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Design of a genetic algorithm for bi-objective unrelated parallel machines scheduling with sequence-dependent setup times and precedence constraints

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ABSTRACT

This paper presents a novel, two-level mixed-integer programming model of scheduling N jobs on M parallel machines that minimizes bi-objectives, namely the number of tardy jobs and the total completion time of all the jobs. The proposed model considers unrelated parallel machines. The jobs have non-identical due dates and ready times, and there are some precedence relations between them. Furthermore, sequence-dependent setup times, which are included in the proposed model, may be different for each machine depending on their characteristics. Obtaining an optimal solution for this type of complex, large-sized problem in reasonable computational time using traditional approaches or optimization tools is extremely difficult. This paper proposes an efficient genetic algorithm (GA) to solve the bi-objective parallel machine scheduling problem. The performance of the presented model and the proposed GA is verified by a number of numerical experiments. The related results show the effectiveness of the proposed model and GA for small and large-sized problems.

1. Introduction

A classical parallel machine problem can be stated as follows: a set of the independent jobs to be processed on a number of available identical parallel machines. Each machine can process only one job at a specific time, and each job can be processed on one machine. Each job is ready at the beginning of the scheduling horizon and has a distinct processing time and due date [1].

Majority of scheduling research studies assume that setup times are negligible or part of the processing time. While this assumption simplifies the analysis and/or represents certain industrial applications, it adversely affects the solution quality for many applications which require explicit treatment of setup times and makes the model inapplicable in real environments.

In a manufacturing environment, setup times consist of all activities that are performed on material, in order to prepare them for the main process phase. Production problems that are related to setup times are divided into two important categories: (1) sequence-dependent setup times and (2) sequence-independent setup times. For example, at a production facility where paint is needed, a setup time is incurred for cleaning the machine whenever a color change is required. The thoroughness required in cleaning the machine depends on both the color being removed and the color for which it is being prepared. Likewise, in the plastic industry, items of different colors are typically assigned to different extrusion machines. When a color change is required, a certain amount of time is taken until the extruded plastic reaches the desired color. Such problems are also common in the glass manufacturing industry, where molten glass is held in huge vats before the actual glass blowing process. The vats have to be changed for different colors and properties of the glass. This changeover process incurs major setup times. Likewise, in the soft drink beverage industry, the manufacturing lines have to go through major setups while changing over from filling glass bottles to soda cans. Many such examples can be found in chemical and paper manufacturing industries [2].

In the past years, many researchers have investigated multi-criteria parallel machines scheduling problems with two or more criteria that apply simultaneously or hierarchically in the objective function. Minimizing the number of tardy jobs is one objective that has received less attention researchers. However, in many situations, we face conditions where missed due dates lead to cancellation of orders by the clients. Therefore, in these situations we have to consider a scheduling problem that minimizes the number of tardy jobs.

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On the other hand, minimization of the total completion time of all the jobs is commonly applied in scheduling problems by researchers. Decreasing the completion times is an effective method in reducing job lateness and tardiness. Decreasing the completion times also leads to the reduction in the total work-in-process (WIP) inventories, and minimization of irregularities and inordinate shop flow crowding due to uncompleted jobs. Therefore, minimizing the completion times is one of the most important criteria for manufacturing and service organizations.

The presented parallel machine can be formulated as a generalized parallel machine problem, and it thus belongs to the class of NP-hard problems. This paper, a genetic algorithm (GA) is proposed to solve the presented model, for the real-sized instances.

The rest of this paper is organized as follows: a brief overview of the extended model and related literature is presented in Section 2. The extended model is formulated in Section 3. The proposed GA is developed in Section 4. Computational results are reported in Section 5, and finally Section 6 covers the conclusion.

2. Literature review

Most of the research work preformed on machine scheduling does not consider sequence-dependent setup times for different jobs. We can find a survey on this problem in [3] and [4]. Different methods for solving this problem exist. Some researchers reach the optimal or near-optimal solution by using the mathematical programming models [5,6], meta-heuristics such as genetic algorithm, and heuristic method based on list scheduling [7–9].

Monma and Potts [10] considered the complex computing of scheduling parallel machines with sequence-dependent setup cost. Balakrishnan et al. [11] and Sivrikaya-Şerifoğlu and Ulusoy [6] considered a problem that minimizes the total earliest and tardiness cost in just-in-time (JIT) production environments and solves them with GA and mixed integer programming. Blidgue et al. [1] solved this problem by minimizing the total tardiness using the tabu search (TS) method, and then compared it with the solution given in [6] and obtained the better result with TS than with GA. A few studies were considered with different objectives [12–14].

Uzsoy et al. [15] presented a model that minimizes the maximum lateness with precedence constraints and sequence dependency of jobs. Each job has its own due date. They also proposed a neighborhood search algorithm to obtain a local optimal solution and a branch-and-bound (B&B) algorithm to obtain optimal solutions. Malve and Uzsoy [16] presented a parallel identical batch processing machine scheduling problem with dynamic job arrivals that minimizes the maximum lateness. They proposed iterative improvement heuristic methods, GA, and the related iterative heuristics embedded with GA. Su [17] presented an identical parallel machine scheduling problem with common due dates that minimizes the total earliness and tardiness. A binary integer programming model was developed to solve the given problem. Rocha et al. [18] considered an unrelated parallel machine scheduling problem under some constraints, such as sequence and machine-dependent setup times, due dates, and weighted jobs. They applied a meta-heuristic method based on a greedy randomized adaptive search procedure (GRASP) to obtain the upper bound that is used with a B&B method. The results are compared with the results obtained from two mixed-integer programming (MIP) models.

Hurink and Knust [19] presented scheduling $P/S_{ij}, Prec/C_{max}$ as an NP-hard problem. They dealt with the question whether it is possible to design an efficient list scheduling algorithm for this problem, which produces a dominant set of list schedules if it is applied to all sequences of jobs which are compatible with the given precedence (i.e., are linear extensions of the partial order induced by the precedence). A positive answer to this question can lead to a solution approach for the considered problem by using the set of all possible job sequences as a solution space and the developed method to generate corresponding schedules. However, they showed that a positive answer to this question is very unlikely. Huo et al. [20] presented a multi-objective model for parallel machines scheduling that minimizes the number of tardy jobs and maximum weighted lateness. The model is solved by a heuristic algorithm. Prakash [21] studied a comprehensive survey on bi-criteria parallel machines scheduling problems, and presented several different heuristic algorithms to solve the given problem.

3. Proposed mathematical model

In this paper, we define the parallel machine scheduling in which some machines operate with different speed and all of them are available at the beginning of the scheduling. Jobs are not independent and there are some precedence relations between them. All jobs are not available at the beginning of the scheduling and each of them has its own due date. We know that setup times depend on job sequences and machine types.

As mentioned before, in many cases customers want to receive their orders on time. In a case of any delay, there is no benefit for customers that may result unsatisfactory and loss the orders. Thus, it is very important to deliver the orders on exact due dates. We consider the minimization of the number of tardy jobs as the main objective in scheduling problems. Minimizing the total completion time is also considered in most studies in the literature. This objective additionally reduces the WIP. In this paper, we propose a novel bi-objective MIP model that minimizes the number of tardy jobs and the total completion time. It is worth noting that the former objective is more significant than the latter one.

3.1. Input parameters

M	Total number of machines.
N	Total number of jobs to be processed.
UB	Maximum number of positions on each machine that jobs are placed on them. It is computed as follows:
UB	$N-M+1$ (i.e., the maximum machine utilization is met, so that all machines are used).
P_{im}	Processing time of job i on machine m; $i=1,2,\ldots,N$ and $m=1,2,\ldots,M$.
d_i	Due date of job i.
r_i	Time at which job i is available for processing (i.e., ready time).
S_{ijm}	Setup time to switch from job i to job j on machine $m : j=1,2,\ldots,N$.
L	A large positive number.
Φ	Set of paired jobs with the precedence relationship when job i must precede job j ($(i,j) \in \Phi$).

3.2. Decision variables

C_i	Completion time of job i.
U_i	1 if job i is tardy; =0 otherwise.
X_{ikm}	1 if job i is assigned on situation k at machine m =0 otherwise $k=1,2,\ldots,UB$.

Based on the definition and notations described above, the proposed model is formulated in the next section.

3.3. Mathematical model for Phase 1

Following is a mathematical model for Phase 1

$$\text{Min} \quad \sum_{i=1}^{N} U_i \tag{1}$$