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Discrete Optimization

# A multi-objective tabu search for a single-machine scheduling problem with sequence-dependent setup times

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**Abstract**

An *m*-objective tabu search algorithm for sequencing of *n* jobs on a single machine with sequence-dependent setup times is proposed. The algorithm produces a solution set that is reflective of the objectives' weights and close to the best observed values of the objectives. We also formulate a mixed integer linear program to obtain the optimal solution of a three-objective problem. Numerical examples are used to study the behavior of the proposed *m*-objective tabu search algorithm and compare its solutions with those of the mixed integer linear program.


*Keywords:* Scheduling; Sequence-dependent setup; Multi-objective; Tabu search

## 1. Introduction

In many real-life scheduling problems, the decision maker is faced with situations in which the appropriateness of a schedule is measured against multiple objectives. These objectives are often conflicting and no single schedule would simultaneously optimize all objectives. Therefore, in the absence of a globally optimum solution, a compromise solution must be sought from among a number of solutions identified within the scope of the preferences set by the decision maker. Traditional mathematical programming approaches for solving multi-objective optimization problems are computationally intractable for practical

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problems, and thus the use of (meta) heuristic methods such as genetic algorithms, simulated annealing, and tabu search have become popular in the past decade (see Jones et al. (2002) for a review of papers in this area).

A machine scheduling problem is a combinatorial optimization problem, and the most common performance measures (objectives) are functions of the jobs' completion times. Examples of such objectives to be minimized include the makespan (i.e., the completion time of the last job to leave the system), the (discounted) total weighted completion time, the maximum lateness, the total weighted tardiness, and the weighted number of tardy jobs (Pinedo, 2002). The first two objectives are focused on improving resource utilization and productivity, while the others are mainly perceived as measures of conformity with due dates. Thus, minimizing makespan, number of tardy jobs and total tardiness at the same time, for example, could be a reasonable set of objectives for a machine scheduling problem.

We consider an $m$-objective non-preemptive scheduling of $n$ jobs on a single machine with sequence-dependent setup times. Sequence-dependent setups are commonly observed in various industrial settings including printing, textile, pharmaceutical, chemical and metallurgical industries. Gagne et al. (2001) describe an industrial application involving holding furnaces that require alloy-dependent draining and cleaning operations between two consecutive castings of metals, and discuss broader applications of sequence-dependent setups in the printing, textile, pharmaceutical, chemical and metallurgical industries. Das et al. (1995), Franca et al. (1996) and Gravel et al. (2000) document other examples of sequence-dependent setups in the plastic and aluminum casting industries.

For the single objective of minimizing the makespan, the problem is known to be a strong NP-hard problem (Pinedo, 2002). Hence, we conclude that its $m$-objective problem must also be an NP-hard problem and consequently, devising a heuristic to solve this problem is highly desirable. As such, we propose a multi-objective tabu search algorithm for identifying a bounded solution space. Our algorithm is novel because it uses an independent tabu list for each objective, it tracks the best identified value for each objective (solution to the single objective case), and it creates a bounded solution space whose boundaries are inversely proportional to the weights assigned to the objectives. That is, bounds for important objectives receiving larger weights will be closer to their best identified values, whereas bounds for less important objectives receiving smaller weights will be further away from their best identified values. In addition, by specifying the constant of proportionality for each objective, the decision maker has an opportunity to control the size of the bounded solution space. The bounded solution space contains a mix of solutions, some of which are on the Pareto frontier and some may be dominated, thereby offering more alternative solutions to the decision maker. Furthermore, the proposed algorithm provides a general framework for solving large-scale multi-objective combinatorial problems.

The rest of this paper is organized as follows. In Section 2 we review the relevant literature. An optimization model for the three-objective single-machine non-preemptive sequencing problem with sequence-dependent setup times is presented in Section 3, followed by a detailed description of the tabu search algorithm in Section 4. Section 5 is devoted to our numerical results, and some concluding remarks are presented in Section 6.

## 2. A review of past research

The published literature pertinent to this work can be divided into two main categories. The first category consists of single-machine sequencing procedures with multi-objective and/or sequence-dependent setup times that are primarily based on traditional operational research global search approaches such as branch and bound, goal programming, dynamic programming, and trade-off curves. In this regard, Emmons (1975), Chand and Schneeberger (1986, 1988), Chen and Bulfin (1994), Lin and Lee (1995) and Koksalan et al. (1998) propose solution methodologies for various single-machine scheduling problems