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Multi-objective optimization of parallel machine scheduling integrated with multi-resources preventive maintenance planning

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ABSTRACT

Many studies on the integration optimization of production scheduling and preventive maintenance usually only consider one resource, i.e., machine. However, in real-world manufacturing, multiple dependent resources (e.g., human, tools and machines) are needed at the same time to avoid mismatch of multi-resource usage, which makes it highly important to jointly schedule production and maintenance tasks of multiple resources in order to improve system availability and system throughput simultaneously. In this paper, a multi-objective parallel machine scheduling problem with two kinds of resources (machines and moulds) and with flexible preventive maintenance activities on resources are investigated. The objective is to simultaneously minimize the makespan for the production aspect, the unavailability of the machine system, and the unavailability of the mould system for the maintenance aspect. A multi-objective integrated optimization method with NSGA-II adaption is proposed to solve this problem. The extensive computational experiments are conducted. The results show that the integrated optimization method of production scheduling and preventive maintenance outperforms the method with periodic preventive maintenance for this problem, in terms of multi-objective metrics, and the results also show the effects of different flexibilities of resources for job processing.

1. Introduction

In the literature on production scheduling, most studies assume that the resources (e.g., machines, tools, people) are always available. However, in the real-world manufacturing or service industry, resource unavailability including breakdown, failure and inspection, often occurs, which interrupts the current production or service. Hence, scheduling problems integrated with preventive maintenance (PM) on resources have been received more and more attention [1–8].

However, most studies focus on single-resource (i.e., machine) maintenance during production scheduling, which may not be sufficient to improve production system reliability as a whole [9], because in a real manufacturing or service system, production or service usually involves several important resources simultaneously [10,11]. For example, in a flexible manufacturing system or cell, typically, machines and corresponding tools should work together to process certain job [12]; in plastic production, injection machines and matched injection moulds should work together [9,10]; in real-world Dual Resource Constrained (DRC) manufacturing systems, both machine and human resources are critical [13]. All these resources (machine, tool, mould) are subject to deterioration and need PM activities to restore the working conditions. For the human resource, leisure time or vacation are also necessary. The introduction of the match requirements between the resources, and the PM planning of multiple resources further make the integrated optimization problem more complicated, but more practical relevance.

In this paper, motivated by a problem from a car-component manufacturing shop floor with more than 10 machines and multiple moulds, we investigate a multi-objective parallel machine scheduling problem with two kinds of resources and with flexible preventive maintenance activities on resources. One resource is machine, and another resource is mould (or tool, or people) that is associated with the machine. There are m parallel machines and mo parallel moulds. Each job can only be performed on one machine with one mould. Full flexibility and partial flexibility of resource eligibility for job processing are considered. Both of these two kinds of resources are subject to random failure with the time to failure (resp. time to repair) subject to exponential distributions. The objective is to simultaneously minimize the makespan for the production aspect, the unavailability of the machine system, and the unavailability of the mould system for the maintenance aspect. To the best of our knowledge, such a multi-objective scheduling

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problem with two kinds of resources and with flexible preventive maintenance activities on resources has not been documented in the literature. The application of the NSGA-II (Non-dominated Sorting Genetic Algorithm version 2) for the problem is also realized.

The paper is organized as follows. A literature review is presented in Section 2 and then Section 3 gives the detailed description of the multi-objective integrated optimization problem of production scheduling with two kinds of resources and with PM activities, the mathematical formulation is also given. In Section 4, an adapted NSGA-II with implementation details is described. In Section 5, the results of computational experiments with comparisons are reported. Finally, Section 6 concludes the paper and gives future research.

2. Literature review

Recently, realizing the inherent conflicts between production and maintenance, more and more researches emphasize on production scheduling integrated with maintenance planning. In general, two types of maintenance activities are included in the integrated problem: fixed and flexible. The former is performed periodically with a fixed time interval, see [14] and [5] for a relative comprehensive overview. While in the latter type, maintenance intervals or the starting time of intervals are supposed to be flexible and must be determined during the process of production scheduling.

Some researchers attempted to consider the flexible maintenance in production scheduling with different optimization objectives in different manufacturing shop floors. Qi et al. [15] studied the problem of simultaneously scheduling jobs and maintenance tasks on a single machine to minimize the sum of completion times. The problem is proven to be NP-hard, and heuristics and a branch and bound (B & B) method are proposed. Cassady and Kutanoglu [16,17] proposed an integrated model for a single machine with time to failure subject to a Weibull distribution, to minimize the total weighted tardiness of jobs and the total weighted completion time, separately. Kubzin and Strusevich [2] studied both a two-machine open shop problem and a two-machine flow shop problem with flexible maintenance activities to minimize the makespan. Ruiz et al. [3] considered the integrated scheduling problem with different preventive maintenance policies in regular flow shops to minimize makespan. Naderi et al. [18] investigated a job shop scheduling problem with sequence-dependent setup times and maintenance activities to minimize the makespan. Sun and Li [19] studied the scheduling problems with multiple maintenances on two identical parallel machines to minimize the makespan and total completion time, separately. Naderi et al. [20] investigated a flexible flow shop scheduling problem with periodic preventive maintenance to minimize makespan. Rustogi and Strusevich [21] presented polynomial-time algorithms for single machine problems with generalized positional deterioration effects and imperfect machine maintenance to minimize the makespan. Dalfard and Mohammadi [22] discussed a multi-objective flexible job shop scheduling problem (FJSP) with maintenance, in which three objectives are equally treated and weighted into one. Two meta-heuristic algorithms, a genetic algorithm (GA) and a simulated annealing (SA) are proposed. Dong [23] studied a parallel machine scheduling problem with flexible maintenance activity to minimize the total cost involved with the completion time and the unavailable time. A B & B method is proposed. Nouri et al. [24] investigated a non-permutation flow shop scheduling problem with flexible maintenance activities to minimize the sum of tardiness costs and maintenance costs. A SA based heuristic is employed. Sarkar et al. [25] studied a job shop scheduling problem with maintenance activities to minimize the makespan. A hybrid evolutionary algorithm is developed.

While all these works provide a strong basis for further work, it was observed that the integrated problems have been treated as single-objective optimization problems. Since production and maintenance must collaborate to achieve the common goal of productivity maximization, both objectives of maintenance and production are suggested to be considered with the same importance level [6]. Proper integrated scheduling can provide an effective means to tradeoff between objectives related to the production scheduling and maintenance aspects.

In the following, we review the researches of bi-objective or multi-objective optimization of production scheduling and preventive maintenance in different settings of machine environments.

For the single machine, Jin et al. [26] extended the model in [17] to a multi-objective optimization problem to minimize the maintenance cost, makespan, total weighted completion time of jobs, total weighted tardiness and machine unavailability. A multi-objective genetic algorithm (MOGA) is proposed.

For the parallel machine, Berrichi et al. [27] studied a scheduling problem with PM activities to minimize the makespan and the system unavailability simultaneously. Two multi-objective genetic algorithms, NSGA-II and WSGA (Weighted Sum Genetic Algorithm) are employed. In their later work, Berrichi et al. [6] proposed a multi-objective ant colony optimization (MOACO) to solve the same problem. The performance of the proposed MOACO is compared with those of the well-known SPEA 2 (Strength Pareto Evolutionary Algorithm version 2) and NSGA-II. In their further work, Berrichi and Yalaoui [7] considered the similar problem in which two objectives of the total tardiness and the unavailability of the production system are included. A multi-objective ant colony optimization approach is proposed. Moradi and Zandieh [28] introduced a similarity-based subpopulation genetic algorithm (SBSPGA) to solve the same problem. The performance of the algorithm is compared with those of two other evolutionary algorithms. Ben Ali et al. [29] studied a scheduling problem integrated with preventive maintenance tasks that should be executed in a tolerance interval. Two objectives: the makespan and the maintenance cost are to be minimized simultaneously. An MOGA is proposed. Rebai et al. [30] considered a multi-objective parallel machine scheduling problem with the requirement of maintenance once on each machine, to minimize the total sum of the jobs' weighted completion times and the preventive maintenance cost. A heuristic method with two-phases is proposed.

There are also a handful of researches in other complicated environments. Moradi et al. [31] investigated a bi-objective FJSP with PM activities to minimize the makespan and the system unavailability simultaneously. Four multi-objective optimization methods are used to solve the problem. Li and Pan [32] proposed an effective discrete chemical-reaction optimization (DCRO) algorithm to solve the multi-objective FJSP with maintenance activity constraints. Later, they proposed a novel discrete artificial bee colony (DABC) algorithm for the same problem [33]. Xiong et al. [34] studied a FJSP with random machine breakdowns, in terms of bi-objectives of makespan and robustness. An evolutionary algorithm based on the NSGA-II is proposed to solve the problem. Lei [35] studied an interval job shop scheduling problem with non-resumable jobs and flexible maintenance to minimize interval makespan and total interval tardiness. An effective multi-objective artificial bee colony (MOABC) is proposed. Azadeh et al. [36] considered a multi-objective open shop scheduling problem with preventive maintenance and they applied the NSGA-II and a multi-objective particle swarm optimization (MOPSO) to solve the problem.

From the above review, it was observed that the integrated scheduling with PM activities has been conducted on one main resource, i.e., machine. Till date, it is surprising that despite the fruitful results of researches on multi-objective production scheduling integrated with PM activities as mentioned above, only