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Bi-criteria group scheduling in hybrid flowshops

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ABSTRACT

We consider a group scheduling problem in a hybrid flowshop where the parallel machines in one or more stages of the flowshop are unrelated and have different run times for the same job. The objective of the problem is to simultaneously decrease the producer's cost by minimizing the Work-In-Process inventory (WIP) or equivalently the total weighted completion time, and increase the customers' satisfaction by minimizing the total weighted tardiness. All of the jobs and machines may not be ready at time zero, meaning that they can be released at different times during the scheduling period. The setup time required to switch between processing jobs from different families is considered to be sequence-dependent. A Mixed-Integer Linear Programming model is developed to mathematically represent this problem and obtain optimal solutions for small size problems. Since the problem is among the strongly NP-hard problems, four efficient algorithms based on tabu search are proposed to find optimal/near optimal solutions. The efficacy of these algorithms is compared to each other by means of a comprehensive statistical analysis, and the best algorithm is identified. Furthermore, the efficiency and effectiveness of the proposed search algorithms are verified by comparing the results of these algorithms with optimal solutions obtained from CPLEX for small size problems.

1. Introduction

In recent decades, Cellular Manufacturing (CM) has become one of the widely recognized technological innovations in production systems, which helps the job-shop and batch-type production to attain economic advantages of mass production. Because of today's competitive market, many companies try to implement the CM concepts in order to increase their flexibility and efficiency, which are vital to compete in an ever changing market. CM is an advanced manufacturing approach, which employs group technology concepts to combine the advantages of job shop manufacturing with flow shop production. In fact, CM systems preserve the flexibility of the job shop, and take advantages of the efficiency of the flow shop; therefore this type of manufacturing systems are more suitable for today's small-to-medium lot production systems (Li et al., 2010).

Group scheduling (GS) is an inherent component of CM, which employs the scheduling techniques with respect to the assumptions of cell formation problem to find an optimal sequence of jobs within each working cell. GS usually is performed in two levels: outside level and inside level. The outside level finds the best sequence of groups to be processed on each machine and the inside level finds the best sequence of jobs within each group (Logendran et al., 1995). GS problems are mainly considered with or without Group Technology Assumptions (GTA). GTA assumes that all jobs within each group should be processed successively; therefore if there is no such assumption in the problem, each group can be split into its individual jobs or subgroups of its jobs. GS problems under the absence of GTA are usually referred to as batch scheduling problems.

Since their emergence, scheduling problems have been considered in many different machining environments. The earliest scheduling problems, which were the simplest ones, were studied only on a single machine. Gradually with technological developments especially in the field of automobile manufacturing, textile industry, tile manufacturing, etc. flow shops and then flexible flow shops were introduced. Therefore many researchers have studied scheduling problems under these new structures of machining environment.

The purpose of this research is mainly to tackle a GS problem in a hybrid flow shop environment. With respect to the state-of-the-art in this class of problems, more sophisticated characteristics have been proposed to be investigated so that the research can truly address a problem applicable to real world situations. In Section 2 a review of the related research has been presented. Thereafter, in Section 3, a statement of the problem addressed in this research is presented together with a Mixed-Integer Linear Programming (MILP) model of the problem. Section 4 provides an overall representation of the methodology proposed to be used to solve the research problem. Comprehensive numerical results including a data generation mechanism as well as the calibration

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of the algorithms and a thorough statistical experiment are presented in Section 5; and finally, the conclusions and future research are presented in Section 6.

2. Related work and motivation

Scheduling problems initially dealt with job scheduling problems, where a set of jobs needs to be processed on a set of machines. A noticeable portion of previous research studied job scheduling problems with different shop structures, different objective functions, and different sets of constraints (see e.g., Almeida and Centeno, 1998; Huang et al., 2000; Miao et al., 1990). Later, with the introduction of CM concept, a considerable amount of attention was given to the GS problems, where the set of jobs is clustered into different groups or families.

The study of GS problems was initiated with the simplest shop structure, i.e. single machine problems (Webster and Baker, 1995; Wang et al., 1999). These problems have been studied with different assumptions and different constraints, such as single or multi-criteria objective functions (Cheng et al., 1996; Pan and Wu, 1998), independent or dependent setup times (Liaw, 1999; Sun et al., 1999), and many other assumptions that help these problems to be a better depiction of the real world scheduling problems. But trying to resemble the more realistic situations forced the researchers to study different types of shop structures.

Shop structure is changed by inserting new machines in different positions of the current structure. Gelogullari and Logendran (2004), for example, studied the carryover sequence-dependent setups in a two-machine GS problem. The structures of shop differ depending on the position where the new machines are inserted. If the new machines are inserted in series, it means that each job has some operation to be performed on each of these machines. Although there are situations where some jobs can skip some of these machines, the flow or movement of all the jobs is the same, from the first machine in the series to the last machine. This structure of machine environment is called flowshop. Since its emergence, the flowshop has attracted the attention of many researchers. Due to the complexity of flowshop scheduling problems (mostly strongly NP-hard), optimal solutions most probably cannot be found in reasonable CPU time and memory consumption. Although some researchers developed mathematical models such as MILP models for these types of problems, most efforts have been focused on heuristic or meta-heuristic approaches to find the optimal/near optimal solutions (Ben-Daya and Al-Fawzan, 1998; Schaller et al., 2000; Gelogullari and Logendran, 2010; Salmasi et al., 2010).

On the other hand, the new machines can be inserted in parallel, which means each job needs to be processed only by one of the machines. There are three types of parallel machines considered in the literature: identical parallel machines where all jobs have the same run time on each machine, uniform parallel machines where each machine has different speed for processing all the jobs, and unrelated parallel machines where the processing time of each job depends on the machine where it is being processed (this is the most general case of parallel machines) (Allahverdi et al., 2008). The complexity of this class of scheduling problems differs depending on the other assumptions made by the researchers. It may be possible to find the optimal sequence of a set of independent jobs on unrelated parallel machines (Liaw et al., 2003), but assuming more realistic attributes for these problems, such as job-splitting, sequence-dependent jobs, dynamic machine availability and dynamic job release times makes the problem strongly NP-hard and forces researchers to use heuristic or meta-heuristic approaches for finding the optimal/near optimal solution (Lin et al., 2011; Bozorgirad and Logendran, 2012).

A more sophisticated shop structure is obtained when at least one of the serial stages of a flowshop includes parallel machines. This type of shop is called flexible flowshop (FFS) or hybrid flowshop (HFS). Typically FFS refers to flowshops with identical parallel machines (Logendran et al., 2006), and HFS refers to flowshops with unrelated parallel machines (Ruiz and Vázquez-Rodríguez, 2010). Due to complexity (strongly NP-hard), most of these problems are not optimally solvable within a reasonable computation time, and therefore heuristic or meta-heuristic approaches are usually applied to find their optimal/near optimal solutions. Nevertheless, a few authors developed mathematical models to find the optimal solutions for very small size problems (Kurz and Askin, 2004; Shahvari et al., 2012).

In addition to the GTA and shop structure, one of the challenges in dealing with scheduling problems is what criteria need to be optimized? Despite the fact that many researchers assumed a single criterion for their problems such as minimizing the makespan, mean flow time, total tardiness, etc., this assumption cannot truly fulfill the real world requirements. For example, a company not only has to minimize its production costs but also has to maximize its customers' satisfaction. A comprehensive review of the literature revealed that a few authors studied multi-objective job scheduling problems without the GTA (Tavakkoli-Moghaddam et al., 2007; Dugardin et al., 2010; Mehravaran and Logendran, 2011; Behnamian et al., 2011), and a few authors studied multi-objective GS problems with GTA (Rana and Singh, 1994; Tavakkoli-Moghaddam et al., 2010).

Even though, extensive research is conducted in the area of scheduling, limited research is found to study GS, HFS and bi-criteria assumptions combined. Karimi et al. (2010) and Zandieh and Karimi (2011) claimed to study this type of problem; however a careful review of their articles reveals that they only considered identical parallel machines and not unrelated parallel machines. In this research, the unrelated parallel machines are considered for this type of problem. In addition, dynamic job releases and dynamic machine availabilities are assumed in order to better depict the more realistic situations. Furthermore, an MILP model is developed to mathematically represent the problem and obtain the optimal solutions for small-size problems.

3. Problem statement

Consider the problem of scheduling N different jobs which are clustered in g different groups. Suppose that the number of jobs in group i is n_i, so $\sum_{i=1}^{g} n_i = N$. There are m different stages of operation that jobs should move through. Each job should be processed in at least one stage, and the direction in which all jobs move through is the same, meaning a flow-line arrangement as required by GS. There is at least one stage that contains more than one machine to process the jobs. Such a stage is called a flexible stage. Parallel machines in a flexible stage are assumed to be unrelated, which distinguishes this problem as an HFS and not an FFS. The problem also follows the GTA, which forces all jobs of a group to be processed successively.

As the objective of the problem, we are trying to simultaneously minimize the work-in-process inventory (WIP) and maximize the customer service level. This is accomplished by minimizing a linear combination of total weighted completion times (TC) and total weighted tardiness (TT) of jobs i.e. $Z = \alpha TC + \beta TT$ where $\alpha + \beta = 1$. α and β are normalized factors that determine the weight of each criterion of the objective function. There is a negligible setup time between jobs within each group, but there is a sequence-dependent setup time between two groups. The machine availability times and job release times are also assumed to be dynamic for this problem.

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