INTRODUCTION

1.1 OVERVIEW

In any operation planning and management, decision making is a very crucial process. Most of the times, the decision is regarding finding an optimum solution. In most of the cases in industries, the design objective is to minimize the production cost or to maximize the profit \[1\]. Optimization can be defined as the process of finding the conditions that provide the maximum or minimum value of a function.

Manufacturing can be defined as the application of physical and chemical processes to alter the geometry, properties, and appearance of a given starting material to make parts or products. Besides, manufacturing also includes the joining of multiple parts to make assembled products \[2\].

The technological and socio-economic transformations brought about by the industrial revolutions in the 18\(^{\text{th}}\) and 19\(^{\text{th}}\) centuries resulted in the development of manufacturing and allied industries. These industries were either involved in manufacturing and processing of items or indulged in the creation of new commodities. The industrial revolution also heralded the beginning of automation replacing labour intensive industrial processes through mechanized manufacturing procedures. The technologies and methods used in these industries have come to be known as manufacturing process management. This Manufacturing process management has played a major role in the evolution of the manufacturing process, the technologies used and the products produced. The manufacturing industries play a very vital role in defining the growth and development of a nation. The health of the manufacturing industries has more often been considered as a reliable index for development of the nation. “The Indian government call for MAKE IN INDIA campaign” \[3\] is a testimony for the significance of manufacturing industries towards Nation building.

The process of globalization has thrown open both opportunities and challenges alike. Manufacturing process and organization have to evolve and adapt continuously to the new and emerging challenges in order to cope up with the rapid pace of development. One key indicator which determines the level of
competitiveness of an industry, is its ability for flexible production of goods. Global competition, rapid introduction of new products and constantly varying product-demand have defined, how the manufacturing industries should operate in 21st century. These companies are required to produce high quality products at low cost to remain in the competition. So the viability and profitability of any industry have come to depend on how easily and quickly these industries can adapt themselves to the changing demand. An industry should be lean, flexible and should be capable of utilizing the existing resources to the optimum to contain these attributes. A manufacturing system which is flexible and has low setup times characterized by multiple degrees of freedom, provides the industry’s nimbleness to adapt to the changes in demand and needs of the consumer. These types of systems are referred to as Flexible Manufacturing Systems.

The idea of FMS was first proposed in England in 1960 under the name "System 24" [2]. It was a Flexible Manufacturing System which could operate 24 hours a day without any operator intervention under the control of a computer. The primary emphasis of these systems was automation rather than the "Reorganization of workflow". Earlier, Flexible Manufacturing Systems were large, complex, comprising of number of Computer Numerical Controlled machines (CNC) coupled with advanced Material handling systems. Even though these systems were highly sophisticated and controlled by incredibly complex software, because of their high capital cost, their usage was limited to very few industries. With the advancement in the process of computation coupled with allied hardware and software availability, today two or more CNC machines are considered as a Flexible cell and two or more Flexible cells are considered as FMS.[4]. So, FMS have several machine tools along with part and tool handling devices like Robots, AGVs [5] are laid out in such a fashion that they are capable of handling any family of parts for which they are designed.

A Flexible manufacturing system is a highly automated Group Technology (GT) Machine cell, consisting of a group of processing work stations, usually CNC machine tools, interconnected by an automated material handling and storage system and controlled by a distributed computer system [2].
Higher levels of consumer awareness have made factors such as flexibility, quality, delivery and consumer satisfaction affect the manufacturers’ perception which was once primarily influenced exclusively by the need to lower the production cost alone. The manufacturing industries are striving hard to be lean [2] and adaptable through innovative methods and concepts like Just-In-Time (JIT), Production Planning and Control (PPC), Enterprise Resource Planning (ERP) [6] etc. FMS is a concept which allows a manufacturing system to be configured and built for highly customized production requirement. FMS is the preferred answer to the numerous challenges thrown at the manufacturing industries by the process of globalization and varied consumer perception.

1.2 MOTIVATION

Flexible Manufacturing Systems are complex interconnected systems, which pose a series of challenges to researchers. Research in FMS can broadly be classified into two prime problem areas [7]; namely, the design problem area and operational problem area. In the design stage, the research focuses on specifying the system so that the desired performance objectives are met. The research in the operational aspects of the FMS is oriented towards decision making with regard to scheduling, planning and also controlling of a given system. The researcher in this work aims at venturing into operational aspects of FMS to provide better scheduling options.

In day to day environment, manufacturing industries are forced to introduce new products more frequently to maintain the market share. This scenario has put tremendous stress on the existing manufacturing setup and manufacturing process. The key here is to optimize the utilization of resources and to increase the throughput and efficiency [8]. The available resources can be optimally utilized by implementing proper scheduling methods.

Scheduling can be defined as “The allocation of resources over a period of time to perform a collection of tasks”. Yet another definition of scheduling is that, “It is a function to determine an actual (optimal or feasible) implementation plan as to the time schedule for all jobs to be executed; that is, when, with what machine and who does that operation”. Scheduling of FMS has been an active area of research right from the inception of FMS. FMS scheduling is considered to be one of the most
difficult NP-hard problems “If there are \( n \) jobs and \( m \) machines, the number of theoretically possible solutions are equal to \((n!)^m\). For example, a simple problem of 5 jobs and 8 machines will give \( 4.3 \times 10^{16} \) numbers of alternatives [16]. Proper scheduling solution has to be chosen from these numbers of alternatives. But checking all the possible solutions are computationally intensive, time consuming and practically not feasible in an industrial environment. Traditional methods based on priority rules [9] like Largest Processing Time (LPT), Shortest Processing Time (SPT), Highest Penalty (HP), Earliest Due Date (EDD), Largest Batch Size (LBS) and Smallest batch size (SBS) provides feasible time bound solutions. But, one cannot guarantee that these solutions are optimum. There is a need to find a scheduling solution i.e. optimum as well as feasible, which necessitates the need to venture into Metaheuristic based approaches to discover whether they are capable of providing optimum to near optimum solutions in an acceptable time frame [10].

The inherent complex nature of the FMS makes it difficult to describe a standard Flexible Manufacturing System control environment in order to aid the decision making process. There is an urgent need for a tool, wherein the operator will be able to input different process scenario and to get an optimum schedule.

1.3. AIM AND SIGNIFICANCE OF THIS RESEARCH WORK

The research identifies the relevance of the existing techniques to optimize scheduling in traditional manufacturing systems, so that they can be shifted into FMS environment. As the implementation of FMS cannot be setup as a whole, it requires a time-horizon. However, FMS is to be introduced according to the managerial decisions, so that they exhibit flexibility with improved productivity. In the current research, priority rule based optimization methods and Metaheuristic approaches like GA, DE and BFOA have been proposed to schedule the jobs on to machines. The interpretation of the numerical case studies may not reflect a more general view of the industries. It is presumed that the information contained in this research work will be of general interest to the Indian industries moving towards implementation of FMS. In this context, this research work presents various perspectives to the problems associated with the industries.
1.4. OBJECTIVES OF THIS RESEARCH WORK

The primary objective of the proposed new framework is to design an automated tool for optimization of scheduling in FMS with primary emphasis on Metaheuristic approaches. The other objectives of this work can be enlisted as follows:

- To evaluate the system performance using total idleness of machines and total penalty cost as performance measures.
- To validate the performance of the proposed system with the Metaheuristic strategies like Genetic Algorithm (GA), Differential Evolution (DE) and BFOA and with Priority rules such as SPT, LPT, EDD, LBS, SBS and HPC.
- To investigate the suitability of a reward in optimizing the scheduling process.
- To design a user friendly Graphical User Interface which can seamlessly integrate with the process of aiding easy decision making.
- To build an FMS simulation model in ProModel simulation software in order to ease the process of decision making by the participated industry.

The above mentioned objectives are validated practically with M/S NELCAST LTD, Gudur, including the data sets taken from past literature [8, 11, 12].

1.5 PROBLEM STATEMENT

The efficient use of Flexible Manufacturing Systems requires effective scheduling of the system. Generally, when a Flexible Manufacturing System is being planned the objective is to design a system which will be efficient in the production of the entire range of parts [12]. This cannot be achieved until the design; production planning, scheduling and controlling stages work well. Depending on the required measure of scheduling performance, many different approaches to the scheduling problem can be generated. Scheduling methods can be classified into different approaches such as combinatorial optimization, Artificial intelligence, Simulation-based scheduling with dispatching rules, Heuristics-oriented and multi-criteria decision making [7]. However, the production scheduling in an FMS is usually very complicated, particularly in dynamic environments. Several manufacturing systems need scheduling for dynamic and unpredictable conditions. So artificial intelligence, heuristic-based approaches and Metaheuristics have been considered in FMS.
scheduling. The efficiency of the manufacturing is largely influenced by the scheduling and optimum utilization of machinery. The ultimate goal in any scheduling approach is to reduce the idleness and increase the machine utilization time.

1.5.1 Objective Function

In this research work, scheduling is modeled as a multi-objective optimization problem with primary objective for selecting a schedule which has less Combined Objective Function (COF). Most of the optimization functions proposed in the literature have penalties incorporated in them, when the scheduled job is not completed in the specified time. Here, it is proposed to incorporate a reward for each job, if the job is completed ahead of time. Such an approach is expected to increase the efficiency with regard to the total machining time.

The objective function is to

Minimize COF = (W1) \times [(X_p/MPP)/(X_r/MPR)] + (W2) \times (X_q/TE) \quad (1)

\[ X_p = \sum_i (CT_i - DD_i) \times UP_{C_i} \times BS_i \quad (2) \]

\[ X_r = \sum_i (DD_i - CT_i) \times UR_{C_i} \times BS_i \quad (3) \]

\[ X_q = \sum_i MD_j \quad (4) \]

\[ MD_j = TE - \sum_i PT_{ji} \quad (5) \]

Subjected to

at \ TE = 0 ; \ PT_{ji} = 0

\[ X_p \leq \sum_i BS_i \times p_i \]

\[ X_r \leq \sum_i BS_i \times r_i \]

For VBS
\[ 0 \leq \text{MPP} \leq (\text{MBS}_i \times p_i) \]

\[ 0 \leq \text{MPR} \leq (\text{MBS}_i \times r_i) \]

For CBS

\[ 0 \leq \text{MPP} \leq (\text{BS}_i \times \text{HP}_i) \]

\[ 0 \leq \text{MPR} \leq (\text{BS}_i \times \text{HR}_i) \]

Where

\[ W_1 = \text{Weight Factor for Customer Satisfaction} \]

\[ W_2 = \text{Weight Factor for Machine Utilization} \]

\[ X_p = \text{Total Penalty cost Incurred} \]

\[ X_r = \text{Total Reward cost Incurred} \]

\[ i = \text{Job Number,} \]

\[ \text{CT}_i = \text{Completion time for job } i \]

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

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

\[ \text{URC}_i = \text{Unit Reward Cost for job } i \]

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

\[ \text{MPR} = \text{Maximum Permissible Reward} \]

\[ \text{BS}_i = \text{Batch Size of job } i \]

\[ X_q = \text{Total Machine Down Time,} \]

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

\[ \text{PT}_{ji} = \text{Processing time of } i^{th} \text{ job with } j^{th} \text{ machine} \]
j = Machine Number
p_i = Penalty cost for job i
r_i = Reward cost for job i
HPi = Highest penalty cost for job i
HRi = Highest reward cost for job i
MBSi = Maximum batch size for job i
MD_{j} = Machine down time for j^{th} machine

In this research work, the weight factors W_1 and W_2 are assumed to be equal. However, different ratios can also be applied according to the manufacturing requirement.

1.5.2 Assumptions

The following assumptions are made when the models have been developed

1. Processing time for each part on each machine is known

2. Every part has a particular processing sequence, batch size, due date, penalty cost for not meeting the due date and incorporate a reward point, if the job is completed before the scheduled date.

3. Each machine can process only one operation at a time

4. Each operation can be processed without interruption on one of a set of available machines

5. Recirculation occurs when a job could visit a machine more than once

6. The order of operations for each job is predefined and cannot be modified.

1.5.3 Illustration of Research Problems

To illustrate the research problems, the following cases are considered in the thesis for interpretation:
1. Case problem-1: This comprises of 43 jobs on 16 machines and sub cases which comprises of 6 jobs on 6 machines. Again the analysis is done for three more models of Job(J) x Machine(M) x Operation (O). Data sets have been considered from the literature (8, 11, and 12).

2. Case problem-2: This comprises of 3 setups, comprising 6 machines, manufacturing 3 parts in 9 different routes. M/S NELCAST LTD, GUDUR has given its consent and participated in the research work [15].

1.6 ORGANIZATION OF THE THESIS

The thesis is presented in 7 Chapters and a brief outline of each chapter is given below. Figure 1.1 shows the simplified overview of this research work.

Chapter 1 gives a brief introduction about Flexible Manufacturing System. This chapter also elaborates on motivation behind the research work in section 1.2. Aim and importance of the research problem along with the research objectives are presented in sections 1.3 and 1.4. The chapter further describes the problem statement and formulates an objective function in section 1.5.

Chapter 2 is devoted to literature review about FMS scheduling, Metaheuristic approaches, simulation tools etc.

Chapter 3 describes about various concepts of FMS and significance of scheduling in detail with reference to FMS environment.

Chapter 4 discusses in brief about the priority rules and Metaheuristic approaches used such as GA, DE and BFOA for optimization of scheduling in the proposed work. It also elaborates on the description of the software tools like Promodel and Matlab used in the research work. In addition, this chapter also discusses in detail about the Automated Tool Designed in the form of Graphical User Interface (GUI) in Matlab for optimizing the scheduling.

Chapter 5 is devoted for analyzing the optimization of scheduling using the proposed approaches for Case problem 1 which comprises of 43 jobs on 16 machines and also comprises of 6 jobs on 6 machines and Case problem 2, which comprises of 3 setups, comprising 6 machines, manufacturing 3 parts in 9 different routes.
Chapter 6 provides the summary and comparison of the results of FMS scheduling using the different Metaheuristic approaches and Priority rules. It also shows various observations of the performance of the system by modeling and simulation with Promodel software.

Chapter 7 gives the conclusion for the research work carried out on FMS scheduling and also proposes possible suggestion for future research.
Fig. 1.1: Simplified overview of this research work