CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Scheduling involves the allocation of resources over a period of time to perform a collection of tasks (Baker 1974). It is a decision making process that exists in most manufacturing and production systems, transportation and distribution settings and in most information-processing environments (Pinedo 2005). Scheduling concepts have been researched for decades. The importance of scheduling has increased in recent years due to the growing customer demand for variety, reduced product life cycles, changing markets with global competition and rapid development of new processes and technologies. These economic and commercial market pressures emphasize the need for maintaining customer satisfaction levels of production and delivery specification. Often this requires an efficient, effective and accurate scheduling plan.
The contribution of this thesis is to the field of scheduling in manufacturing systems. Scheduling in the context of manufacturing systems refers to the determination of the sequence in which jobs are to be processed over the production stages, followed by the determination of the start-time and finish-time of processing of jobs (Conway et al. 1967). An effective schedule provides the basis for utilizing the plant effectively and attaining the strategic objectives of the firm as reflected in the production plan.

The most common manufacturing system worldwide is the job shop. Job shops are associated with the production of small volumes/large variety products and operate in a make-to-order environment (Groover 2003). Hoitomt et al. (1993) mentions that approximately 50 to 75 % of all manufactured components fall into this category of low volume/high variety and due to the market trends this percentage is likely to increase. Even though flexible manufacturing systems are today’s keywords that frequently appear in many research agendas, scheduling of job shops still receive ample attention from both researchers and practitioners due to the reason that job shop scheduling problems exist in most of the advanced manufacturing systems (Kutanoglu and Sabuncuoglu 1999). Besides, analysis of job shop scheduling problems provides important insights into the solution of the scheduling problems encountered in more realistic and complicated systems (Pinedo 2005). In this context, this thesis focuses on scheduling job shops which is an important task for manufacturing industry in terms of improving machine utilization and reducing cycle-time.

1.2 JOB SHOP SCHEDULING ENVIRONMENTS
In the job shop, machines tools are functionally grouped according to the general type of manufacturing process: lathes in one department, drilling press in another, milling machines in still another, etc. Each different product or component requires its own sequence of operations so that it can be routed through the required departments in the proper order. There are three types of scheduling environments in job shop, they are, Classic Job shop, Open Job shop and Assembly Job Shop (Morton and Pentico 1993). Table 1 shows the characteristics of the three scheduling environments.

Table 1. Job Shop Scheduling environments

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
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<tr>
<td>1. Closed Job Shop</td>
<td>Discrete, complex flow, unique jobs, no multi-use parts</td>
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<tr>
<td>2. Open Job Shop</td>
<td>Discrete, complex flow, some repetitive jobs and/or multi-use parts</td>
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<tr>
<td>3. Assembly Job Shop</td>
<td>Assembly version of Classic/Open Job Shop</td>
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The classic job shop is more popularly known as the closed job shop which involves manufacturing of components or parts requiring operations ordered in a linear sequence. In classic job shop, job orders are distinct and WIP cannot typically be borrowed from one job order to another. Generating a feasible schedule in a classic job shop requires satisfying the following two constraints: precedence relationship constraints between the operations and the constraint that no two operations can be performed simultaneously on the same machine (King 1975). These two technological constraints lead to conflicts between operations while loading on scarce resources during schedule generation that causes queuing delay for operations on bottleneck machines. The lead time of a component, therefore, depends upon the number of operations, the operation time and the time
the operations have to wait at processing centers (queuing delay). Due to these reasons, scheduling classic job shops are highly complicated.

A job shop that produces to final inventory rather than directly to orders is called an open job shop (Morton and Pentico 1993). In open job shop there may be several customers with demand for the same products so that it makes sense to maintain final inventories, or larger WIP, or to divert activities or jobs meant for one customer to another customer of higher priority. Scheduling issues are generally similar to those of closed job shops.

An assembly job shop refers to a shop that manufactures products involving both processing and assembly operations (Nof et al. 1997). Assembly jobs consist of a set of components which have to be assembled together after their processing is complete. A component, in turn, consists of a set of serial operations ordered in a linear sequence. Scheduling an assembly job shop requires proper coordination of materials flow through the various stages necessary to complete a product (Kolisch 2001). The lead time of a product consists of a combination of the following: the flow time of its components, the assembly time, the time the assembly operations have to wait at assembly centers, and the staging delay at various assembly points in the product. Unlike a queuing delay, which occurs due to resource limitations, a staging delay occurs whenever an assembly operation has to wait for the completion of all segments (component or subassembly) coming into the assembly point. Consequently, assembly job shop scheduling is a much more complex problem than that of scheduling a single-stage classic/open job shop.
1.3 SCHEDULING JOB SHOPS ASSOCIATED WITH MULTIPLE ROUTINGS

The general job shop scheduling problem (JSP) is the most popular scheduling model in practice (French 1982, Brucker 1995, Pinedo 1995). It has attracted many researchers due to its wide applicability and inherent difficulty (Jain and Meeran 1999). The formulation of the JSP is based on the assumption that for each part type or production order (job) there is only one processing plan, which prescribes the sequence of operations and the machine on which each operation has to be performed. It is also well known that JSP is NP-hard (Garey et al 1986).

In practice, the shop-floor setup typically consists of multiple copies of the most critical machines so that bottlenecks due to long operations or busy machines can be reduced (Ho et al 2007). Therefore, an operation may be performed on more than one machine. Job shops also consists of multi-purpose machines such as numerically controlled (NC) machines that are loaded with tool magazines and are capable of performing several different types of operations (Vaikartarakis and Cai 2003). Due to the overlapping capabilities of the machines, a given operation can be performed by more than one machine. However, in real life it has been a practice that machining operations are assigned to a certain machine tool during the process planning stage and the assignment of machine tools over time to different operations is performed during the scheduling stage. Recently, researchers considered the possibility of integrating process planning with scheduling by allowing alternative machine tool routings for operations at the scheduling stage.
Hankins et al. (1984) discussed the advantages of using alternative machine tool routings to improve the productivity. They showed, through an example, that using alternative machine results in reduced lead-time and improves overall machine utilization. Chryssoulouris and Chan (1985) discussed the integration of process planning and the decision making process for production resource assignment. They discussed the issue of generating alternative machines/resources based on the process planning information. Wilhelm and Shin (1985) investigated the effectiveness of alternative operations in flexible manufacturing systems. They showed via computational experiments that alternate operations could reduce flow time while increasing machine utilization. However, the introduction of alternative routing option adds an additional decision of machine allocation during scheduling that increases the complexity of the problem.

The consideration of multiple routings for the operations in scheduling job shops is addressed as job shop scheduling with alternative machine tool routing (Nasr and Elsayed 1990) in the literature. The scheduling model of the job shop problem associated with multiple routings is also addressed as flexible job shop scheduling problem (FJSP) (Brandimarte 1993) and job shop scheduling with multi-purpose machines (MPM-JSP) (Brucker and Schilie 1990) in the literature. FJSP/MPM-JSP is much more complex than the JSP.

In this context, this thesis addresses two different models of job shop scheduling applications that are associated with multiple routings.
Model 1: The first model addressed in this thesis is the Flexible job shop scheduling problem (FJSP) which can be described as: There are a set of machines and a set of jobs consisting of chain of operations and each operation can be performed in one or more than one machine with certain processing time or cost that differs with machine features.

Model 2: The second model addressed in this thesis is based on the production environment of a capital goods industry involved in the manufacturing of printing machines, packaging machines and CNC machine tools. The industry has a production division where the components of different products are processed in a job shop type environment and then assembled in independent assembly lines. This problem is referred as Assembly job shop scheduling in the literature (Nof et al. 1997, Kolisch 2001). The processing operations on all components in the model also consider alternative routing option. This problem is, therefore, addressed as assembly job shop scheduling associated with multiple routings (AJSP), is much more complex than FJSP.

**OBJECTIVES**

- Modeling the two different scheduling applications of Job Shops associated with multiple routings
- Defining the problems for the proposed models under consideration
- Selection of suitable objective function for the problems under consideration
- Identification and design of suitable heuristics to be applied
• Application of proposed heuristics to the problem under consideration

1 Comparison and evaluation of the proposed heuristics based on the objectives to obtain optimal or near optimal schedule for the respective manufacturing environments.

MODELLING AND SOLUTION APPROACHES FOR SCHEDULING PROBLEMS

A large number of approaches to the modeling and solution for job shop scheduling problems have been reported in the OR literature, with varying degrees of success. These approaches revolve around a series of technological advances that have occurred over that last four decades. These include optimization approaches such as mathematical programming, enumerative techniques, etc. and approximation approaches such as dispatching rules, local search technique, AI techniques, neighbourhood based search heuristics and population based search heuristics. The salient remarks concerning these approaches are (Hutchison 1991, Brucker 1996, Mattfeld 1996, Portmann 1997)

Optimization algorithms provide satisfactorily or optimal results if the problems to be solved are not too large and are restricted to low-dimensional over-simplified problems. Since, most of the scheduling problems have been proved to be NP-hard, i.e., the computational time grows exponentially as a function of the problem size, therefore, optimization algorithms are ruled out in practice. Approximation algorithms are capable of guaranteeing the solution within the fixed percentage of the actual optimum and are considered urgent and useful tools for solving discrete optimization problems.

• Mathematical programming has been applied extensively to scheduling problems. Problems have been formulated using integer
programming, mixed-integer programming, and dynamic programming. The use of these approaches has been limited because scheduling problems belong to the class of NP-hard problems.

- Lagrangian relaxation is a mathematical technique that solves integer-programming problems by omitting specific integer-valued constraints and adding the corresponding costs (due to these omissions and/or relaxations) to the objective function. Lagrangian relaxation is computationally expensive for large scheduling problems.

- Branch-and-bound is an enumerative technique for integer-programming problems. The basic idea of branching is to conceptualize the problem and search for the optimal solution as a decision tree. Although efficient bounding and pruning procedures have been developed to speed up the search, this is still a very computational intensive procedure for solving large scheduling problems.

- Dispatching rules have been applied consistently to scheduling problems. The performance of these rules has been analyzed with simulation experiment, which is evaluative rather than generative. Hence, generalization on the use of a particular rule is difficult to establish. These rules are questionable for stability and environment dependence.

- Artificial intelligence (AI) techniques include expert systems, knowledge-based systems and neural networks. They have two main advantages. First, and perhaps most important, they use both quantitative and qualitative knowledge in the decision-making process. Second, they are capable of generating heuristics that are significantly more complex than the simple dispatching rules
described above. There are, however, serious disadvantages. They can be time consuming to build and verify, as well as difficult to maintain and change. Moreover, since they generate only feasible solutions, it is rarely possible to tell how close that solution is to the optimal solution. Consequently, they have not been used to solve realistic scheduling problems.

- The performance of heuristics is satisfactory as long as the operating characteristics and objectives of the systems remain the same. Heuristics yield good solutions, but are robust to the system.
- Neighbourhood based search heuristics include Tabu search (TS), simulated annealing (SA), and hill climbing algorithm. They are known for producing excellent results in short run times. The primary deficiency of these heuristics is that their performance is dependent on the initial solutions. Poor initialization can lead to weak final schedules or excessive computing times. They are also susceptible of getting stuck in local optima.
- Population based search heuristics, which belong to the random search strategy, guarantees near optimal solutions in actual cases. The popularly known population based search heuristics are Genetic Algorithm (GA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). These approaches are useful for any hard optimization problem.

**ORGANIZATION OF THE THESIS**

In this chapter, the scope of scheduling job shops, various job shop scheduling environments, the advantages and challenges of considering alternative
machine tool routings in scheduling job shops and the salient features of various modeling and solution techniques in scheduling are discussed.

The rest of the thesis is organized as follows:

- Chapter 2 addresses the literature review.
- Chapter 3 describes the models and problems considered in this thesis.
- Chapter 4 proposes the heuristics for the flexible job shop scheduling problem.
- Chapter 5 presents the heuristics for the assembly job shop scheduling problem.