^7\}$,

$AS_3^7 = \{ O_{12}^7, O_{23}^7, O_{34}^7\}$,

$AS_4^7 = \{ O_{13}^7, O_{21}^7, O_{34}^7\}$,

$AS_5^7 = \{ O_{13}^7, O_{22}^7, O_{34}^7\}$,

$AS_6^7 = \{ O_{13}^7, O_{23}^7, O_{34}^7\}$,

$AS_7^7 = \{ O_{14}^7, O_{22}^7, O_{34}^7\}$,

$AS_8^7 = \{ O_{14}^7, O_{22}^7, O_{34}^7\}$.

$AS_9^7 = \{ O_{14}^7, O_{22}^7, O_{34}^7\}$.

Step 9:

M	ATM_m^*	ATS_m^*	ERM_m^*	ERT_m^*
1	142	3	312	3
2	270	4	423	3
3	123	0	84	1
4	44	1	333	2

Step 10: $q = 1$.

Note: Step 11-13 involves repetitive calculations, therefore results are summarized below:

$PI(AS_1^{7)} = \propto$

$PI(AS_2^{7)} = \propto$

$PI(AS_3^{7)} = \propto$

$PI(AS_4^{7)} = \propto$

$PI(AS_5^{7)} = \propto$

$PI(AS_6^{7)} = \propto$

$PI(AS_7^{7)} = \propto$

$PI(AS_8^{7)} = 0.5537$ and,

$PI(AS_9^{7)} = \propto$

Step 14: Select AS_8^7 as $PI(AS_8^{7)} = 0.5537$.

M	t_{ropm}	T_{aopm}
1	142	3
2	114	3
3	123	0
4	-184	0

Step 16: Updation

M	t_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	142	3	312	3
2	114	3	423	3
3	123	0	84	1
4	-184	0	333	2

Step 17: $I_8 = 5$.

Step 8: $AS_1^8 = \{ O_{11}^8, O_{22}^8, O_{31}^8\}$,

$AS_2^8 = \{ O_{11}^8, O_{21}^8, O_{31}^8\}$,

$AS_3^8 = \{ O_{12}^8, O_{22}^8, O_{31}^8\}$,

$AS_4^8 = \{ O_{12}^8, O_{21}^8, O_{31}^8\}$,

$AS_5^8 = \{ O_{13}^8, O_{22}^8, O_{31}^8\}$ and,

$AS_6^8 = \{ O_{13}^8, O_{21}^8, O_{31}^8\}$.

Step 9:

M	ATM_m^*	ATS_m^*	ERM_m^*	ERT_m^*
1	-170	0	0	0
2	114	3	423	3
3	123	0	84	1
4	-184	0	333	2

Step 10: $q = 1$

Note: Step 11-13 involves repetitive calculations; therefore the calculated results are summarized below:

$PI(AS_1^8) = \propto$

$PI(A2_1^8) = \propto$

$PI(A3_1^8) = \alpha$

$PI(AS_4^8) = 1.0048$

$PI(AS_5^8) = \propto$

$PI(AS_6^8) = \propto$

Step 14: For AS_4^8 , PI $(AS_4^8) = 1.0048$.

Step 15: AS_4^8 is selected.

Step 16: Updation

m	t_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	-170	0	0	0
2	-306	1	423	3
3	123	0	84	1
4	-184	0	333	2

Step 17: $I_5 = 6$.

Step 8: $AS_1^5 = \{O_{12}^5, O_{22}^5\}$,

$AS_2^5 = \{O_{13}^5, O_{22}^5\}$.

Step 9:

m	ATM_m^*	ATS_m^*	ERM_m^*	ERT_m^*
1	-170	0	0	0
2	-153	0	198	2
3	123	0	84	1
4	-184	0	333	2

Step 10: q = 1

Note: Step 11-13 involves repetitive calculations; therefore the calculated results are summarized below:

$PI(AS_1^5) = \propto$

$PI(AS_2^5) = \propto$

Step 14: For every AS_j^5, the value PI = α. Part type 5 is rejected due to tool slot constraints and $I_4 = 7$

Step 8: $AS_1^4 = \{ O_{13}^5, O_{24}^5 \}$.

Step 9:

m	ATM_m^*	ATS_m^*	ERM_m^*	ERT_m^*
1	-170	0	0	0
2	-306	1	423	3
3	-39	-1	0	0

4	-403	-1	219	1

Step 10: q = 1.

Note: Step 11-13 involves repetitive calculation, therefore the calculated results are summarized below:

PI (AS_1^2) = ∝

PI (AS_2^2) = ∝

Step14: For every AS_q^2, the value of PI(α). Part type 2 is rejected due to tool slot constraints.

Step 15: Part type 2 is rejected PI = ∝

Step 16: Updation:

M	t_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	-170	0	0	0
2	-306	1	423	3
3	123	0	84	1
4	-184	0	333	2

Step 17: $I_p = I_P$.

Step 18: System unbalance SU = (-170-306+123-184) = -537 and

Part throughput TH = (13+8+10+12+13) = 56.

PU_{TSC} = {5, 4, 2}.

Step 19: system unbalance is negative so go for reallocation.

Step 20: Reallocation.

(A). For p = 1, ,3, 6, 7, and 8 , where $p \notin PU_{TSC}$ and PU_{NSU}, add TPT_p to SU and get SU^{*}.

(B) The minimum positive value of $SU^{*} = 123$ is obtained by adding $TPT_7 = 660$ and the corresponding throughput $TH^{*} = 44$.

(C) Reject the part type 7 from the set of pool of assigned part types. This part type is rejected due to negative system unbalance. $PU_{NSU} = \{7\}$.

(D) Corresponding machining time and tool slots of the allocated operations of part type 7 is added to the respective machines.

Updation:

m	t_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	58	1	0	0
2	-150	2	423	3
3	123	0	84	1
4	92	3	333	2

(G) Reallocated part type 5, 4, and 2.

Part type 5 cannot be allocated due to Tool Slot Constraints [$PI(AS_1^5) = \propto$ and $PI(AS_2^5) = \propto$.]

Part type 4 cannot be reallocated due to Tool Slot Constraints [$PI(AS_1^4) = \propto$]

Part type 2 can be reallocated and the updated status is as follows:

m	t_{aopm}	T_{aopm}	ET_{mp}	ES_{mp}
1	-167	0	0	0
2	-348	1	225	2
3	123	0	84	1
4	-124	2	117	1

SU = -516 and TH = 53

(H) The SU is negative for all part types of PU_{TSC}, and hence reject part type and

Finally System Unbalance SU = 123 and throughput TH = 44, PU_{NSU} ={7}.

PU_{TSC} = {5, 4, 2}.

SAQ

1. What are the different steps involved in the Reallocation paradigm?
2. define tool slot index and priority index?

6.6 SCHEDULING

6.6.1 DEFINITION

Scheduling is a process of adding start and finish time information to the job order dictated in the sequencing process. Sequencing process in turn, is defined as getting the order in which jobs are to be run on a machine. The sequence thus obtained determines the schedule, since we assume each job is started on the machine as soon as the job has finished all predecessor operations and the machine has completed all earlier jobs in the sequences. This is referred to as semi-active schedule and acts as an optimal policy for minimizing the completion time, flow time, lateness, tardiness, and other measures of performance. Scheduling problems are often denoted by N/ M/ F/ P, where N is the number of jobs to be scheduled, M is the number of machines, F refers to the job flow pattern, and P is performance measures that are to be appropriately minimized or maximized. The solution of scheduling problems are generally presented in the form of gannt-chart which is a chart plotted between different work centers and total processing time on that work center. Following is given an example problem to illustrate the formation of Gantt-chart.

Example 6.1. Consider a set of jobs and processing times shown in table 6.4 generate the schedule assuming jobs are processed in the order {2, 4, 1, 3}

	station			
Job	1	2	3	4
1	2.0	3.5	1.5	2.0
2	4.5	3.0	2.5	1.0
3	1.5	1.5	5.0	0.5
4	4.0	1.0	2.5	0.5

Table 6.4 flow shop processing time

Solution.

We start by assigning job 2 on station 1 at time t=0. Since $p_{21} = 4.5$, the operation last on station 1 for 4.5 unit time. Since all the operation starts with station 1 thus in that particular time rest station are in idle condition. At time when job 2 is moved to station 2 then job 4 move to station 1 for processing and other jobs remain in the buffer. Station 2 finishes operation 2, when $P_{22} = 3.0$ time units later (time is now t=7.5). Station 1 is still busy with job 4; thus, while job 2 is begun on station 3, station 2 is idle, waiting for job 4 to be completed on station 1. Similarly, the process continues till processing of the entire job takes place. The result is given in figure 6.4 through a Gantt chart. The gap in between two bars represents idle time.

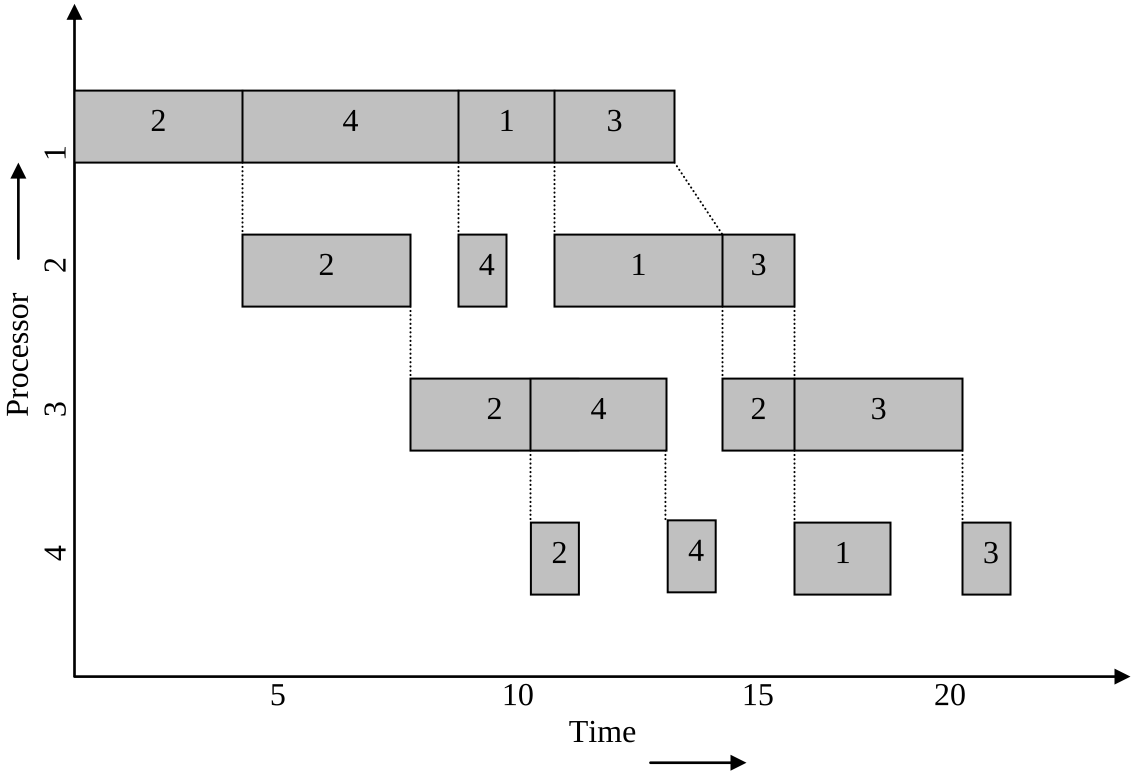

Figure 6.4 Gantt chart for above example

In a flow shop all N jobs is made to visit machines in the same sequence. Suppose we also restrict our solutions in such a way that all machines process jobs in the same order, then it will refer to as permutation schedule. In this case, at time t=0, the first job is started on machine 1 and as soon as this operation is completed the first job begins on machine 2 and the second job begins on machine 1. This process is continued until the last job finishes on machine M. the benefit of this process is that we have to consider only N! Sequence instead of $(N!)^M$.

6.6.2 Dispatching Rules

When a processing unit gets ready, a job must be selected from its input queue for immediate setup and processing. This refers to as dispatching. Dispatching rules are generally classified as being static or dynamic. Static rules are those that stay constant as jobs travel through the plant, e.g. LTWK, EDD where as dynamic rules are those that changes with time and queue characteristic e.g. LWKR. Sometimes dispatching rules are also distinguished as myopic or global. Myopic rules look only at the individual machine e.g. SPT where as global rules look at the entire shop e.g. WINQ.

Name	Description
SPT	(shortest processing time) select a job having minimum processing time.
EDD	(earliest due date) select a job with earliest due date.
FCFS	(first come, first served) select the job that arrived first in the queue.
FISFS	(first in system, first served) select a job that has been on the shop floor the longest.
S/RO	(slack per remaining operation) select the job with the smallest ratio of the slack to operations to be performed.
LTWK	(least total work) select a job with smallest total processing time.
LWKR	(least work remaining) select a job with smallest total processing time for unfinished operations.
MOPNR	(most operation remaining) select a job with the most operations remaining in the processing sequence.
MWKR	(most work remaining) select a job with the most total processing time remaining.
RANDOM	(random) select a job at random.
WINQ	(work in next queue) select a job whose subsequent machine has the shortest queue

Table 6.5 Standard Dispatching Rules

6.6.3 Numerical example

Current time is 30. Machine Q has just finished a job, and it is time to select its next job. Table 6.6 provides information on the four jobs available. For each of the dispatching rules described in table 6.5, determine the corresponding sequence.

Job	Arrival to the system	Arrival at Q	Due date	Operation (machine $P_{i,j}$)		
				1	2	3
1	5	10	30	(Q,5)	(P,1)	(S,6)
2	0	5	20	(P,5)	(Q,3)	(R,2)
3	9	9	10	(R,3)	(S,2)	(Q,2)
4	0	8	25	(T,6)	(Q,4)	(R,4)

Table 6.6 Machine-Job data

Solution.

SPT: job {1,2,3,4} have processing time of {5,3,2,4} on machine Q. placing job in increasing order of processing time yield the job sequence {3,2,4,1}. Thus, load job 3 into machine Q.

EDD: job {1, 2, 3, 4} have due date {30, 20, 10, 25}, respectively. Ordering by due earliest due dates we get sequence {3, 2, 4, 1}.

FCFS: jobs arrived at Q at times {10, 5, 9, 8}. Placing earlier arrival time first, we obtain a sequence {2, 4, 3, 1}.

FISFS: jobs arrived the system at {5, 0, 9, 0}. In this case job 2 and 4 can be arranged arbitrary thus we get 2 sequences {2,4,1,3} and {4,2,1,3}.

S/RO: slack = (due date – current time – remaining processing time).

S/RO = slack/remaining operations.

Slacks for job 1,2,3,4 are as follows:

For job 1 = (30 – 10 – 5 – 1 – 6) = 8

For job 2 = (20 – 10 – 3 – 2) = 5

For job 3 = (10 – 10 – 2) = -2

For job 4 = (25 – 10 – 4 – 4) = 7.

S/RO for jobs is

For job 1 = 8/3 = 2.67

For job 2 = 5/2 = 2.50

For job 3 = -2/1 = -2

For job 4 = 7/2 =3.50

Placing the job in the increasing order of S/RO we get the sequence {3, 2, 1, 4}

LTWK: total work can be calculated by adding all the processing time.

Thus remaining work on jobs are {12, 10, 7, 14}. Arranging by the total work values we get sequence {3, 2, 1, 4}.

LWKR: remaining workload until job completion is {12, 5, 2, 8}. The corresponding sequence is {3, 2, 4, 1}.

MOPNR: Numbers of remaining operation are {3, 2, 1, 2}. Applying MONPR we get sequence {1, 2, 4, 3}.

MWKR: remaining processing time are {12, 5, 2, 8}. The sequence obtained is {1, 4, 2, 3}.

RANDOM: selecting the job randomly we get {1, 4, 3, 2}.

WINQ: let the length of the queue are 12 at machine P and 6 at machine R. job 3 goes first since it has no next queue. Jobs 2 and 4 come next since they are headed for machine R, which has less work in its queue that P. thus, the sequence obtained is {3,2,4,1}

SAQ

Problem 6.1. What do you understand by scheduling?

Problem 6.2. Define dispatching and name different types of dispatching rule?

Problem 6.3. Current time is 30. Machine A has just finished a job, and it is time to select its next job. Table 6.7 Provide information on the five jobs available. For each of the dispatching rules described in table 6.5, determine the corresponding sequence.

Job	Arrival to the system	Arrival at A	Due date	Operation (machine $P_{i,j}$)		
				1	2	3
1	3	7	29	(A,6)	(B,2)	(D,8)
2	5	9	23	(C,2)	(A,3)	(D,1)
3	9	3	18	(A,3)	(C,5)	(D,5)
4	8	7	13	(D,6)	(C,6)	(A,3)
5	0	5	12	(E,4)	(A,5)	(C,3)

Table 6.7 Machine-Job data

6.7 METHODS AND PRACTICAL APPLICATIONS

The concept of flexible automaton is applicable to a variety of manufacturing operations. In this section, some practical applications of flexible manufacturing systems are presented and their layouts are provided:

1. **System with linear track**. Systems having linear tracks usually have only one vehicle. Most frequently used vehicle in such systems is rail-guided vehicle; however an AGV can also be used. The physical layout of a simple FMS with linear track, employed at Andreson Strathclyde plc[12], in Motherwell, near Glasgow in Scotland, is given in figure 6.5. There are five machines, each with a tool magazine of 100 tools capacity. Four of them are identical, while fifth one has facing head, required for certain operations. Each machine has two pallet stands providing on-queue and off-queue buffers. The load/unload area constitute two pallet stands and some work stands, where the part is put into the fixture, before putting it on the pallet at one of the pallet stands. There are 13 identical pallets, and an AGV that can handle one pallet at a time and travel through a track with no branches.

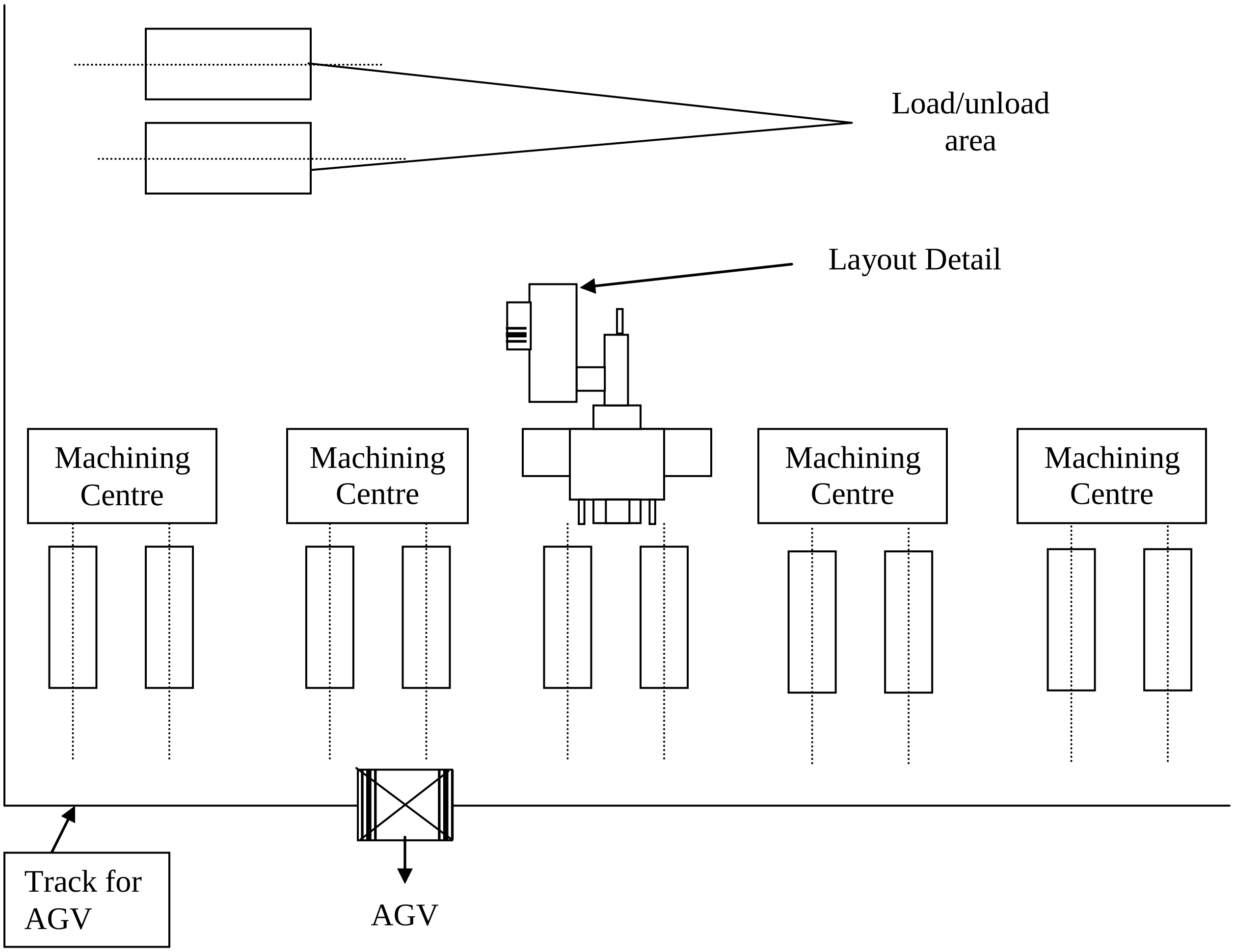

Figure. 6.5. Layout of Andreson Strathclyde FMS

The major problem with this particular kind of system is that, there are no places for storing the pallets with part-machined components except pallet stands at the machine centers and load/unload area.

2. Systems with AGV networks.

Whenever a system track consists of networks of loops and branches, AGVs are employed. Systems with AGV networks have generally more than one vehicle. However, if the workload is too low, one vehicle is sufficient to cope with the traffic. A system which illustrates this arrangement is the FMS cell at Cincinnati Milacron in Birmingham, England and is shown in figure 6.6 It has two machining centers with pallet shuttles, a wash machine, a co-ordinate measuring machine, and two load/unload stations.

<< Include scanned Figure 6.6 >>

Figure 6.6 Line diagram for an FMS used by Cincinnati Milacron Plastics Machinery Division

3. Systems with number of distinct cells.

Such systems consist of a number of distinct sub-divisions or cells, each of which has some characteristics of an FMS. One example is the Holset engineering in Huddersfield that has installed a system consisting of seven cells for the manufacture of shaft and wheel assemblies for their turbochargers[18.32]. The layout of the system is shown in figure 6.7. The manufacturing sequence is split into self-contained stages and a cell created to perform the operation of that stage. The operation involves machining, welding, hardening and tempering, grinding and balancing. Within each cell there are two pallet stands from which parts are moved among workstations using gantry robot. It also consists of a storehouse for storing raw materials, and semi-finished and finished components.

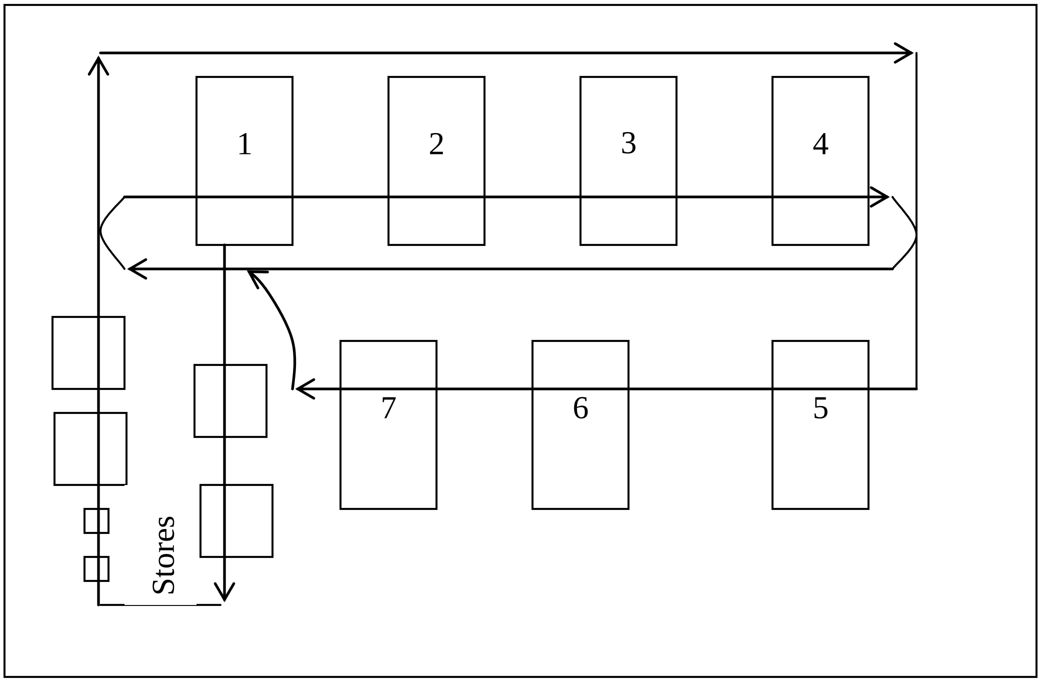

Figure 6.7.Layout of cells in Holset engineering FMS (courtesy Holset engineering Ltd.)

The system is designed to allow each cell to operate independently, so that the effects of any possible breakdown could be minimized.

6.8 CONTROL OF FMS SYSTEM

The FMS includes a distributed computer system that is linked to the work stations, material handling system and other hardware components. A typical FMS computer system consists of a central computer and micro computers controlling the individual machines and other components. The control system in FMS causes the process to accomplish its defined function. The control can be either closed loop or open loop. A closed loop control system is one in which the output variable is compared with an input parameter and any difference between the two is used to drive the output into agreement with the input. It is also known as feedback control system. A closed loop control system consists of six basic elements which is shown in figure 6.8

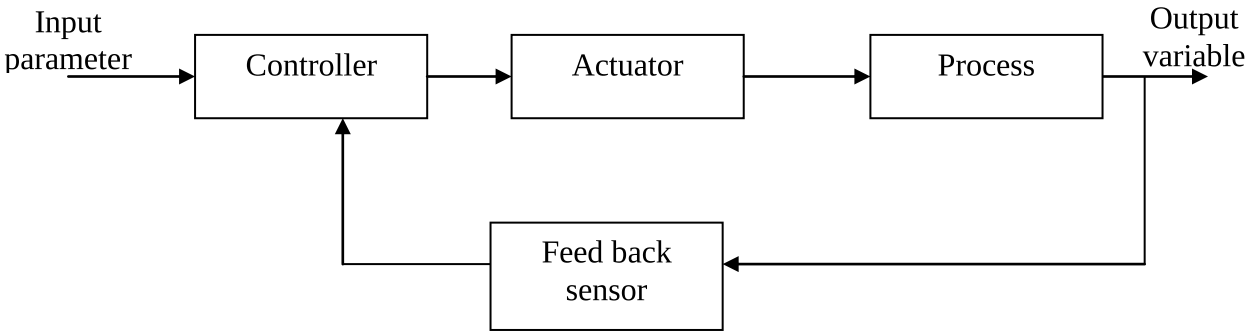

Figure 6.8 A Feedback control system

Here, the controller compares the output value with the input and makes the required adjustment in the process to reduce the difference between them, which is accomplished by actuators. Actuators are the hardware devices that physically carried out the control actions such as an electric motor, electric fan. A sensor is used to measure the output variable and closed the loop between input and output.

In contrast to the closed loop control system an open loop operates without the feedback loop as in figure 6.9

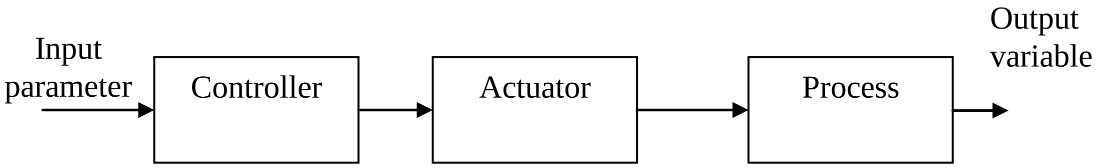

Figure 6.9 An open loop control system

Its advantage is that it is generally simpler and lesser expensive then a closed loop system. Open loop system is usually appropriate to use when (1) the actions performed by the control system are simple. (2) The actuating function is very reliable and (3) any reaction forces opposing the actuation are negligible to effect the actuation. Functions performed by the FMS computer control system can be grouped into the following categories:

- **Workstation control.** In a fully automated FMS, a computer control system is used at the individual processing or assembly stations.
- **Distribution of control instructions to workstations.** DNC is used for this purpose. The DNC system stores the programs, allows submission of new programs and editing of existing programs as needed.
- **Production control.** The production control functions are accomplished by routing and applicable pallet to the load/ unload area and providing instructions to the operator for loading the desired work part.
- **Material handling control.** It is accomplished by actuating switches at branches and merging points, stopping parts at machine tool transfer location, and moving pallets to load/ unload stations.
- **Tool control.** It is concerned with managing mainly two aspects of the machine tool,

- Tool locations i.e. Keeping track of the machine tools at each work-station by receiving the information that whether tools required to process to particular work piece is present at the station or not.
- Tool life monitoring deals with the idea that whether the cumulative machining time is below the specified tool life or not. In case machining time reaches the specified life of the tool, the operator is notified that a tool replacement is needed.

- **Performance evaluation.** The computer system is programmed to collect data on the operation and the performance of the FMS. This data is then periodically summarized to report to the management system.

6.9 RECENT TRENDS

Depending upon the problem environment, many new trends have been accommodated with FMS to accord with the requirements of highly customized production, high flexibility, low production cost, and low lead time. Some of these recent developments in the field of manufacturing sector made in order to stack up against the competitive market scenario are given below:

1) Production planning and control (PPC). It is concerned with the logistic problems that are encountered in manufacturing processes. It includes the details of what and how many products to produce and when to obtain the raw materials, parts and resources to produce those products.
2) Master production schedule (MPS). It is a list of the product to be manufactured, when they should be completed and delivered, and in what quantities. The master schedule must be based on an accurate of demand and realistic assessment of the company’s production capacity.
3) Material requirements planning (MRP). It is a planning technique, usually implemented by computer, that translates the MPS of end products into a detailed scheduled for the raw materials and parts used in those end products. MRP is often thought of as a method of inventory control. However its implementation is

complicated due to the sheer magnitude of data to be processed. For example several component may be made out of the same gauge sheet metal the component are assembled into simple sub assemblies, and these sub assemblies are put together into more complex sub assemblies, and so on, until the final products are assembled. Each step in the manufacturing and assembly sequence takes time. All of these factors must be incorporated into the MRP calculations which make it a complicated one.

4) Just in time (JIT). It refers to a scheduling discipline in which materials and parts are delivered to the next production line station just prior to their being used. In this type of discipline tends to reduce inventory and other kinds of waste manufacturing. The ideal JIT production system produces and delivers exactly the required number of each component to the down stream operation in the manufacturing sequence just at the time when that component is needed.
5) Manufacturing resource planning (MRP II). It is defined as a computer based system for planning, scheduling, and controlling the materials, resources, and supporting activities needed to meet the MPS. The recent generations of MRP II such as enterprise resource planning (ERP), manufacturing execution system (MES), customer oriented manufacturing management systems (COMMS) etc have found great applications in the areas of quality control, maintenance management, customer field service, supply chain management, and product data management.
6) E-manufacturing. In the modern manufacturing system internet has enabled the manufacturers in such a way that the lead time of the manufacturing of the products have come down and the quality of the product has been enhanced.

6.10 SUMMARY

The flexible manufacturing system is a manufacturing concept for mid-volume, mid-variety part production. There could be a number of FMS's configurations possible depending upon its feature such as number of machines, kinds of operation, and level of flexibility designed into the system. Further more, the degree of automation of the machine tools, material handling systems and central computer system, depends on the objectives of an organization.

An FMS is capable of accommodating engineering and process changes that are liable to occur during manufacturing. In this chapter, various aspects of FMS such as physical and control components, its types, and some analytical treatments of machine loading problems, scheduling problems is illustrated to characterize its supremacy over the other conventional manufacturing system.

6.11 KEYWORDS

Flexibility , Penalty of change (POC), System Unbalance (SU), Throughput (TH), Reallocation Paradigm, Priority Index (PI), essential operations, optional operations, shortest processing time (SPT), earliest due date(EDD), first come first served (FCFS), first in system first served (FISFS), slack per remaining operation (S/RO) , least total work (LTWK) , least work remaining (LWOR), most operation remaining (MOR), most work remaining (MWKR), random(RANDOM), work in next queue (WINQ), Production planning and control (PPC), Master production schedule (MPS), Material requirements planning (MRP), Just in time (JIT), Manufacturing resource planning (MRP II).

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