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Discrete Optimization

Algorithms for single machine total tardiness scheduling with sequence dependent setups

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Abstract

We consider the problem of scheduling a single machine to minimize total tardiness with sequence dependent setup times. We present two algorithms, a problem space-based local search heuristic and a Greedy Randomized Adaptive Search Procedure (GRASP) for this problem. With respect to GRASP, our main contributions are—a new cost function in the construction phase, a new variation of Variable Neighborhood Search in the improvement phase, and Path Relinking using three different search neighborhoods. The problem space-based local search heuristic incorporates local search with respect to both the problem space and the solution space. We compare our algorithms with Simulated Annealing, Genetic Search, Pairwise Interchange, Branch and Bound and Ant Colony Search on a set of test problems from literature, showing that the algorithms perform very competitively.

Keywords: Scheduling; Total tardiness; Heuristics; Sequence dependent setups

1. Introduction

Starting with the seminal work of Conway et al. [1], the area of scheduling has grown considerably, and there is an extensive literature available on this subject. Most research on scheduling problems assumes that setup times are independent of the sequence of tasks on a machine. It is assumed that setup times are negligible or are added to the processing times of the tasks. However, significant setup times are incurred in some situations whenever a machine switches service from one task to another. In these cases, the machine processes many different jobs, and the setup time for a job depends on the job that has just finished processing before it. Some noteworthy examples are found in petroleum producing plants, car spraying facilities,

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textile dying plants and pharmaceutical industries, and are described in Allahverdi et al. [2].

In spite of the fact that a majority of the literature deals with problems without sequence dependent setups, some surveys and studies indicate that setups are important in a majority of practical situations, and must be accounted for in the design of algorithms for scheduling problems. In a survey of industrial schedulers, Panwalkar et al. [3] report that about 70% of the schedulers stated that setup times depended on processing sequence in at least 25% of the jobs they scheduled. Kim and Bobrowski [4] study the impact of setup times on the performance of scheduling systems using simulation; they conclude that to better model practical situations, setup times should be considered explicitly whenever they are significantly greater than the processing times. An excellent survey of scheduling problems with setups is presented in Allahverdi et al. [2].

On the other hand, some of the simplest and most studied scheduling problems involve due date based objectives on a single machine. These problems deal with scheduling multiple tasks that compete for service on a single resource, or machine to meet some objective concerning due dates of the tasks. A frequently encountered due date based objective is to minimize the total *tardiness* of all the tasks. The single machine scheduling problem to minimize total tardiness is NP-hard [5], suggesting that it is unlikely for any algorithm to always find an optimal solution within a practical time limit. Koulamas [6] presents a comprehensive survey of the single machine scheduling problem to minimize total tardiness.

This paper considers a single machine scheduling problem with sequence dependent setup times with the objective to minimize total tardiness of the jobs. As per the standard scheme for deterministic scheduling problems introduced by Graham et al. [7], our problem is represented as $1|s_{ij}|\sum T_j$. The problem is stated as follows [8]. A set of n jobs are available for processing at time zero on a continuously available machine. Each job has a processing time p_j, a due date d_j, and a setup time a_{ij} which is incurred when job j immediately follows job i. It is assumed that all the processing times, due dates and setup times are non-negative integers. Job preemptions are not allowed. Let q be a sequence of the jobs ($q = [q_0, q_1, \ldots, q_n]$). q_j denotes the index of the jth job in sequence, and $q_0 = 0$. The due date of the jth job in sequence is denoted as d_{q_j} and the processing time of the jth job in sequence is denoted as p_{q_j}. Thus, the completion time of the jth job in sequence is given as

$$C_{q_j} = \sum_{k=1}^{j} (a_{q_{k-1}q_k} + p_{q_k}).$$

The tardiness of the jth job in sequence is given as

$$T_{q_j} = \max(C_{q_j} - d_{q_j}, 0).$$

The objective is to minimize the total tardiness of all the jobs [8], which is given as

$$\sum_{j=1}^{n} T_{q_j}.$$

We present two heuristics to solve this problem. The first algorithm is a Greedy Randomized Adaptive Search Procedure (GRASP); GRASP is a multi-start heuristic, which consists of a greedy randomized construction phase, followed by a local search improvement phase. We incorporate a new variation of Variable Neighborhood Search (VNS) for the local search phase. This is a combination of three different search neighborhoods, which proves to be very effective for this problem. The second algorithm is a variation of problem space-based neighborhood search heuristic. Here, the neighborhood search is performed both with respect to the problem space and the solution space. Computational testing is performed on a set of test problems available from literature. We report on our experimental results and conclude with some remarks and future research directions.

2. Literature review

When the objective is to minimize makespan in the basic single machine model (without setups), any permutation of jobs essentially gives the same makespan. However, the addition of sequence dependent setup times considerably complicates the problem. It is well known that the single