Int. J. Production Economics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Scheduling rules for two-stage flexible flow shop scheduling problem subject to tail group constraint

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ARTICLE INFO

Article history:
Received 17 July 2012
Accepted 9 August 2013

Keywords:
Heuristic
Flexible flow shop
Tail group constraint
Worst-case analysis

ABSTRACT

This paper considers a two-stage flexible flow shop scheduling problem with task tail group constraint, where the two stages are made up of unrelated parallel machines. The objective is to find a schedule to minimize the total tardiness of jobs. For this problem, a mathematical model is formulated. Through analyzing this kind of problem, it is proved to be NP-hard and an advantage scheduling rule is proposed. According to the advantage scheduling rule, a new heuristic method called EL algorithm, is designed to solve this problem. From the theoretical analysis of EL algorithm, we provide EL algorithm with the time complexity and worst-case analysis. To test the performance of EL algorithm, a computational experiment is designed. In the computational experiment, both the twelve dispatching rules based on the literatures and EL algorithm are applied to the benchmark instances. Simulation results indicate that LPT–CDS, SPT–Pal, SPT–CDS and EL algorithms are effective and EL algorithm outperforms the other twelve dispatching rules with respect to the two-stage flexible flow shop scheduling problem proposed in this paper.

1. Introduction

In discrete manufacturing industries, it is common for flexible flow shop (FFS) scheduling problem. Therefore, it is important to study FFS scheduling problem which is one of the most studied scheduling problems. Arthanari and Ramamurthy (1971) and Salvador (1973) are the pioneers who define the FFS scheduling problem. They define that the FFS environment is a generalization of the classical flow shop model, where there are k stages and some stages may have only one machine, but at least one stage must have multiple machines, the problem is to assign the jobs to machines at each stage and sequence the jobs assigned to the same machine so that some optimality criteria are minimized. Since the concept of FFS scheduling problem was proposed, it has been widely studied in the literatures (Gupta et al., 2003; Alisantoso et al., 2003; Lin and Liao, 2003; Wang and Hunsucker, 2003). However, the classical FFS has been frequently criticized because of the excessive simplicity, i.e., all parts are available at time zero; machines are parallel. In fact, it is more complex in the real production environment. As a result, many researchers proposed a variety of FFS models based on the classical FFS scheduling problems. Wang Hui (2007) and Tian et al. (2010) considered a two-stage flexible flow shop scheduling problem subjected to release dates. WenJing (2006) pointed out a two-stage flexible flow shop scheduling with fuzzy processing times. Chun-Lung and Chuen-Lung (2008) proposed a FFS scheduling problem with unrelated parallel machines at each stage. Jungwattanakit et al. (2009) regarded a FFS scheduling problem with unrelated parallel machines, setup times, and dual criteria under the context of the textile industries. Yazid et al. (2011) considered a practical FFS scheduling problem with blocking constraints. Almeder and Hartl (2013) considered a real-world stochastic flexible flow shop problem with limited buffer.

To the best of the authors' knowledge, few investigations aimed at combining group scheduling with FFS scheduling, have been reported in the published literatures. Most of the investigations combined group scheduling with flow shop scheduling problems (i.e., Baker, 1990; Leu and Nazemetz, 1995; Cheng et al., 2000; Reddy and Narendran, 2003; Wilson et al., 2004). In fact, FFS scheduling problems with group constraint generally exist in discrete manufacturing industries, such as heat treatment of jobs, electrical discharge machining (EDM) of jobs in mould industry and so on. In this paper, according to the location of group constraint, this kind of problem can be divided into three sub-categories, including flexible flow shop problem with head, mid and tail group constraint respectively. For FFS scheduling problems with group constraints, Logendran et al. (2005) considered the combination of group scheduling problem with flexible flow shop problem to minimize the makespan and, Bozorgirad and Logendran (2013) considered the same problem with multiple objectives. Long-min et al. (2008) proposed a two-stage flexible flow shop scheduling problem where there are identical parallel machines at the first stage, while there is only one batch machine at the second stage. Wusheng (2008) considered a two-stage

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0925-5273/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2013.08.020

flexible flow shop scheduling problem with tail group constraint where the two stages consist of identical parallel machines. In this paper, we propose a two-stage FFS scheduling problem with tail group constraint and released dates, where the two stages consist of unrelated parallel machines and the objective is to minimize the total job tardiness. The main differences between the literatures (Logendran, Long-min and Wusheng) and the problem addressed in this paper are as follows:

- Logendran considered flexible flow shop scheduling problem with group constraint at each stage, while Long-min, Wusheng and this paper concerned a two-stage flexible flow shop with tail group constraint.
- Logendran and Wusheng considered identical parallel machines at each stage, Long-min considered identical parallel machines at the first stage and one batch machine at the second stage, while this paper regards unrelated parallel machines at each stage.
- Logendran and Long-min considered that all the jobs were available at the beginning, while this paper considers the jobs are released to workshop in batch.

There are lots of studies in literatures that apply algorithms to solve the FFS scheduling problems. Among the algorithms, they are divided into two categories: exact algorithms and approximation algorithms. Salvador (1973) proposed a branch and bound method to track the classical FFS scheduling problem whose objective was to minimize the makespan. Tavakkoli-Moghaddam et al. (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. Li et al. (2010) proposed a branch and bound method with a heuristic algorithm to solve a two-stage flexible flow shop scheduling problem with head group constraint. Huang (2010) modified a branch and bound algorithm to solve a two-machine flexible flow-shop scheduling problem with setup times. Although the exact algorithms can get an optimal solution, they only apply to very small instances. They cannot solve the large scale problems in the polynomial time, which it is useless for the real production. Thus, many researchers concentrate on the approximation algorithms. Gupta (1988) proposed a heuristic algorithm based on Johnson algorithm for a two-stage flexible flow shop problem where there was 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 result. Jungwattanakit et al. (2009) developed a genetic algorithm for FFS problem with unrelated parallel machines, setup times, and dual criteria. Kia et al. (2010) considered a dynamic FFS problem with sequence-dependent setup times and compared with eight adapted heuristic algorithms. For FFS problem with group constraint, Wusheng (2008) proposed a heuristic algorithm based on Johnson algorithm and EDD rule for a two-stage FFS problem with tail group constraint, where each stage consists of identical parallel machines. He concluded that his algorithm was effective. But we question Wusheng's algorithm, because the example simulated in this paper is simple, which cannot support his conclusion. Logendran et al. (2005) proposed three heuristic algorithms (LN–PT–S, LN–PT–M, and PT–LN–S) based on Petrov (1966) and Logendran and Nudtasomboon (1991) for the FFS problem with group constraint. They designed a statistical model based on split-plot design to conduct the experiments to compare the performance of the three different heuristic solution algorithms. Long-min 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 performances of corresponding approximation algorithms in 12 cases are estimated.

As we will see, two-stage flexible flow shop scheduling problem with tail group constraint considered in this paper is an extension of the classical FFS scheduling problem. Because of the complexity of this problem, heuristic algorithms are the best method to solve it according to the relevant literatures. In this paper, we propose a heuristic algorithm based on combination of scheduling rules to solve this problem. The remainder of this paper is organized as follows: Section 2 gives the problem definition and introduces notions and mathematical model. Section 3 gives two theorems, Theorem 1 and Theorem 2 (a scheduling advantage rule). Section 4 proposes a new heuristic algorithm called EL based on Theorem 2. Section 5 proves three theorems of EL algorithm, Theorem 3 (complexity of EL algorithm), Theorem 4 (lower bound of EL algorithm) and Theorem 5 (worst-case analysis of EL algorithm). Section 6 designs a simulation experiment to estimate the performance of EL algorithm. In this experiment, twelve combination scheduling rules based on the six classical heuristic rules are improved as the benchmark algorithms and their complexities are proved. Finally conclusions and further research direction are presented in Section 7.

2. Problem definition

2.1. Problem statement

In this paper, we deal with a two-stage flexible flow shop scheduling problem with tail group constraint and released dates, where each stage is constituted by unrelated parallel machines. Such kind of scheduling problem is stated as follows. There are two processing stages, where there is one work centre at each stage, denoted by E_1 and E_2, respectively. Each work centre has m_1 and m_2 unrelated parallel machines, respectively. There are two kinds of jobs (A and B) where the number of A and B jobs is n and q, respectively. A jobs are released to the first stage in group and the released dates (denoted by R_i) are arithmetical progression, while B jobs are available for processing at time zero. A jobs have to be processed on the two stages in sequence. B jobs are only processed at the second stage. There are a few of processing restrictions as follow: (1) each B job needs to be co-processed with several A jobs at the second stage, which means that A jobs are grouped by B jobs at the second stage and each group is co-processed with one B job; (2) the A jobs in the same group are serially processed at the second stage, namely one A job in the same group is co-processed with its corresponding B job at a time; (3) jobs are processed without preemptions on any machine; (4) every machine can process only one job at a time; (5) there are infinite buffers in between two stages; (6) A jobs have to be processed sequentially without overlapping between two stages. The objective is to minimize the total tardiness of B jobs denoted by $\sum_{j=1}^{q} D_{B_j}$. Such problem is described with Graham's three-field representation as $FF2-GT2|R_i, m_1, m_2|\sum_{j=1}^{q} D_{B_j}$, where two-stage flexible flow shop is denoted by FF2 and tail group constraint is denoted by GT2 (Fig. 1).

2.2. Mathematical model

Before presenting the mathematical model, the notions used are introduced below.

Basic notions

B_j: jth B job, $j=1, 2\ldots q$.
D_{B_j}: the tardiness of B_j.