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A robust hybrid approach based on particle swarm optimization and genetic algorithm to minimize the total machine load on unrelated parallel machines

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ABSTRACT

This paper dealt with an unrelated parallel machines scheduling problem with past-sequence-dependent setup times, release dates, deteriorating jobs and learning effects, in which the actual processing time of a job on each machine is given as a function of its starting time, release time and position on the corresponding machine. In addition, the setup time of a job on each machine is proportional to the actual processing times of the already processed jobs on the corresponding machine, i.e., the setup times are past-sequence-dependent (p-s-d). The objective is to determine jointly the jobs assigned to each machine and the order of jobs such that the total machine load is minimized. Since the problem is NP-hard, optimal solution for the instances of realistic size cannot be obtained within a reasonable amount of computational time using exact solution approaches. Hence, an efficient method based on the hybrid particle swarm optimization (PSO) and genetic algorithm (GA), denoted by HPSOGA, is proposed to solve the given problem. In view of the fact that efficiency of the meta-heuristic algorithms is significantly depends on the appropriate design of parameters, the Taguchi method is employed to calibrate and select the optimal levels of parameters. The performance of the proposed method is appraised by comparing its results with GA and PSO with and without local search through computational experiments. The computational results for small sized problems show that the mentioned algorithms are fully effective and viable to generate optimal/near optimal solutions, but when the size of the problem is increased, the HPSOGA obtains better results in comparison with other algorithms.

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1. Introduction

In classical deterministic scheduling, the processing times of jobs are generally assumed as given constants. However, this assumption may not be appropriate due to deterioration jobs and/or learning effect phenomena. In scheduling with deteriorating jobs, any delay in starting of processing a job may lead to increase of required time and effort to accomplish the job. For instance, Kunnathur and Gupta [1] gave a practical example in the production of steel rolling where the temperature of a molten ingot, while waiting to enter a rolling machine, drops below a certain level, the ingot requires to be reheated before rolling. Extensive surveys of scheduling problems with deteriorating jobs have been conducted by Alidaee and Womer [2], Cheng et al. [3], and Gawiejnowicz [4]. In addition, more recent papers which have considered scheduling problems with deteriorating jobs include [5–8]. In scheduling with learning effects, the time needed to perform a job may be decreased by the repetition of processing operation. For example, is pairman has to repair a number of similar products. The time required to repair a product depends on his knowledge, skills, tools and equipment. The repetition of similar operation will be lead to increase of repairmans' skills and knowledge and more appropriate application of tools and equipment. As a result, the repair time of a product will be decreased. Biskup [9] and Cheng and Wang [10] were the pioneers that introduced the concept of learning in a scheduling setting. Moreover, in recent years, extensive surveys of research related to scheduling with learning effects were provided by [11–15].

However, scheduling problems with deteriorating jobs and learning effects simultaneously have received considerable attention recently because the phenomena can be found in many real-life situations. For example, Cheng et al. [16] gave a practical example in the manual production of glass crafts in which silicon-based raw material is first heated up in an oven until it becomes a lump of malleable dough from which the craftsman cuts pieces and shapes them according to different designs into different glass

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craft products. On the other hand, the pieces that are shaped later require shorter shaping times because the craftsman's productivity improves as a result of learning. Lee [17] first considered single machine scheduling problems with deteriorating jobs and learning effect which the objectives are to minimize makespan and total completion time. He proposed two models that the actual processing time of job J_j scheduled in position r of a sequence is $P_{j[r]} = \alpha_j t r^a$ or $P_{j[r]} = (P_0 + \alpha_j t) r^a$, where α_j is the deterioration rate, t is the starting time of job J_j, a is the learning index, and P_0 is the common basic processing time. He showed that the both scheduling problems are polynomially solvable under simple linear deterioration. Wang [18] considered the scheduling problem that the processing time of job J_j is $P_{j[r]} = (\alpha_j + \beta t) r^a$, where α_j is the basic processing time of job J_j and β is the common deteriorating rate. He showed that several single machine problems and several flow shop problems are polynomially solvable. In addition, Wang [19] studied a linear combination model of Pinedo [20] and Biskup [9] in which the processing time of job J_j is $P_{j[r]} = P_j(\alpha(t) + \beta r^a)$, where P_j is the basic processing time, and $\alpha(t)$ is an increasing deterioration function. He showed that the single-machine problems are polynomially solvable when the objectives are the makespan, the total completion time, and the sum of squared completion times. Wang and Cheng [21] considered a model in which the processing time of job J_j is defined as: $P_{j[r]} = (P_j + \alpha_j t) r^a$, where P_j is the basic processing time and α_j is the deterioration rate of job J_j. They introduced polynomial-time solutions for some single machine problems and flow shop problems. Wang and Cheng [22] studied the single-machine problem to minimize makespan in which the actual processing time of job J_j is $P_{j[r]} = (P_0 + \alpha_j t) r^a$, where P_0 is the common basic processing time and α_j is the growth rate of the processing time of job J_j. They showed that the schedule of jobs by the largest growth rate rule is unbounded for their model. Apart from these articles, other studies which have investigated scheduling problems with deteriorating jobs and learning effects simultaneously include [16,23–27].

On the other hand, it is reasonable that in scheduling problems addition to effects of deterioration and learning, the setup times are also considered. Scheduling problems involving setup times are divided into two classes: sequence-independent and sequence-dependent. In the first case, the setup time is usually added to the job processing time while in the second case, the setup time depends not only on the job currently being scheduled but also on the last scheduled job. Koulamas and Kyparisis [28] first introduced the concept of "past-sequence-dependent" (p-s-d) setup times to scheduling problems whereby the setup time is dependent on all already scheduled jobs. They considered standard single machine scheduling with p-s-d setup times and proved that the problems of minimizing maximum completion time (makespan), the total completion time and the total absolute differences in completion times can be solvable in polynomial time, respectively. They also extended their results to nonlinear p-s-d setup times. Kuo and Yang [29] studied single-machine scheduling problem with past-sequence-dependent setup times and learning effects. They showed that the problems of minimizing makespan, the total completion time minimization, the total absolute differences in completion times and the sum of earliness, tardiness, and common due-date penalty could be solved in polynomial time, respectively. Biskup and Herrmann [30] considered single-machine scheduling problems with past-sequence-dependent setup times and due dates. Their results showed that the single-machine problems remain polynomially solvable when the objectives are total lateness, total tardiness (with agreeable processing times and due dates), maximum lateness (with agreeable processing times and due dates) and maximum tardiness (with agreeable processing times and due dates). However, for other problems, namely, the number of tardy jobs, maximum lateness and maximum tardiness, the well-known solution approaches that guarantee optimality are no longer valid. Wang et al. [31] considered single-machine scheduling with past-sequence-dependent setup times and exponential time-dependent learning effect. They showed that the makespan minimization problem, the total completion time minimization problem and the sum of the quadratic job completion times minimization problem can be solved by the SPT rule, respectively. Apart from these articles, there are other contributions to scheduling problems with p-s-d setup times, see for example [32–35].

Within the aforesaid researches done on scheduling with deteriorating jobs, learning effects and p-s-d setup times neglected the release dates and almost all studies concentrated on single machine problems. Release dates help to the attractiveness of problems and may lead to decrease in deterioration of jobs and their actual processing time. Also, since the setup time is dependent to the actual processing times of the past processed jobs, it may lead to reduction of setup times and production cost. Thus, in this paper we study scheduling problem with past-sequence-dependent setup times, release dates and effects of deterioration and learning on unrelated parallel machines. Some of the applications of this type of scheduling problem can be pointed out for industries with high technology, such as manufacturing of integrated circuit (IC) boards. An IC board consists of a number of electronic components mounted on it. These electronic components must be processed one-by-one by a machine, where by each component prior to processing requires a setup operation which is proportional to the actual processing times of the already processed components [28]. On the other hand, release dates and effects of deterioration and learning arise from the unavailability of components at the beginning of the scheduling horizon, erosion of machine and equipment, and increase in workers' proficiency by repeating the tasks, respectively.

In recent years, many nature-inspired meta-heuristic algorithms such as genetic algorithm (GA), ant colony optimization algorithm (ACO), simulated annealing algorithm (SA), particle swarm optimization algorithm (PSO), artificial immune system algorithm (AIS), artificial bee colony algorithm (ABC), harmony search algorithm (HS), differential evolution algorithm (DE) and cuckoo search algorithm (CSA) have been widely used to solve optimization problems with complex nature in which a process for enhancing the obtained solution is repeated until a pre-defined terminating criterion is reached [36–39]. Ruiz-Torres et al. [36] considered the unrelated parallel machine scheduling problem with deteriorating effect. They designed a simulated annealing algorithm for the given problem with the objective of makespan minimization. Yeh et al. [38] addressed parallel machine scheduling with learning effects to minimize the makespan and proposed two heuristic algorithms, called the simulated annealing algorithm and the genetic algorithm.

During the past decade, hybrid methods are also received significant interest to improve performance of evolutionary algorithms and to find the global optimum solutions [40–44]. The artificial immune algorithm is hybridized with hill climbing local search algorithm to solve optimization problems by Yildiz [40] and then applied to single objective test problem, multi-objective I-beam and machine-tool design optimization problems from the literature. In another study, Yildiz [43] proposed a hybrid robust differential evolution (HRDE) by adding positive properties of the Taguchi's method to the differential evolution algorithm and then applied for multi-pass turning operations to illustrate the effectiveness and robustness of the proposed algorithm in machining operations. The results found by the HRDE reveal that the proposed hybrid algorithm is more effective than particle swarm optimization algorithm, immune algorithm, hybrid harmony search algorithm, hybrid genetic algorithm, scatter search algorithm,

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