CHAPTER – I
INTRODUCTION

1.1 Introduction

To stay competitive in the present day manufacturing environment that demands low cost products with short delivery times, an effective scheduling of the shop floor equipment is essential. Scheduling deals with allocation of resources over time to perform a set of tasks and is of crucial importance in achieving the required targets [1]. It is a decision making process that has the goal of optimizing one or more objectives. The most obvious objective is to increase the utilization of resources i.e. to reduce the resource idle time, for a finite set of tasks, the utilization of resources is inversely proportional to the time required to accomplish the entire task.

1.2 Background

Sequencing involves the determination of the order of processing a set of tasks over a period of time whereas scheduling involves sequencing as well as the determination of the starting and completion times of the activities. The decisions regarding which job is to be loaded on which machine are normally made with the help of dispatching rules and it is observed that no single rule has been found to perform well for all-important scheduling criteria [2,3]. Job shop scheduling problem (JSSP) is one of the most general production problems where ‘n’ jobs have to be processed on ‘m’ machines and typically the job characteristics impose certain constraints such as precedence relations among the operations of a job, job priorities and job due dates. In job shop scheduling each job requires processing on each machine exactly once. For each job, technology constraints specify a complete, distinct routing, which is fixed and known in advance. Processing times are sequence-independent, fixed, and known in advance. Each machine is continuously available from time zero, and operations are processed without preemption. The most important scheduling objective is to minimize the total completion time of all the jobs referred as makespan and other important objectives include reduced mean flow time and mean tardiness [3].

Flexible Job-shop Scheduling Problem (F-JSSP) is an extension of the job shop scheduling problem with an assumption that a machine is capable of performing more than one type of operation i.e., for any operation there must be at least one
machine capable of performing it[4]. Basically, there are two versions of flexibilities, total flexibility where each operation can be performed on any machine and partial flexibility where only some operations can be performed on more than one machine. The major problem is to assign operations on machines and to schedule operations assigned on each machine, subject to the constraints. The general objectives of flexible job shop scheduling are minimization of makespan, maximum machine workload and total workload.

1.3 Motivation

Scheduling problems are combinatorial in nature and solving such problems amounts to make discrete choices of an optimal solution among a finite number of alternatives. Most of the real world scheduling problems are NP Hard, involves simultaneous optimization of multiple objectives and it is difficult to find an optimal solution without the use of an enumerative algorithm. Finding near-optimal solutions’ using approximate algorithms within a reasonable time has become a practice [4].

Recently evolutionary algorithms [EA] are widely used to address both single and multi-objective optimization problems. Differential Evolution (DE) is an exceptionally simple evolution strategy that is significantly fast and robust for numerical optimization and can be classified as a class of floating point encoded evolutionary algorithm [6]. It is a population based evolutionary mechanism, which uses simple operators to create new candidate solutions and one-to-one competition schemes to greedily select new candidates. Due to its simple concept, easy implementation and relatively fast convergence, DE has attracted much attention and wide applications in different fields.

Flexible job-shop scheduling problem is more complex than JSSP because of the additional need to determine the assignment of operations to the machines [5,7]. The job shop is flexible, i.e. there are multiple job routes. The scheduling problem of a F-JSSP consists of a routing sub-problem, that is, assigning each operation to a machine out of a set of capable machines and the scheduling sub-problem, which consists of sequencing the assigned operations on all machines in order to obtain a feasible schedule minimizing a predefined objective function. It is quite difficult to achieve an optimal solution with traditional optimization approaches owing to the high computational complexity. But it is one of the most critical issues in the planning and managing of manufacturing processes. Many practical problems have an
underlying flexible job shop structure, such as Multiprocessor task scheduling, Network routing, Robotic cell scheduling, Project scheduling, Railway scheduling and Air traffic control.

This complex nature of job shop scheduling gained the attention of many researchers for quite a long time but most of them addressed only single objective optimization. Present day it is not enough to focus on only single objective optimization instead two or more objectives are to be considered simultaneously to achieve the required scheduled targets. In the single objective optimization, one tries to find the best decision, which is usually the global minimum or the global maximum. In case of multiple objectives, there may not be one solution, which is the best with respect to all objectives.

In multi-objective optimization problems, there exists a set of solutions, which are superior to the rest of solutions in the search space when all the objectives are considered but are inferior to the other solutions in the set in one or more objectives. These solutions are known as Pareto-optimal solutions or non-dominated solutions and the rest of the solutions are known as dominated solutions [7]. In the present work, multi objective flexible job shop scheduling problems are addressed using differential evolution (DE) algorithm for minimization of makespan, total machine load and critical machine load using random keys encoding mechanism and non-dominated sorting method.

1.4 Job shop Scheduling Model

The classic $n \times m$ Job Shop Scheduling Problem is given by a finite set $J$ of $n$ jobs $\{J_i\} 1 \leq i \leq n$ and a set $M$ of $m$ machines $\{M_j\} 1 \leq j \leq m$. Each job has to be processed on every machine. For this purpose, a job is subdivided into a set of $m_i$ operations $\{O_{ikj}\} 1 \leq k \leq m$ which have to be scheduled in a strictly sequential way according to a given technological order, also referred to as the precedence constraints. Thus $O_{ikj}$ denotes the operation of job $J_i$ that has to be processed on machine $M_j$ for a certain uninterrupted processing time $p_{ikj}$.

1.4.1 Objective Criteria

The main objectives of the JSSP model are minimization of makespan, Mean Flow time and Mean Tardiness

1. Makespan ($t_{M}$), i.e., the maximum of completion times of all jobs;

2. Mean Flow Time ($\bar{F}$), i.e., the average flow (completion) time of all jobs;
3. Mean Tardiness ($\bar{T}$), i.e., the average of positive lateness of all jobs.

1.4.2 Mathematical Model for JSSP

Decision Variables:

$$t_{ikj} : \text{Completion time of } O_{ikj} \text{ on machine } M_j \text{ for each job } J_i$$

$$\min \ t_M = \max_i \{C_i\} \quad (1.1)$$

$$C_i = \sum_{k=1}^{\infty} t_{ikj} \quad (1.2)$$

$$F_i = C_i - r_i \quad (1.3)$$

$$T_i = \max\{0, C_i - d_i\} \quad (1.4)$$

$$\min \ \bar{F} = \frac{\sum_{i=1}^{n} F_i}{n} \quad (1.5)$$

$$\min \ \bar{T} = \frac{\sum_{i=1}^{n} T_i}{n} \quad (1.6)$$

$$s.t \quad t_{i,k-1,j} + p_{ikj} \leq t_{ikj}, \forall i,k,j \quad (1.7)$$

$$t_{ikj} \geq 0, \forall i,k,j \quad (1.8)$$

The objective functions at Eq. 1.1, 1.5 and 1.6 are to minimize the makespan, mean flow time and mean tardiness respectively. The constraint at Eq.1.7 is the operation precedence constraint, the $(k-1)^{th}$ operation of job $i$ should be processed before the $k^{th}$ operation of the same job.

1.5 Flexible Job shop Scheduling Model

The flexible job shop scheduling problem is defined as follows: $n$ jobs are to be scheduled on $m$ machines. Each job $i$ contains number of ordered operations. The execution of each operation requires one machine, and will occupy that machine until the operation is completed. The F-JSSP problem is to assign operations on machines and to schedule operations assigned on each machine. The constraints of the F-JSSP model can be described that the operation sequence for each job is prescribed and each machine can process only one operation at a time.

1.5.1 F-JSSP Constraints

1. Disjunctive constraint: Each operation can be processed by only one machine at a time. In case a task cannot be processed on a machine, the processing time of the task on the machine is set to a very large number.

2. Non-preemption condition: Each operation, which has started, runs to completion

3. Capacity constraint: Each machine performs operations one after another
4. Precedence /conjunctive constraint: Although there are no precedence constraints among operations of different jobs, the pre-determined sequence of operation for each job forces each operation to be scheduled after all predecessor operations i.e. precedence relationships among operations of a job are predetermined.

5. Resource constraint: The machine constraints emphasize the operations can be processed only by the machine from the given set.

6. The set-up time for the operations is machine-independent and is included in the processing time.

1.5.2 Objective Criteria

The main objectives of the F-JSSP model are minimization of makespan, maximal workload and total workload

1. Makespan \((t_M)\), i.e., the maximum of completion times of all jobs;
2. Maximal machine workload \((w_M)\), i.e., the maximum working time spent at any machine;
3. Total workload \((w_T)\), which represents the total working time over all machines.

The relationships between the three objectives are very complex. As in most multi-objective optimization problems, the three objectives considered conflict with one another. For example, the machines may have different efficiencies for each operation, so the total workload would always be minimized by using exclusively the most efficient machine. Yet, that may not minimize Makespan, since the less efficient machines would be idle. On the other hand, a small makespan requires a small maximal workload and a small maximal workload implies a small total workload. In this sense, the three objectives depend on each other. In contrast to most multi-objective optimization problems in which there are no priorities among the objectives, makespan is given overwhelming importance in the F-JSSP problem [8].

1.5.3 Mathematical Model

**Decision Variables**

\[
X_{ijk} = \begin{cases} 
1 & \text{if machine } j \text{ is selected for the operation } O_{ik} \\
0 & \text{otherwise}
\end{cases}
\]

\[C_{ik} = \text{completion time of } O_{ik}\]

\[
\min t_M = \max_i \max_k \{C_{ik}\} \quad (1.9)
\]

\[
\min W_M = \max_f \{W_f\} \quad (1.10)
\]
\[
\min W_T = \sum_{j=1}^{m} W_j 
\]  
(1.11)

\[
s.t \quad c_{ik} - t_{ikj}x_{ikj} - c_{i(k-1)} \geq 0 \quad k = 2, \ldots, K_i ; \quad \forall \ i, j
\]  
(1.12)

\[
\sum_{j=1}^{m} x_{ikj} = 1, \forall \ k, i
\]  
(1.13)

\[
x_{ikj} \in 0,1, \forall \ j, k, i
\]  
(1.14)

\[
c_{ik} \geq 0, \forall \ k, i
\]  
(1.15)

1.6 Objectives of Research & Methodology

The present research has been initiated with the following objectives.

- To study the feasibility of solving job shop scheduling problems using evolutionary algorithms like differential evolution algorithm.

- To develop a suitable random key encoding mechanism to implement a stochastic based adaptive scheme, i.e. differential evolution algorithm to a discrete optimization problem like scheduling and to test the efficacy of the developed models with that of standard scheduling heuristics.

- To consider the Flexible Job shop scheduling as a multi objective optimization problem by simultaneously considering the objectives like minimization of makespan, maximum machine workload and total workload using hybrid differential evolution algorithm.

- To develop a hybrid approach of differential evolution, local search algorithm and non dominated sorting algorithm to generate a Pareto set of non-dominated solutions for the given scheduling problems.

- To study the performance of the developed hybrid approach to different varieties of scheduling problems ranging from small size to large size.

- To investigate the generality of the developed algorithm by implementing the algorithm to a different, yet related and multi objective machine scheduling problems.

The work has been carried out in two stages to achieve the said objectives. In the first stage, the proposed differential evolution algorithm implemented for single objective optimization and tested against several other algorithms. In the second stage the algorithm is extended for the multi objective optimization problems of JSSP and F-JSSP. The results are compared with the results of other standard algorithms to assess the performance of the developed algorithm.
1.7 Organization of the Thesis

This thesis is organized as follows: Chapter 2 gives a detailed overview of literature related to Job shop Scheduling, Flexible job shop scheduling and Multi objective approach. Chapter 3 presents the working nature and importance of the Proposed Hybrid Differential Evolution Algorithm among the other evolutionary algorithms. Chapter 4 presents the single objective approach and the methodology followed to develop the Hybrid differential evolution algorithm-based adaptive flexible job shop scheduling model for minimizing Makespan. Chapter 5 presents the multi objective optimization of flexible job shop scheduling model for minimizing Makespan, Total machine work load and Critical machine workload. It also explains the problems tested and experimentation to evaluate the effectiveness of the proposed model. Chapter 6 presents the results of the test cases followed by the discussion of trends observed. Finally, Chapter 7 provides the conclusions and future research directions.