CHAPTER 3

THE MODEL AND PROBLEMS CONSIDERED FOR THE STUDY

3.1 INTRODUCTION

The type, its layout and configurations, and its system components of any FMS are determined by the envisaged product variety and demand, product mix and the existing set-up of the particular manufacturing organization [6, 108]. No two FMS around the globe exhibit striking similarities. Hence, the operational procedure and so the related issues differ from one FMS to another. This is the reason why most of the research works are confined to specific FMS configuration and problem environment.

In this thesis, a FMS is modeled, taking into account all the generic configurations and features that are normally found in different types of FMS in practice. The detailed description of the FMS model, assumptions made, it’s operating environment and problem considered are presented in this chapter.

The model and problems described in this chapter are used as the common platform for conducting experiments and evaluating the different search heuristic algorithms developed in this work.

3.2 FLEXIBLE MANUFACTURING SYSTEM MODEL

In this work, a FMS based on the standard system architecture (as shown in Figure 1.1) is modeled for the study. The FMS is modeled to cater to a production environment wherein a maximum of \( n \) number of jobs/parts are required to be
processed using a maximum of \( m \) number of machines/work stations and in low to mid volume batch quantities. The details of the model are described as below:

### 3.2.1 Configuration of the FMS Model

The configuration of the modeled FMS is as under:

1) The set of \( m \) number of machines, \( M = \{m_i\}_{1 \leq i \leq m} \) and the set of \( n \) number of jobs \( J = \{j_j\}_{1 \leq j \leq n} \) are grouped based on part-machine incidence matrix, into \( g \) number of FMCs and \( g \) number of part families such that:

\[
\bigcup_{u=1}^{g} F_u = M
\]

\[
|F_u| \geq 1 \quad \forall \ 1 \leq u \leq g \quad \text{and} \quad \sum_{u=1}^{g} |F_u| = m
\]

and

\[
\bigcup_{v=1}^{g} P_v = J
\]

\[
|P_v| \geq 1 \quad \forall \ 1 \leq v \leq g \quad \text{and} \quad \sum_{v=1}^{g} |P_v| = n
\]

where \( F_u \) represents set of machines in \( u^{th} \) FMC and \( P_v \) represents set of jobs in \( v^{th} \) part family

2) There is a loading station from where the parts are released in batches into the FMS for manufacturing.

3) There is an unloading station from where the finished parts are collected and conveyed to the finished storage.

4) There is a dedicated robot for loading and unloading AGVs at the Loading and Unloading station.

5) There is one AS/RS to store the Work-In-Progress (WIP) inventory.
6) The FMCs are interconnected by \( z \) number of identical AGVs. These AGVs perform the movement of loaded pallets from the loading station to any of the FMCs, the inter-cellular movements of parts between the FMCs, movement of the finished part from any of the FMCs to the unloading station and the movement of the semi finished parts between the AS/RS and the FMCs.

7) Within the FMS, the FMCs have the following configurations:

a. Each CNC machine is equipped with an independent and self-sufficient Tool Magazine, an ATC, an APC and other accessories and attachments.

b. In each CNC machine, there is an Input and an Output Buffer each with a capacity of holding two pallets loaded with parts.

c. There is an APC with each CNC machine for the transfer of pallets (loaded with raw/semi-finished part) from the Input Buffer to the machine table and pallets (with the machined part) back from the machine table to the Output Buffer.

d. Robots within FMC, transfer parts from the Output Buffer of a CNC machine to the Input Buffer of another CNC machine.

e. Each FMC is supported by \( r \) number of robots, for the intra-cellular movements of the parts between operations,

\[
r = \frac{n_f}{2} \quad \text{when} \quad n_f \text{ is even}
\]

\[
= \frac{(n_f + 1)}{2}, \quad \text{otherwise}
\]

where \( n_f \) is the number of machines/work stations in the particular FMC.
f. There is a machine Controller with each CNCs machine to control all the machining and handling of parts and tools activities of the machine.

g. There is a Cell Controller to control and co-ordinate the activities among the CNC machines and Robots within the cell.

h. The FMC Controller is connected to the controllers of AGV, AS/RS and the main controller of the HCS of the FMS (through which the FMC is integrated with other FMCs of the FMS).

The configuration of an example FMS with \( m = 16, g = 5, z = 2, r = 1 \) to \( 3 \) and \( n = 40 \) to \( 50 \) is shown in Figure 3.1.

![Figure 3.1 Configuration of an example FMS](image)

The configuration of an example FMC with two CNC machines and one robot (say, the FMC 1 of the example FMS shown in Figure 3.1) is shown in Figure 3.2
3.2.2 Assumptions

1. Each part has a particular processing sequence, batch size, due date and penalty cost for not meeting the due date. The processing sequence is based on the optimum route with respect to minimum manufacturing lead time.

2. Each processing step has a processing time on a specific machine.

3. CNC operations are not preemptive and all jobs have zero ready times.

4. All the incoming parts (clamped onto the pallets), arriving at the Input Buffer do not require any setting up work at CNC machine.

5. There is no constraint on the availability of pallets and fixtures.
6. The transfer of parts from the Input Buffer to the machine table and from
the machine table to the Input Buffer takes equal time and is constant for
all the jobs.

7. If the CNC machine is busy in processing a part on the machine table, the
part(s) in the Input Buffer waits till the CNC machine becomes free.
Similarly a machined part waits in the Output Buffer, till any one of the
AGVs becomes available for transferring (in the case of an inter-cell
transfer) or till the associated robot becomes available for transferring (in
the case of an intra-cell transfer).

8. The product mix is planned to meet the current market demand. The
example product mixes considered for experimentation (with the example
FMS shown, in Figure 3.1) are shown in Appendix I.

3.2.3. Mode of FMS Operation

The FMS model described in the above sections is operated with the following
sequence:

1. The given set of \( m \) number of jobs is fed into the FMS in a specific input
sequence through the loading station.

2. From the loading station, the parts (loaded in pallets) of a particular part
family are delivered to the concerned FMC by the available AGVs.

3. Within the FMC, the parts are processed at different CNC machines as per
the order of the processing sequence. Within the FMC, the parts are
transferred from one machine to the next machine (that is, the intra-cell
movements are done) by the associated robots available in the FMC.
4. In case the parts are required to be processed by machines in other FMCs, they are transferred (that is the inter cell movements are done) by the available AGV.

5. The jobs arriving at the workstations are processed on first-come-first-served basis.

6. During the execution of the given job input sequence, deadlocks or shop locking [109] occurs when (i) the input and output buffers of some or all of the CNC machines are simultaneously full and these machines are blocked; (ii) all the AGVs loaded with WIP parts can not make their deliveries because the corresponding input buffers are full and there is no other AGV available to free any space from the Output Buffers. The phenomenon of deadlock in FMS is explained in Figure 3.3. During such deadlock occasions, the WIP parts are delivered to the AS/RS by the AGVs and temporarily stored till the dead locks are released.

![Diagram of FMS with deadlock](image)

*Job 2 can not be moved to machine A, whose input buffer is full and is blocked by job 8. Again, job 6 can not be moved to machine B, whose input buffer is full and is blocked by job 3 – FMS is locked.*

**Figure 3.3 Deadlock in FMS**
7. As and when all the operations are completed, the finished parts from various FMCs are collected back at the unloading station by the AGV and stored at the shipping yard.

8. On arrival of the last part produced at the unloading station, the performance measure of the FMS with respect to the objective criteria (explained in the following section) is evaluated.

3.2.4 Objective Criteria

While establishing the appropriate performance measure for the capital intensive FMS, the operational executives need to consider the following primary goals of the organization:

(i) to improve overall utilization of the capital intensive FMS
(ii) to run the FMS with minimum deadlocks and machine blockings
(iii) to reduce the overall material handling, that is, the total travels (both empty and loaded) by the AGVs and robots
(iv) to promptly deliver the finished parts to the customers by reducing the manufacturing lead time

While the first three goals are aimed at improving the productivity and overall efficiency of the system, the last goal is aimed at the customer satisfaction, an important aspect in the world of global market. To achieve these goals, the following two objectives are considered in this work

(1) Maximizing the system utilization through minimizing the total idleness of all the machines/workstations
(2) Maximizing the customer satisfaction through minimizing the total penalty (for the tardiness) of all the tardy jobs produced
For simultaneously optimizing the above said objectives, a Combined Objective Function (COF) is formulated as below:

Minimize: \[ COF = (W_1) \times \left( \frac{X_p}{MPP} \right) + (W_2) \times \left( \frac{X_q}{TE} \right) \]

where

\[ X_p = \sum_i (CT_i - DD_i) \times UPC_i \times BS_i \quad X_q = \sum_j MD_j \quad \text{and} \quad MD_j = TE - \sum_i PT_{ij} \]

\[ W_1 = \text{Weightage factor for customer satisfaction} \]

\[ X_p = \text{Total Penalty Cost incurred for tardiness of all tardy jobs produced} \]

\[ i = \text{Job number} \]

\[ CT_i = \text{Completion Time of job } i \]

\[ DD_i = \text{Due Date for job } i \]

\[ UPC_i = \text{Unit Penalty Cost for job } i \]

\[ BS_i = \text{Batch size of job } i \]

\[ MPP = \text{Maximum Permissible Penalty} \]

\[ W_2 = \text{Weightage factor for system utilization} \]

\[ X_q = \text{Total System Down Time on account of idleness of all machines} \]

\[ MD_j = \text{Total Machine Down Time on account of idleness of } j^{th} \text{ machine} \]

\[ j = \text{Machine number} \]

\[ TE = \text{Total Elapsed Time} \]

\[ PT_{ij} = \text{Processing Time of } i^{th} \text{ job with } j^{th} \text{ machine} \]

Note: In order to balance the search, that is, during the search process not to let any one of the objective function taking preference over the other, in getting optimized, by the virtue of its absolute value, both \( X_p \) and \( X_q \) are divided by \( MPP \) and \( TE \) respectively.
3.2.5 Problem Statement

Hence the problem considered for the study can be stated as,

*Determination of an optimal input sequence of n jobs, resulting in an integrated schedule of the general FMS model described in section 3.2.1, 3.2.2 and 3.2.3, for a combined objective criterion (as described in section 3.2.4) that maximizes the system utilization of the FMS and minimizes the tardiness of all parts produced, given their processing requirements of individual parts and the operating environment of the FMS.*

The FMS scheduling problem is *approximately solved* using the intelligent search heuristics developed in this work, through an integrated scheduling framework which is described in Chapter 4.