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A NSGA-II based memetic algorithm for multiobjective parallel flowshop scheduling problem

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ABSTRACT

In many real-world manufacturing applications, a number of parallel flowshops are often used to process the jobs. The scheduling problem in this parallel flowshop system has gained an increasing concern from the operational research community; however, multiple scheduling criteria are rarely considered simultaneously in the literature. In this paper, a special parallel flowshop scheduling (PFSS) problem that consists of two parallel non-identical shops, one with two consecutive machines and the other with only one machine, is investigated with two objective functions of minimizing the total flow time of jobs and the number of tardy jobs in the two-machine flowshop. A multiobjective evolutionary algorithm (MOEA) based memetic algorithm hybridizing the local search technique into the framework of NSGA-II, which is well known as the most popular MOEA, is proposed for addressing the investigated PFSS problem. A set of test instances are employed to examine the performance of the proposed algorithm in comparison with two peer MOEAs, which also adopt the similar algorithm mechanism of NSGA-II. Experimental results indicate the effectiveness and efficiency of the proposed NSGA-II based memetic algorithm in solving the multiobjective PFSS problem.

1. Introduction

Due to the rapid development of manufacturing technique and equipment, scheduling in the production system has become more and more complicated in the past decade. As one of new complicated scheduling variants, parallel flowshop scheduling (PFSS) problem can be referred to a special hybridization of parallel machine scheduling (PMS) and flowshop scheduling (FSS), where a number of flowshops are employed to process the jobs in parallel so as to optimize a given scheduling criterion. Fig. 1 presents an example of two parallel shops, each consisting of two consecutive machines.

In general, this PFSS problem can be broken down into two subproblems: first assign each job to one of two flowshops and then determine the scheduling sequence of jobs in each flowshop (Vairaktarakis & Elhafsi, 2000). In recent years, PFSS has gained a good deal of concerns from the community of operational research (OR). Sundararaghavan, Kunnathur, and Viswanathan (1997) firstly studied a parallel two-machine flowshop scheduling problem, where a slower flowshop and a faster flowshop were used to process the jobs in parallel and the processing time in the slower one was a multiple of the processing time in the faster one. Two heuristic methods were developed to minimize the makespan. Cao and Chen (2003) investigated a PFSS problem in which there are a number of two-machine flowshops. The objective function is to minimize a weighted sum of the production cost and the cost incurred from late product delivery. A hybrid algorithm, which combined tabu search (TS) that was employed for job assignment and Johnson's method that was used to generate a local optimal schedule for each flowshop once the jobs were assigned, was developed to address their investigated problem. Al-Salem (2004) studied the scheduling problem on a two-stage parallel flowshops with the proportional process times. The objective function is to minimize the makespan. A partitioning flowshop heuristic method, where the constructive heuristic was employed in the initial phase and then the improvement heuristic was applied to refine the generated initial solution, was developed. Zhang and van de Velde (2012) investigated the applications of the approximation algorithms for a PFSS problem with the objective function of minimizing the makespan in which a number of two-stage flowshops were considered. In the work of Kim, Yu, and Lee (2015), a PFSS problem was considered in the reprocessing workstation, which was the second stage in the three serial workstations of a remanufacturing

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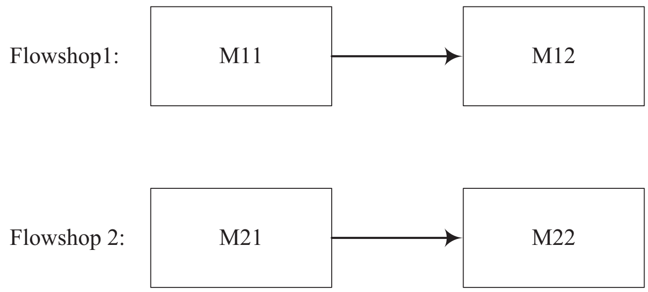

Fig. 1. An example of parallel identical two-machine flowshops.

system. Three heuristics, that is, priority rule-based heuristic, NEH-based heuristic and iterated greedy algorithm, were developed for the investigated scheduling problem with the objective function of minimizing the total flowtime. In addition, Naderi and Ruiz (2010) firstly investigated a distributed flowshop scheduling (DFSS) problem, which can be regarded as a new generation of the regular PFSS problem. In this DFSS problem, jobs were distributed among a number of identical factories or shops, each one with multiple machines disposed in series. In their following work (Naderi & Ruiz, 2014), a scatter search (SS) method was proposed for this DFSS problem to optimize the makespan. Wang, Wang, Liu, and Xu (2013) also present an effective estimation of distribution algorithm (EDA) for solving this DFSS problem and examined its performance on a huge number of test instances.

It is valuable to notice that the most research on PFSS or DFSS often assumed that each shop is identical, that is, m11 and m21 belong to the same kind of machines while m12 and m22 also belong to the same ones. However, the non-identical shops often appear simultaneously in many real-world manufacturing industries. For example, in the quartz glass process, the molding and welding operations usually are processed in two serial machines (molding machine and welding machine), while these two operations can be combined into one operation in a multifunction machine. Therefore, a special machine layout of parallel non-identical flowshops can be shown in Fig. 2, where m1, m2 and m3 can be regarded as the molding machine, the welding machine and the multifunction machine respectively.

It is also noticeable that few work on the PFSS problem involved in the domain of multiobjective optimization although multiobjective scheduling had been widely concerned by many researchers (Lei, 2009). In fact, it is very necessary to consider multiple objectives simultaneously especially in the PFSS problem with the non-identical configurations. As shown in Fig. 2, the molding operation must process continuously, that is, one job must be processed immediately once it arrives. Since the welding operation has a requirement for the temperature of job, there is a maximal waiting time limit between the two machines m1 and m2. If one job's temperature does not meet the temperature of welding, it has to be reheated when it begins to be processed in m2. However, this situation does not occur in the multifunction machine m3 due to the molding and welding operations are combined together. It seems that the number of jobs that needs to be reheated should be regarded as an important cost criterion in this parallel non-identical flowshop scheduling problem together with the traditional efficiency criteria, such as the makespan and the total flowtime.

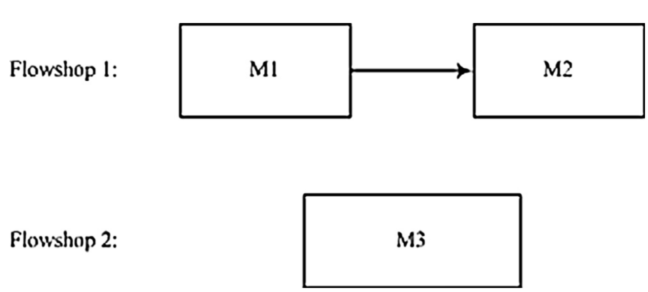

Fig. 2. An example of parallel non-identical flowshops.

Therefore, this paper will study a multiobjective parallel non-identical flowshop scheduling problem. In this production system, there are two parallel non-identical flowshops, one having two consecutive machines and the other having one machine to process the jobs, as shown in Fig. 2. Job scheduling is to minimize the total flowtime and the number of tardy jobs in the two-machine shop simultaneously. In order to solve the investigated problem effectively, a solution algorithm that hybridizes the technique of local search into the framework of multiobjective evolutionary algorithm (MOEA) is developed.

The rest of this paper is organized as follows. Section 2 reviews the related work in brief. Section 3 describes the investigated multiobjective PFSS problem in detail and presents its mathematical model. Section 4 develops a memetic algorithm that combines a local search method and NSGA-II that is well-known as the most popular MOEA. Section 5 carries out the experiments on a set of test instances and gives the corresponding experimental results and analysis. The final section concludes this paper with some discussions on the future work.

2. Related work

Over the past decades, PMS and FSS have been studied widely from the community of OR (Hejazi & Saghafian, 2005; Mokotoff, 2001). In particular, the hybrid scheduling problems that combine the features of these two classical types of scheduling problems together have begun to attract a great of attentions in the recent years. Besides the PFSS problem investigated in this paper, the hybrid or flexible FSS problem that comprises a series of production stages and at least one stage has multiple parallel machines can be also seen as another particular hybridization of PMS and FSS. Considering that it is not involved in this research, the detailed reviews on the hybrid or flexible FSS problem is not given in this section and the readers can be referred to the works of Linn and Zhang (1999), Ruiz and Vázquez-Rodríguez (2010) and Ribas, Leisten, and Framiñan (2010).

Since many real-world production requirements always involve multiple scheduling criteria, multiobjective scheduling problems have gained more and more concerns recently. However, it is noticeable that multiple scheduling objective functions are rarely considered simultaneously in this parallel flowshop production system, though FSS and PMS have been well studied separately in the research field of multiobjective scheduling. Obviously, multiobjective PFSS problem should become more interesting research topics due to its natural requirements in the real-world applications.

In the current literature, FSS had been reported as one of the mainly research topics on multiobjective scheduling (Minella & Ruiz, 2008; Yenisey & Yagmahan, 2014) and a lot of approaches have been developed by the researchers when addressing multiobjective FSS problem, which can be classified into two categories. One category can be called as 'a priori' approach, where multiple objective criteria are firstly weighted into a single-objective function and then most single-objective optimization algorithms can be applied. For example, Nagar, Heragu, and Haddock (1995), Yeh (2001), Lin and Wu (2006) and Lemesre, Dhaenens, and Talbi (2007) utilized the exact methods to optimize the weighted combination of multiple scheduling criteria in their works. Similarly,