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A hybrid genetic algorithm with two-stage dispatching heuristic for a machine scheduling problem with step-deteriorating jobs and rate-modifying activities

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ABSTRACT

This article is concerned with a single machine scheduling problems that integrate by step-deterioration along with multiple rate-modifying activities (RMAs). The actual processing time of a job is defined by a step function of its starting time and a specific deterioration threshold. The starting rate of the actual processing time of jobs is restored through the application of RMAs, which recover the original processing time. In this scheduling environment, we simultaneously determine the schedule of step-deteriorating jobs and the number and positions of RMAs to minimize the makespan. We derive a mixed integer programming model to obtain the optimal solution and propose a hybrid genetic algorithm with a two-stage dispatching heuristic represented by a simple chromosome. The performance of the proposed genetic algorithm (GA) is compared with GAs with two types of chromosome representations using randomly generated test instances.

1. Introduction

Scheduling is a decision-making process that assigns of a set of jobs to resources and determines the sequence in which the assigned jobs can be executed by each resource in the context of manufacturing or service processes. It has been widely applied to all stages of the supply chain process, such as procurement, production, transportation, distribution, and information processing. Regarding classical scheduling problems, most research has proceeded under the assumption that the processing time of a job is known in advance and remains constant during the whole decision-making process. However, in many practical situations, the processing times of jobs are not constant but increase over time depending on the sequence of jobs or their starting times. This phenomenon is generally known as the *deterioration* of resources in scheduling problems. In such cases, the production rate of a machine deteriorates due to a mal-position of tools, misalignment of jobs, abrasion of tools, scraps of operations, and so on. This effect can also be observed in the production rate of a worker as a result of normal human fatigue. Therefore, scheduling problems with deterioration are popular in a number of industrial applications, such as steel production, equipment maintenance, order picking, and firefighting. Gupta and Gupta (1988) and Browne and Yechiali (1990) first investigated machine scheduling problems with deterioration. They assumed that the processing time of all jobs is a function of starting time. Following the pioneering works, extensive research has been carried out on various aspects of scheduling problems with deterioration. Alidaee and Womer (1999) and Cheng, Ding, and Lin (2004) provided comprehensive reviews of different models and problems, including details on the stream of the problem. Recently, most studies have focused on scheduling problems with time-dependent continuous deterioration (Bahalke, Yolmeh, & Shahanaghi, 2010; Bank, Fatemi Ghomi, Jolai, & Behnamian, 2012; Cheng, Lee, & Wu, 2011; Huang & Wang, 2011; Jafari & Moslehi, 2012; Ji & Cheng, 2009; Wang, Jiang, & Wang, 2009; Wang & Wang, 2010; Yin, Cheng, Xu, Cheng, & Wu, 2013). They aimed to find the optimal schedule for jobs, assuming that processing times continuously deteriorate depending on their starting times. However, in many manufacturing applications, jobs require extra time for successful completion unless they are processed before a pre-specified deterioration threshold because of unstable machine conditions after it. Kubiak and Velde (1998) proposed a scheduling model incorporating *piecewise-linear deterioration*. They considered a single machine scheduling with a generalization of the unbounded deterioration model proposed by Browne and Yechiali (1990) and proved that their proposed model is NP-hard. Cheng, Ding, Kovalyov, Bachman, and Janiak

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(2003) presented problems of scheduling jobs with piecewise-linear decreasing processing times, on a single or multiple machines and proved that their models are NP-hard. To solve the single machine scheduling problem with piecewise-linear deterioration, Ji and Cheng (2007) proposed a polynomial time approximation model, and Wu, Shiau, Lee, and Lee (2009) proposed two heuristic algorithms. Moslehi and Jafari (2010) proposed a branch and bound algorithm and a heuristic algorithm with $O(n^2)$ to minimize the total number of tardy jobs.

Some articles have focused on scheduling models with a different type of deterioration: *step-deterioration*, which indicates that if a job is not processed before a pre-specified threshold, its processing time will be extended by adding some extra penalty time. Sundararaghavan and Kunnathur (1994) first presented some solvable cases for a single machine scheduling problem with step-deterioration. Mosheiov (1995) studied single and multi-machine scheduling problems with step-deterioration with the aim of minimizing the makespan and proposed several heuristics. Cheng and Ding (2001) proved that the flow time problem is NP-complete. Jeng and Lin (2004) introduced a branch and bound algorithm to minimize the makespan in a single machine scheduling problems with multiple deterioration rates. He, Wu, and Lee (2009) proposed an exact algorithm to solve problems with up to 24 jobs and a heuristic algorithm for deriving a near-optimal solution. Because it is difficult to find an optimal solution for scheduling problems with step-deterioration, some articles have focused on meta-heuristic algorithms. Layegh, Jolai, and Amalnik (2009) studied a single machine scheduling with step-deterioration to minimize the total weighted completion time using a memetic algorithm. Cheng, Guo, Zhang, Zeng, and Liang (2012) developed a variable neighborhood search algorithm to minimize the flow time on parallel machine scheduling problems with step-deterioration. Guo, Cheng, and Wang (2013) used a general variable neighborhood search algorithm to solve a single machine problem with step-deterioration to minimize total tardiness.

Meanwhile, the deteriorated processing times of jobs can be restored to the original processing times through the maintenance or cleaning processes on the machines. An activity that changes the production efficiency of a machine is called a *rate-modifying activity* (RMA). Lee and Leon (2001) first introduced a single machine scheduling problem with an RMA by assuming that one rate-modifying activity during the planning horizon. According to the type of objective function, they separately classified the scheduling problem and proposed a dynamic programming algorithm based on the optimality properties. Lee and Lin (2001) considered a single machine scheduling problems with repair and maintenance activities and derived optimal policies for scheduling fixed-length RMAs and job sequencing. Mosheiov and Sarig (2009) determined the sequencing of jobs and the positioning of an RMA with a common due-window assignment. Ji, Ge, Chen, and Cheng (2013) also considered a single machine scheduling with a common due-window and an RMA proposed two algorithms, but Cheng and Cheng (2014) showed that the second algorithm is incorrect with counter examples. Zhao, Tang, and Cheng (2009) presented a problem for two parallel machines for minimizing the makespan with the assumption of a single RMA at each machine. They showed that the minimization of the total completion time is solvable in $O(n^{2m+3})$ time, where n is the total number of jobs and m is the number of machines. They also introduced a pseudo-polynomial algorithm for solving the total weighted completion time minimization problem. Lodree and Geiger (2010) studied scheduling problems incorporating time-dependent processing times and a single RMA. Under a certain condition, they provided the optimal policy for determining the optimal position of the RMA and sequencing of the jobs. Zhao and Tang (2012) considered a single machine scheduling problem involving the positioning of a single RMA and the deterioration of jobs. Iranpoor, Ghomi, and Zandieh (2012) presented a single machine scheduling problem with sequence-dependent setup times and a single RMA. Zhu, Li, and Zhou (2015) developed a single machine scheduling problem with resource-dependent RAM in the consideration of makespan, flowtime and maximum lateness and proposed polynomial-time algorithms.

Kim and Joo (2011) studied a single machine scheduling models with multiple RMAs where the deterioration of jobs increased nonlinearly depending on the difference between the position of the job and that of the previous RMA. Wang, Wang, and Liu (2011) studied an identical parallel-machine scheduling problem with multiple RMAs. They assumed that each machine might have at most one RMA. They showed that the time complexity of the total completion time minimization problem in this case is $O(n^{2m+3})$. Yang and Yang (2013) investigated scheduling problems with multiple RMAs on an unrelated parallel-machine. They proposed two efficient polynomial time algorithms with a fixed number of machines and with restricted processing times. Joo and Kim (2013) derived a new mathematical model and proposed genetic algorithms for a single machine scheduling problems with time-dependent linear deterioration and RMAs. In that study, they assumed that the number of RMAs was predetermined and that both the position of RMAs and the jobs are the scheduled based on the RMAs.

Our review of the above literature reveals that few articles have focused simultaneously on machine scheduling involving deterioration of jobs and multiple RMAs, even though the deterioration of jobs and RMAs are intrinsically connected. It is a challenging work to simultaneously determine the optimal schedule of step-deteriorating jobs and the number and positions of RMAs with the environment of job deterioration and multiple RMAs. Furthermore, to the best of our knowledge, no scheduling problem considering step-deteriorating jobs and multiple RMAs has yet been studied. In this article, we deal with a single machine scheduling problem with step-deteriorating jobs and multiple RMAs.

The remainder of this article is organized as follows. In Section 2, we describe the problem and derive a mixed integer programming model to find the optimal solution. In Section 3, we introduce two types of chromosome representations for conventional genetic algorithms and a simple chromosome representation for a hybrid genetic algorithm with a two-stage dispatching heuristic for our problem. In Section 4, we propose a two-stage dispatching heuristic applied to the genetic algorithm with a simple chromosome representation. The performances of the proposed heuristics are evaluated through computational experiments in Section 5. Finally, conclusions and areas for further research are provided in Section 6.

2. Problem description and model formulation

In this section, we derive a mathematical model to minimize the makespan for a single machine scheduling with step-deterioration and multiple RMAs. RMAs are recovery processes that restore original processing times and are scattered throughout the planning horizon. It is assumed that there are J independent jobs to be scheduled. Job j has an original processing time of p_j, a deterioration threshold d_j, and a deterioration penalty rate r_j. The actual processing time of job j increases depending on the relationship between x_j and d_j. If $x_j > d_j$, the step deterioration $p_j \cdot r_j$ is added to original processing time p_j. Otherwise, the actual processing remains the same as the original processing time, p_j. The deteriorated processing times of jobs are restored to their original