CHAPTER 3
MODELS AND PROBLEMS CONSIDERED FOR STUDY

3.1 INTRODUCTION

There are different types of FMS and their operation differs with the configuration. Since generalised configuration is not possible, most of the research is confined to specific manufacturing systems. In this context, two systems are modelled and are as follows.

1. Set-up constrained FMC (Figure 3.1) that is analogous to the conventional twin table planners/plano-millers. The FMC considered consists of a computer-controlled machining centre, a robot, a buffer storage, a set-up platform that can accommodate two job mounting tables, and a rail guided vehicle (RGV).

2. A general job shop type FMS that comprises (Figure 3.2) several computer numerical controlled processors (WCs), an AGV, part carrying conveyors (input and output), a robot, and an AS/RS. Host computer links and controls the operations.

The operating environment, which specifies the configuration of the system along with the assumptions and the objective criterion, and the problems considered in this research are presented in the following sections.

3.2 SYSTEM 1: SET-UP CONSTRAINED FMC

The industries such as automobiles, pumps, machine tools, etc., use the conventional twin table planners/plano-millers, which have the feature of twin tables to carry out simultaneously both machining and setting activities with the specific objectives of reducing the idle time of machine and labour, for the manufacture of heavy and large parts in small batches where the set-up times are job dependent. The FMC model considered is analogous to the conventional twin table planners/plano-millers. It has been developed to automate the existing few CNC machining centres of PSG Industrial Institute, the manufacturer of industrial pumps and lathes, which produces the parts such as motor body, pump casing and lathe head stock and bed, that are involved with set-up tasks.
3.2.1 Configuration of FMC model

The FMC considered consists of a computer-controlled machining centre, a robot, a buffer storage, a set-up platform that can accommodate two job mounting tables and a RGV. The arrangement of the hardware components of the FMC is as shown in figure 3.1. The machining centre processes the parts, fixed on one of the two job mounting tables, one by one.
in the order it receives from the set-up platform. The robot carries out the following tasks: Loading (picking a job from the buffer and placing it over the free job mounting table), Setting (positioning and clamping) and Unloading (unclamping and moving the finished job back to buffer). RGV transfers the jobs from set-up platform to machining centre and vice versa. Six tasks are involved with every job. The chronological orders of them are loading, setting, transferring to machining centre, processing, transferring from machining centre, and unloading. The sequence at which the tasks are to be carried out for a job 'i' is summarised and given in TABLE 3.1.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Task</th>
<th>Hardware</th>
<th>Task Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Loading</td>
<td>ROBOT</td>
<td>$l_i$</td>
</tr>
<tr>
<td>2</td>
<td>Setting</td>
<td>ROBOT</td>
<td>$s_i$</td>
</tr>
<tr>
<td>3</td>
<td>Transfer to machine</td>
<td>RGV</td>
<td>$t_{t_i}$</td>
</tr>
<tr>
<td>4</td>
<td>Processing</td>
<td>M/Cing CENTRE</td>
<td>$o_i$</td>
</tr>
<tr>
<td>5</td>
<td>Transfer to setup platform</td>
<td>RGV</td>
<td>$t_{f_i}$</td>
</tr>
<tr>
<td>6</td>
<td>Unloading</td>
<td>ROBOT</td>
<td>$u_{l_i}$</td>
</tr>
</tbody>
</table>

### 3.2.2 Assumptions

1. Jobs arrive the system in random fashion. At any point of time, there is more than one job waiting to be processed.
2. The required times for loading $l_i$, setting on table $s_i$, transfer to machining centre $t_{t_i}$, machining operation $o_i$, transfer from machining centre $t_{f_i}$ and the unloading $u_{l_i}$ are known for each job 'i'.
3. RGV operates at constant speed. For each transfer task the time needed ($t_{t_i}$ or $t_{f_i}$) is assumed constant, and fixed as 't'.
   
   \[ t_{t_i} = t_{f_i} = t \quad i = 1, \ldots, n \]  
   \[ \quad \text{........................................... (3.1)} \]
4. Time taken for handling task (loading or unloading) of the robot that operates at constant speed is independent of jobs and depends on the distance between the set-up platform and the buffer location. Since the locations of them are assumed at fixed places, the loading ($l_i$) and unloading ($u_{l_i}$) times are equal and constant as 't'.
   
   \[ l_i = u_{l_i} = t_i \quad i = 1, \ldots, n \]  
   \[ \quad \text{........................................... (3.2)} \]
5. There is no correlation between operation time ($o_i$) and set up time ($s_i$).
3.2.3 Objective criterion

Production systems are designed essentially to meet demand efficiently. Productivity indicates the efficiency of the system effectiveness and depends on many aspects such as hardware utilisation, tardiness, in-process inventory and manufacturing lead time. One or more of the above parameters are used to measure the efficiency of the system. The scheduling objective criterion is selected based on those performance parameters. The performance parameter is decided based upon the business environment. The utilisation function, which leads to increased hardware usage (the complement of idle time), is widely adopted, where the capital cost is high. The FMS belong to the high capital intensive category since they comprise sophisticated and integrated components. Considering this aspect, the utilisation of hardware is considered as a measure of system performance.

In this proposed FMC model, the set-up time constraint influences the utilisation function. This has much significance when set up and processing times are independent. Even though, the model considered allows to carry setting-up task of next job on one job-mounting table when machining activity of a job is in progress in the machining centre with the other table, as the number of job mounting tables are limited to two, the hundred percent utilisation of either the machining centre or the robot is not feasible because of the reasons explained below.

1. The robot on completing a setting up task can not take up the next setting task immediately if the processing of the previous job loaded on the machining centre has not been finished and the robot has to wait till the previous job reaches the set-up table and moves to buffer.

2. Similarly when the machining centre finishes processing one job and the next job has not been set by the robot, the machining centre has to wait till the completion of the setting-up task of the next job.

However, if the jobs are properly sequenced, then the idle time of the robot and the machining centre can be minimised and their utilisation can be maximised.

The utilisation of each component of a system is the ratio of their respective total service time requirements and the time span of the entire schedule (i.e. makespan time). As all the tasks of the FMC are associated with deterministic time elements, the total time required for its hardware is constant. Hence the utilisation becomes a function of makespan time (schedule length) and is inversely proportional. The maximum hardware utilisation and
minimum makespan are one and the same; the sequence with minimum makespan provides optimal sequence for maximum utilisation of hardware. In this context, the makespan minimisation is considered as the scheduling objective for this sequencing problem.

3.2.4 Problem description

In the proposed model, the flow of jobs through the various components of the FMC strictly follows the chronological order. In this view, the problem is addressed as a flow shop problem. In a pure flow shop, where the processors are arranged in a serial fashion, the operations in any processor can be taken up continuously till all the jobs in its queue becomes exhausted. This is not the case with the FMC model considered since the limitation imposed by the number of job mounting tables (two) restricts the continuous flow of jobs. Also there are only three hardware components that perform the serial six tasks. Hence the problem associated with this FMC model is not considered a pure flow shop of 'n' jobs on 'm' processors and it is addressed as a special case of flow shop. In the specific operating scene delineated, the objective of the problem is to find an optimal sequence of the jobs for the performance criterion of maximum utilisation of hardware or minimum makespan time schedule.

*The problem under consideration is to derive the optimum sequence of the jobs for maximum utilisation of the hardware components (Robot, RGV and Machining centre) of the Set-up constrained FMC and subsequently to derive control program to effect smooth part flow.*

A GA based scheduling scheme is proposed to the above problem and is detailed in chapter 4.

3.3 SYSTEM 2: RANDOM FMS

The FMS model considered in this thesis is of pure job shop nature which is described as follows:

3.3.1 FMS descriptions

The configuration of the FMS considered is described as under:

1. The overall system comprises (Figure 3.2) several computer numerical controlled processors (referred as WCs), an AGV, part carrying conveyors (input and output), a robot, and an AS/RS. Host computer links and controls the operations associated with them.
2. The number of such WCs in the system will be from 2 to 10. The WC is either a machining centre or an assembly machine or an inspection station. Each WC is provided with independent tool magazines, automated part loading/unloading arrangement, part program controller, automatic tool changer (ATC) and buffer storage.

3. The robot transfers the components from AS/RS to output conveyor and from input conveyor to AS/RS.

4. The AGV transfers materials (Raw material, WIP and finished product) between WCs, WC and AS/RS, and loading/unloading station and WC. This handles the part flow within the system.

5. Sufficiently large number of general purpose pallets and fixtures are available.

6. The AS/RS stores the raw materials necessary for the parts to be processed as well as the WIP inventories.

The arrangement of the FMS hardware with six WCs is shown in figure 3.2.

![Figure 3.2 Configuration of Flexible Manufacturing System](image)
3.3.2 Assumptions

1. There are \( n \) jobs to be processed in one or more of \( m \) facilities or WC\s during a certain planning horizon. The urgent parts arrive the system randomly in between and join the queue.

2. Each job once started must be performed to completion (no pre-emptive priorities).

3. The operation sequence of all jobs along with alternate WC choices for each operation are known. For each operation a particular WC is selected based on the availability of the tools and the economical aspects. This consideration restricts the use of only one WC for one operation and assures the availability of tools necessary at the WC at any instant.

4. The maximum number of operations associated with each job is equal to number of WC\s in the system.

5. The revisit of jobs for another operation to a same WC is not allowed.

6. The operation time of a job at each facility includes the loading, unloading, tool changeover and set-up times (both tool and workpiece) along with processing time (i.e. the time between the events the part is picked and returned to the local buffer).

\[
T_{ij} = Q \times \left[ L_{ij} + \sum_{y=1}^{Y(ij)} (M_{y(ij)} + W_{y(ij)} + T_{y(ij)}) + U_{L_ij} \right] 
\]  

Where,

- \( i \) : job number
- \( j \) : work cell (WC) number
- \( L_{ij} \) : loading time of job \( i \) at WC \( j \)
- \( M_{y(ij)} \) : time for machining an operation \( y \) of job \( i \) at WC \( j \)
- \( Q \) : batch size \((Q \geq 1)\)
- \( T_{ij} \) : processing time of job \( i \) on machine \( j \)
- \( T_{Sy(ij)} \) : tool changeover time between each m/cing activity for job \( i \) at WC \( j \)
- \( U_{Ly(ij)} \) : unloading time of job \( i \) at WC \( j \)
- \( W_{Sy(ij)} \) : set-up time between each machining activity for job \( i \) at WC \( j \)
- \( Y(ij) \) : number of machining operations involved with job \( i \) on WC \( j \)

7. Deadlines (due dates) are assumed between 2 to 6 times that of total processing time of the job.

8. There are no local buffers in the system. The raw materials as well as WIP are stored in AS/RS, the structure of which is briefly described as follows. The storage structure...
considered is rectangular with 'm' rows and 'n' columns. Each storage cell is capable of holding one item of any type. The center distance between any two adjacent cells in a row is $X_r$, and in a column is $X_c$. A typical storage structure is shown in figure 3.3. The numbers given inside the cell indicate the address/label of the storage locations/cells. There is one shuttle of the crane type which is capable of moving vertically and horizontally. The P&D station is at the lower left corner of the aisle. The ordered lots of raw materials required for the planned period, which arrive at the manufacturing system just prior to start of the schedule, and semi-finished components that are not needed to be loaded immediately for the next operation, are stored in one specific vacant location of AS/RS. At any point of time, any vacant location can be used for storing any part (i.e. size & shape will not impose any restrictions).

![Figure 3.3 AS/RS Storage structure](image)

9. The transportation time ($TT_p$) depends upon the locations of WCs and AS/RS (Layout of the System), and mode of operation and speed of the AGV. The following

* Address of any location A in row 'r' and column 'c' is $(r-1)n+c$
* Bottom row is labelled as row 1
* Left column is labelled as column 1

If $r = 3$, $c = 5$, $n = 10$ and $m = 10$, then $A = 25$
assumptions are made with respect to the layout and operation mode of AGV. The distance between the neighbouring elements of the system is the same and is equal to one unit length. The AGV moves at a constant speed of one unit length per one unit time in bi-directional mode. The distance and the transportation time (that includes loading and unloading time) thus arrived for the layout with six WCs is given in TABLE 3.2.

**TABLE 3.2 Distance/Transportation time (TT\(_{ij}\)) matrix**

<table>
<thead>
<tr>
<th></th>
<th>From</th>
<th>AS/RS (0)</th>
<th>WC1 (1)</th>
<th>WC2 (2)</th>
<th>WC3 (3)</th>
<th>WC4 (4)</th>
<th>WC5 (5)</th>
<th>WC6 (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS/RS (0)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>WC1 (1)</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>WC2 (2)</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>WC3 (3)</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>WC4 (4)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>WC5 (5)</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>WC6 (6)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

3.3.3 **Objective criterion**

The utilisation function, which leads to increased hardware usage (the complement of idle time), is widely adopted as performance criterion, where the capital cost is high. The FMSs belong to the high capital intensive category since they comprise sophisticated and integrated components. Considering this aspect, the utilisation of hardware is considered a measure of system performance. The utilisation is a function of makespan time (schedule length) and is inversely proportional. The schedule with minimum makespan provides optimal for maximum utilisation of hardware. The maximum hardware utilisation and minimum makespan are one and the same; the schedule with minimum makespan provides optimal for maximum utilisation of hardware. In this context, the scheduling objective criterion considered for this system is minimisation of makespan time.

3.3.4 **Problem statement**

The objective of the problem is to determine production (machine) schedule that is integrated with AGV schedule and AS/RS operations. Further, there is a need to develop rescheduling concept that revises the schedules to incorporate the new job arrival cases and machine break downs to address the real time environment. The problem is defined as follows.
Given the processing requirements (operation/job matrix) of 'n' jobs on 'm' machines or WCs, the problem is to derive the time table of all tasks associated with 'n' jobs in the FMS (System 2, whose operating environment has been just described above) with minimum makespan criterion that maximises the utilisation of the hardware of the system, and to revise the schedule on arrival of new jobs and machine break downs.

The time table of activities requires to furnish the production schedule, AGV schedule and control program for AS/RS operation. The methodology that is proposed to achieve the objective involves three steps and is as follows.

1. Generation of an optimal finite production schedule (time table) for makespan criterion incorporating alternate route choices and neglecting transportation times.

2. Derivation of an optimal integrated schedule for makespan criterion, which gives the modified production schedule that integrates the AGV moves (AGV schedule) with minimum right shift, from the production schedule that is obtained neglecting transfer activities.

3. Development of an optimal control program for AS/RS shuttle operation in order to regulate the flow of materials in conjunction with production schedule and minimum movement of the S/R machine by optimal allocation of materials in AS/RS.

Three off-line rescheduling algorithms (including a GA) and two knowledge-based scheduling schemes are proposed to generate schedules under negligible transportation time. They are addressed in chapter 5 and Chapter 6 respectively. A heuristic algorithm that integrates the machine schedule with AGV schedule is addressed in chapter 7. The optimal storage allocation problem is dealt with in chapter 8.