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Approximation algorithms for the three-stage flexible flow shop problem with mid group constraint

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ABSTRACT

This paper considers a three-stage flexible flow shop scheduling problem, where the jobs have the group constraint at the second stage and the three stages consist of unrelated parallel machines. Because of the complexity of this problem, approximation algorithms are more appropriate to solve it. Firstly, we propose ten heuristic algorithms based on the idea of combined algorithms proposed by Soewandi and Elmaghraby (2001) and give their time complexities. Secondly, since there is no reference on the worst-case performance ratios of RDM, SP.H1 and SP.H2 algorithms for the unrelated parallel machines, we provide the worst-case performance ratios of these three algorithms and then give the worst-case performance ratios of the nine algorithms proposed in this paper. Finally, to evaluate the performance of the ten algorithms, four lower bounds of this problem are proposed in Appendix A and a computational experiment is designed, where lots of instances are generated and each algorithm is run with every instance. Experimental results indicate that the performances of ten heuristic algorithms are contingent on different configurations and SP.JH-MJ algorithm generally outperforms the others with respect to the three-stage flexible flow shop scheduling problem addressed in this paper.

1. Introduction

In the discrete manufacturing industry, flexible flow shop (FFS) scheduling problem generally exists in real production (e.g. communication, project planning, automobile assembly and so on). The study of FFS is critical because of its numerous practical applications. The general FFS scheduling problem is to schedule a set of jobs which are available for processing, in a group of machines following the same order. In a FFS problem, there are a series of stages, each of which consists of several parallel machines; the jobs have to be processed by one of the machines at each stage; all the jobs are available and ready to start at time zero. Arthanari and Ramamurthy (1971) and Salvador (1973) were the earliest researchers who defined this problem. For the past four decades, FFS scheduling problems have attracted many researchers. However, most of them were focused on this problem with excessive simplicity, e.g., all parts are available at time zero; machines in each stage are parallel; there is only one machine at some stages; buffers between stages are infinite; the optimal objective is single. In fact, the real production environment is more complicated. Therefore, many researchers propose varieties of FFS models based on the classical FFS problem. Mahadevan and Narendran (1993) designed the buffer capacities through simulation for the flexible manufacturing system. Kurz and Askin (2004) examined scheduling in flexible flow lines with sequence-dependent setup times to minimise makespan. Guo (2006) pointed out a two-stage flexible flow shop scheduling with fuzzy processing times. Jungwattanakit, Reodecha, Chaovalitwongse, and Werner (2009) regarded a FFS scheduling problem with unrelated parallel machines, setup times, and dual criteria under the context of the textile industry. Yazid, Chams, and Stephane (2011) considered a practical FFS scheduling problem with blocking constraint.

To the best of our knowledge, few investigations aimed at combining group constraint with FFS scheduling problem, have been reported in the published literature. Logendran, Carson, and Hanson (2005) considered the combination of group constraint with flexible flow shop to minimise makespan. He, Sun, and Luo (2008) proposed a two-stage flexible flow shop scheduling problem where there are identical parallel machines at the first stage and there is only one batch machine at the second stage. Wusheng (2008) regarded a two-stage flexible flow shop scheduling problem with group constraint where the two stages consist of identical parallel machines. Li, Chen, and Mao (2013)regarded a two-stage flexible flow shop scheduling problem with group constraint at the first stage where the two stages consist of parallel machines. Li, Chen, Mao, Wang, and Liu (2013) extends this problem to consider a two-stage flexible flow shop problem with tail

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group constraint where the two stages consist of unrelated parallel machines and the objective is to minimise the total tardiness of jobs.

In fact, FFS problem with group constraint generally exists in the real production environment. According to the location of the group constraint, this problem is divided into three sub-problems, including flexible flow shop problem with head, mid and tail group constraint respectively. For example, the head group constraint exists in the tire mould manufacturing. In the process of tire mould making, there are two operations: engraving and branding. Since the diameter of the tire mould is out of the range of the engraving machines, the tire mould is divided into several pieces. However, these pieces of tire mould are processed as an entirety in the branding. Thus these pieces of tire mould are respectively allocated on the machines at the same time as possible as they can be in the engraving. Also in the tire mould manufacturing, the mid group constraint exists in the grinding process of the sidewall and insert. The sidewall and insert have three operations: milling, grinding and engraving. In the grinding process, several sidewalls matching one insert are processed simultaneously. Before and after the grinding, the sidewall and insert are processed separately. The tail group constraint is analogous to the final assembly process existing in the clothing manufacturing. At the assembly process, all the components should be ready and processed in group. Before the assembly process, the component parts are processed separately. Since the wide applications of FFS with group constraint and few investigations on FFS with mid group constraint have been reported in the published literatures, we consider a three-stage flexible flow shop scheduling problem with mid group constraint and released time, where each stage consists of unrelated parallel machines and the objective is to minimise makespan. Fig. 1 is the chart of a three-stage flexible flow shop scheduling problem with mid group constraint. There are two sorts of jobs (A and B) both of which have three operations. When the jobs are processed at the second operation, they have to be assembly processed (the detail description of this problem is in Section 2). The main differences between the above-mentioned literatures and the problem addressed in this paper are as follows:

- Logendran et al. (2005) considered a flexible flow shop scheduling problem with group constraint at each stage; He et al. (2008), Sun (2008) and Li, Chen, Mao, Wang, et al. (2013) concerned a two-stage flexible flow shop with tail group constraint; Li, Chen, and Mao (2013) concerned a two-stage flexible flow shop with head group constraint; while this paper considers a three-stage flexible flow shop with mid group constraint.
- Logendran et al. (2005) and Sun (2008) considered identical parallel machines at each stage; He et al. (2008) considered identical parallel machines at the first stage and one batch machine at the second stage; Li, Chen, and Mao (2013)considered two work canters at the first stage and parallel machines at the second stage, while this paper regards unrelated parallel machines at each stage.
- Logendran et al. (2005) and He et al. (2008) considered that all the jobs are available at time zero, while Sun (2008) and this paper consider that the jobs are released to workshop in batch.

For the solutions of the FFS scheduling problems, a large amount of solution algorithms have been developed. They are classified into two categories, i.e. exact algorithm and approximation algorithm. Salvador (1973) proposed a branch and bound method to tackle the classical FFS scheduling problem to minimise makespan. Tavakkoli-Moghaddam, Safaei, and Sassani (2009) proposed an efficient memetic algorithm combined with a novel local search engine (nested variable neighbourhood search, NVNS) to solve the FFS scheduling problem with machine blocking and without intermediate buffers. Although the exact algorithms can get an optimal solution, it takes hours or days to derive a solution for the large problems, which is unpractical for the real production. Therefore, many researchers concentrate on the approximation algorithm. Although approximation algorithm cannot guarantee to obtain an optimal solution, it has less time consumption and gets a sub-optimal solution, which is more meaningful for the real production. Gupta (1988) proposed a heuristic algorithm based on Johnson algorithm for a two-stage flexible flow shop problem where there is one machine at the second stage. Brah and Loo (1999) proposed a heuristic algorithm for the FFS problem with identical parallel machines at each stage. By comparing the proposed algorithm with CDS, Palmer and NEH algorithms, he concluded that his algorithm gave good results. Kia, Davoudpour, and Zandieh (2010) proposed eight heuristic algorithms for a dynamic FFS problem with sequence-dependent setup times. For the FFS problem with group constraint, Sun (2008) proposed a heuristic algorithm combined Johnson algorithm with EDD rule for a two-stage FFS problem with tail group constraint, where each stage makes up of identical parallel machines. Logendran et al. (2005) proposed three heuristic algorithms (LN-PT-S, LN-PT-M, and PT-LN-S) based on Petrov's heuristic (1966) and Logendran and Nudtasomboon's heuristic (1991) for the FFS problem with group constraint. He et al. (2008) proposed four heuristic algorithms for a two-stage flexible flow shop scheduling problem with a batch machine at second stage, and the worst-case performance ratios of corresponding

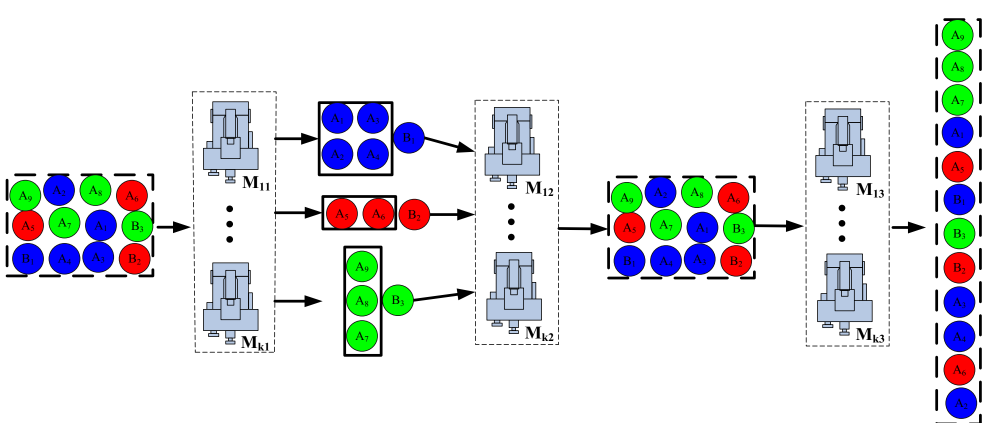

Fig. 1. The chart of three-stage flexible flow shop scheduling problem with mid group constraint.