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A GA/TS algorithm for the stage shop scheduling problem ☆

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ABSTRACT

This paper presents a special case of the general shop called stage shop problem. The stage shop is a more realistic generalization of the mixed shop problem. In the stage shop problem, each job has several stages of operations. In order to solve the stage shop problem with makespan objective function, an existing neighborhood of job shop is used. In this neighborhood, few enhanced conditions are proposed to prevent cycle generation. In addition, a new neighborhood for operations that belong to the same job is presented. These neighborhoods are applied to the stage shop problem in a tabu search framework. A genetic algorithm is used to obtain good initial solutions. An existing lower bound of the job shop is adapted to our problem and the computational results have been compared to it. Our algorithm has reached the optimal solutions for more than half of the problem instances.

1. Introduction

The *job shop* scheduling problem (JSP) is one of the most interesting areas of research in the field of scheduling. The problem is well-known as a notably difficult combinatorial optimization instance. In fact, it is NP-Complete (Gary & Johnson, 1979).

Several efforts have been made to extend the job shop with the purpose of making the model more realistic. One of the well known extensions of the job shop in the literature is the *mixed shop*. As a generalization of the mixed shop, the *general shop* is the most generalized form of the shop scheduling problems.

Some points are common in job shop, mixed shop and general shop: given n jobs that have to be processed on m machines. Each job consists of a set of operations, each of which needs to be processed without interruption for a given period of time on a given machine. Each job can only be processed by one machine at a time and each machine can only process one job at a time. A schedule is an assignment of operations to time slots on a machine. The objective is to find a feasible schedule that minimizes some objective function of the finishing times of the jobs.

The distinction between job shop, mixed shop and general shop is associated with the precedence relations of the operations. In a job shop, the sequence of the operations of each job is predetermined. In a mixed shop, the set of jobs is partitioned to two sets: job shop jobs and open shop jobs. The operations of a job that belongs to the set of job shop jobs have a predetermined route, while the route of the operations of a job that belongs to the set of open shop jobs is immaterial. In a general shop, there may be precedence relations between the operations of all jobs, i.e. the operation of one job can be a predecessor of the operation of another job (Brucker, 2004).

Extensive efforts have been applied to research in job shop scheduling. See papers by Nowicki and Smutnicki (1996), Blazewicz, Domschke, and Pesch (1996), Balas and Vazacopoulos (1998), Vaessens, Aarts, and Lenstra (1996), and Pezzella and Merelli (2000).

Park, Choi, and Kim (2003) used a scheduling method based on Single Genetic Algorithm (SGA) and Parallel Genetic Algorithm (PGA). Murovec and Suhel (2004) proposed a repairing technique for local search algorithms to avoid infeasibility in a different manner. Goncalves, Mendes, and Resende (2005) used a hybrid GA that the chromosome representation is based on random keys. Grabowski and Wodecki (2005) used a modified neighborhood in TS framework to solve the job shop problem. Nowicki and Smutnicki (2005) proposed *i*-TSAB algorithm that was highly effective in makespan minimization. Watson, Howe, and Whitley (2006) deconstructed *i*-TSAB and proposed several algorithms; however, none of them are more effective than *i*-TSAB. Pardalos and Shylo (2006) presented an algorithm based on global equilibrium search techniques. Sha and Hsu (2006) proposed a hybrid PSO whose particle position based on preference list-based representation, particle movement based on swap operator, and particle velocity based on the tabu list concept. Zhang, Li, Guan, and Rao (2007) strived to extend the neighborhood of Balas and Vazacopoulos (1998). Zhang, Li, Rao, and Guan (2008) combined TS and SA to propose TSSA and performed comprehensive computational experiments on different problem

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sets. Further, Huang and Liao (2008) presented a hybrid algorithm combining ant colony optimization with the tabu search. Rego and Duarte (2009) proposed a heuristic algorithm that combines shifting bottleneck procedure with a filter-and-fan approach. Pardalos, Shylo, and Vazacopoulos (2010) used the properties of the search space such as backbone and "big valley" to accelerate the search process. The newest results for the job shop scheduling problem with makespan criterion in Taillard's website are due to an unpublished work of Nasiri and Kianfar (Taillard, 2011).

The mixed shop is a combination of the job shop and the open shop problems. In its general form, mixed shop is NP-hard. Shakhlevich, Sotskov, and Werner (2000) discussed the complexity of mixed shop problems under various criteria and clarified the boundary between polynomially solvable and NP-hard problems. It is worth noting that some authors (like Ferrell, Sale, Sams, & Yellamarju, 2000) considered the mixed shop as a combination of the flow shop and the open shop problems.

Furthermore, there are other generalizations of the job shop problem. In Ramudhin and Marier (1996) a problem entitled "shops with a partial ordering on operations pertaining to each job or machine" is stated and solved by an extension of the shifting bottleneck method. In addition, Kis (2003) presented an extension of the job shop scheduling problem where the job routings are directed acyclic graphs. These graphs can model partial orders of operations and contain sets of alternative subgraphs consisting of several operations each. Moreover, Nasiri and Kianfar (2011) defined another extension for the job shop problem, called partial job shop problem, and solved it using a hybrid scatter search.

Generally in an ordinary manufacturing shop, the job is equivalent to the workpiece and the operations of a job are equivalent to the operations that should be done on the workpiece. The sequence of the operations that should be done on a workpiece is correlated with the design of it. Thus, some of the operations of a job have a predetermined order (e.g. milling and grinding the top of the workpiece) while the others do not have (e.g. knurling the bottom of the workpiece and drilling a hole on the top of it). This case cannot be modeled with the mixed shop since some jobs cannot be assigned to any of the partitions (job shop jobs and open shop jobs). In addition, the general shop is too general to be an effective model for this case. In the general shop problem, there is no restriction in the precedence relations between operations, so that the operation of one job can be a precedent of the operation of another job. Such an assumption complicates the graph of the problem and we think it has rare application in the real world. For instance, the cutting operation of a job can be precedent of the drilling operation of that job but generally cannot be precedent of the drilling operation of another job.

Therefore, the *stage shop* problem is defined as a generalization of the mixed shop and a special case of the general shop problem. In a stage shop, each job has several stages of operations. A *stage* is a subset of operations of a job that can be processed in any arbitrary relative order. If a stage includes all operations of a job, the job is like an open shop job in the mixed shop problem. The stages of a job (like the operations of a job in a job shop) should be processed in a predetermined order. Therefore, if each stage of a job includes only one operation, the job is like a job shop job in a mixed shop problem. Hence, the stage shop is a generalization of the mixed shop. It is worth noting that in the stage job shop problem the operation of one job can only be a precedent of the operations of the same job.

The proceeding organization of the paper is as follows. Section 2 gives the problem formulation and notations. Section 3 focuses on our GA/TS algorithm. Computational results are included in Section 4. Finally, Section 5 concludes the paper.

2. Problem formulation and notations

A *stage shop* consists of a set of m different machines $M = \{1, 2, \ldots, m\}$ that perform operations of jobs. There is a set of n jobs $J = \{1, 2, \ldots, n\}$, where each job j has s_j stages of operations. These stages should be performed in the consecutive order $1, 2, \ldots, s_j$. It means that when the processing of all operations of the stage k is finished, then the processing of the operations of the stage $k + 1$ can be started. Operation l should be processed p_l time units on a predetermined machine without preemption.

The rest of the assumptions are as follows:

- No machine can process more than one job (operation) at a time.
- The processing of the operations cannot be interrupted.
- All jobs and all machines are available from time 0 on.
- Each job visits each machine once at most, in other words, *recirculation* is not permitted.
- No precedence relation between operations of different jobs is allowed.
- Stage k of job j has w_{jk} operations so that between these operations no precedence relation exists. They can be performed in any arbitrary order.
- There is no transportation time between machines.
- There are infinite buffers between machines.

An example of the directed graph for a stage shop problem is shown in Fig. 1. There are three jobs in this problem. The job 1 has three stages. In stage 1, three operations exist. These operations are predecessors of all operations in the stages 2 and 3.

This research considers the *makespan* ($C_{\max}$) as the objective function of the problem. A disjunctive graph can represent the minimization of the makespan in a stage shop. Consider a directed graph $G = (N, A \cup B)$ as follows: The nodes N denote all operations and A is the set of conjunctive (solid) arcs connecting consecutive stages of the same job. Two operations that have to be processed on the same machine are connected to one another by two so-called disjunctive (broken) arcs that go in reverse directions. In addition, this is true for two operations that belong to the same stage of a job. The disjunctive arcs B form $m + \sum_j s_j$ cliques of double arcs, one clique for each machine and s_j cliques for the stages of job j. (A clique is a term in graph theory that refers to a graph in which any two nodes are connected to one another; in this case, each connection within a clique consists of a pair of disjunctive arcs. Clique approach for the job shop problem was introduced for the first time by Carlier and Pinson (1989).)

In addition, two dummy nodes 0 and $*$ represent the start (source) and finish (sink) operations, respectively. The source node 0 has conjunctive arcs emanating to operations of the first stage of the jobs and the sink node $*$ has conjunctive arcs coming in from operations of the last stage of the jobs. The length of each arc originating from a node, conjunctive as well as disjunctive, is equal to

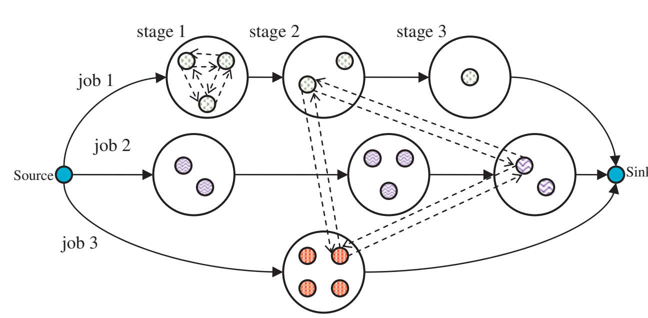

Fig. 1. Directed graph for a stage shop problem.