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Group-shop scheduling with sequence-dependent set-up and transportation times

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A B S T R A C T

This paper considers a group-shop scheduling problem (GSSP) with sequence-dependent set-up times (SDSTs) and transportation times. The GSSP provides a general formulation including the job-shop and the open-shop scheduling problems. The consideration of set-up and transportation times is among the most realistic assumptions made in the field of scheduling. In this paper, we study the GSSP with transportation and anticipatory SDSTs, where jobs are released at different times and there are several transporters to carry jobs. The objective is to find a job schedule that minimizes the makespan, that is, the time at which all jobs are completed and transported to the warehouse (or to the customer). The problem is formulated as a disjunctive programming problem and then prepared in a form of mixed integer linear programming (MILP). Due to the non-deterministic polynomial-time hardness (NP-hardness) of the GSSP, large instances cannot be optimally solved in a reasonable amount of time. Therefore, a genetic algorithm (GA) hybridized with an active schedule generator is proposed to tackle large-sized instances. Both Baldwinian and Lamarckian versions of the proposed hybrid algorithm are then implemented and evaluated through computational experiments.

1. Introduction

The group-shop scheduling problem (GSSP), which frequently occurs in manufacturing environments, includes both the job-shop and the open-shop scheduling problems. Hence, it is non-deterministic polynomial-time hard (NP-hard) and difficult to solve optimally. In the GSSP, a set of jobs has to be processed on a set of machines, where the operations of each job are partitioned into a number of groups by taking the technological constraints into account. That is, the operations that are not subject to precedence constraints and can be processed in any order are placed in the same group, while those operations that have to satisfy precedence constraints are placed in distinct groups.

In the majority of research efforts conducted on scheduling problems, researchers usually have either ignored set-up times or combined them with their corresponding processing times to simplify the analysis. In recent years, however, it has been of interest to consider set-up times in scheduling decisions. The main reason why scheduling problems involving set-up times (or costs) have attracted a lot of attention is because there are tremendous savings when set-up times are explicitly considered [1,2]. The set-up times could be either sequence independent or sequence dependent. In the sequence-independent type, set-up depends only on the job to be processed. In general, the sequence-independent set-up

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times can be simply included in the job-processing times. On the other hand, in the case of sequence-dependent set-up times (SDSTs), set-up depends not only on the job to be processed but also on the job just completed. For example, Pinedo [3] has described a paper-bag factory where a set-up is required whenever a machine switches from one type of paper bag to another; the set-up duration clearly depends on the similarities between the two consecutive products (e.g., the similarities in size and the number of colors). In such situations, it is not valid to include the set-up times in the job-processing times [4].

The SDST can be either non-anticipatory or anticipatory [2]. A set-up is non-anticipatory if it can begin only when both corresponding job and machine are available. On the other hand, a set-up is anticipatory if it can begin when the machine is available even when the job is not available to be processed.

In the past, researchers have usually assumed that transportation times between stages/machines are negligible. Recently, however, a popular assumption made in scheduling decisions is that it may be impossible to begin the processing of a job on a machine immediately after the completion of the preceding operation of the job because of the transportation time; a transporter must first deliver the job between the two stages. When a transporter reaches a stage, the processing of the delivered job can be started only if one of the machines available at that stage is ready to receive the job and the set-up required has been completed. If not, the transporter leaves the job in the buffer of the stage until the processing can begin.

The transportation times could be either job independent or job dependent [5]. In the job-independent type, the magnitude of a transportation time depends only on the distance between the two consecutive stages/machines, while in the job-dependent type it is determined by the distance as well as the job to be carried. Moreover, the transportation system may be multi-transporter or single transporter [6]. In a multi-transporter system, there are several (unlimited) transporters to carry jobs; so, a job never has to wait for a transporter before its transportation. However, in a single-transporter system, all transportations between stages are carried out by a single transporter; so, a job may wait for the transporter to return.

When simultaneously considering the SDSTs and transportation times, there are two cases to be considered. In the first case that corresponds to the anticipatory SDSTs, the overlapping of the set-ups and transportations is allowed, and so, the processing of a job on a machine can be started if both the transportation and the set-up required have been completed (see, e.g., Fig. 1). However, in the second case that corresponds to the non-anticipatory SDSTs, no overlapping of the set-ups and transportations is allowed, that is, the set-up of a machine can be started after the transportation has completed. Fig. 2 shows an example of this case in which, although machine i' is available, it is kept idle before being set up to process job j.

Assuming that jobs are released at different times, this paper investigates a GSSP with two realistic and rarely considered assumptions: (1) the set-up times are anticipatory and sequence dependent and (2) the transportation times are job dependent and the transportation system is a multi-transporter system. The aim is to minimize the makespan. A mathematical formulation of the problem is proposed; it is first formulated as a disjunctive programming problem, and then prepared in a form of mixed integer linear programming (MILP). Moreover, to tackle large-size problem instances, a genetic algorithm (GA) hybridized with an active schedule generator is proposed. Both Baldwinian and Lamarckian versions of the hybrid algorithm are then implemented and evaluated through a series of computational experiments. To the best of our knowledge, no similar studies are known in the scheduling context.

The rest of the paper is organized as follows. The next section goes over the literature on the GSSP as well as the literature on shop scheduling problems with the SDSTs and transportation times. In Section 3, the problem is introduced. Sections 4 and 5, respectively, describe the proposed MILP model and hybrid algorithm, followed by Section 6 providing the computational results. Finally, the conclusions and future research directions are stated in Section 7.

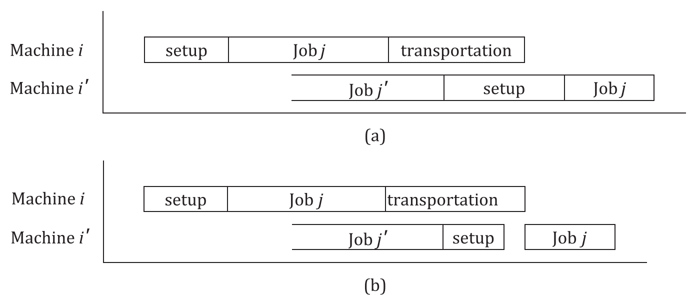

Fig. 1. Overlapping of transportation and set-up when (a) set-up determines the starting time and (b) transportation determines the starting time.

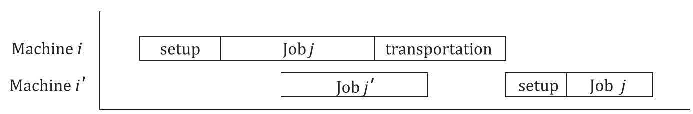

Fig. 2. No overlapping of transportation and set-up.