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Beam search algorithms for the single machine total weighted tardiness scheduling problem with sequence-dependent setups

Jorge M.S. Valente[a,*], Rui A.F.S. Alves[b]

[a]LIACC/NIAAD - Faculdade de Economia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-464 Porto, Portugal
[b]Faculdade de Economia, Universidade do Porto, Portugal

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Abstract

In this paper, we consider the single machine weighted tardiness scheduling problem with sequence-dependent setups. We present heuristic algorithms based on the beam search technique. These algorithms include classic beam search procedures, as well as the filtered and recovering variants. Previous beam search implementations use fixed beam and filter widths. We consider the usual fixed width algorithms, and develop new versions that use variable beam and filter widths.

The computational results show that the beam search versions with a variable width are marginally superior to their fixed value counterparts, even when a lower average number of beam and filter nodes is used. The best results are given by the recovering beam search algorithms. For large problems, however, these procedures require excessive computation times. The priority beam search algorithms are much faster, and can therefore be used for the largest instances.

Scope and purpose

We consider the single machine weighted tardiness scheduling problem with sequence-dependent setups. In the current competitive environment, it is important that companies meet the shipping dates, as failure to do so can result in a significant loss of goodwill. The weighted tardiness criterion is a standard way of measuring compliance with the due dates. Also, the importance of sequence-dependent setups in practical applications has been established in several studies.

In this paper, we present several heuristics based on the beam search technique. In previous beam search implementations, fixed beam and filter widths have been used. We consider the usual fixed width algorithms, and also develop new versions with variable beam and filter widths.

The computational tests show that the beam search versions with a variable width are marginally superior to their fixed value counterparts. The recovering beam search procedures are the heuristic of choice for small and medium size instances, but require excessive computation times for large problems. The priority beam search algorithm is the fastest of the beam search heuristics, and can be used for the largest instances.

Keywords: Scheduling; Weighted tardiness; Sequence-dependent setups; Beam search

1. Introduction

In this paper, we consider the single machine weighted tardiness scheduling problem with sequence-dependent setups. Formally, this problem can be stated as follows. A set of n jobs $\{J_1, J_2, \ldots, J_n\}$ has to be scheduled without

* Corresponding author. Tel.: +351 22 557 11 00; fax: +351 22 550 50 50.
E-mail address: jvalente@fep.up.pt (J.M.S. Valente).

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preemption on a single machine that can handle at most one job at a time. The machine and the jobs are assumed to be continuously available from time zero onwards. Job J_j, $j = 1, 2, \ldots, n$, requires a processing time p_j, and has a due date d_j and a positive weight or penalty w_j. The weight w_j may represent rush shipping costs that are incurred when an order is overdue, or even a contractual penalty for late delivery. This weight can also be associated with the importance of a specific customer to the company, as well as with a loss of goodwill and future lost sales.

For any given schedule, the tardiness of J_j is defined as $T_j = \max\{0, C_j - d_j\}$, where C_j is the completion time of J_j. If job J_j is processed immediately after job J_i, a setup time s_{ij} is incurred. The setup times are therefore sequence-dependent, since they depend on both the job that is to be processed next, and the job that precedes it. If job J_j is processed first, it is assumed that it requires a setup time s_{0j}. The objective is then to find a sequence that minimizes the total weighted tardiness $\sum_{j=1}^{n} w_j T_j$.

In the current competitive environment, it is important that companies meet the shipping dates submitted to their costumers, as failure can result in rush shipping costs, lost sales and a significant loss of goodwill. The weighted tardiness criterion has been a standard way of measuring compliance with the due dates. Several studies have also established the importance of sequence-dependent setups in practical applications. Wilbrecht and Prescott [1] point out that sequence-dependent setups are important when a job shop is operated at or near full capacity. In a survey of industrial managers, Panwalkar et al. [2] found that approximately three quarters of the managers reported that at least some operations required sequence-dependent setup times, while about 15% reported that all the operations they scheduled involved sequence-dependent setups. Wortman [3] emphasized the importance of explicitly considering sequence-dependent setups for an appropriate management of the production capacity.

The single machine weighted tardiness scheduling problem with sequence-dependent setups is strongly NP-hard, since it is a generalization of weighted tardiness scheduling [4]. The problem with sequence-dependent setups has been previously considered by Raman et al. [5] and Lee et al. [6]. Raman et al. presented a dispatching heuristic. Lee et al. proposed a three-phase heuristic solution procedure. In the first phase, some instance statistics are calculated. The second phase uses the Apparent Tardiness Cost with Setups (ATCS) dispatching procedure to schedule the jobs. The parameters required by this dispatching rule are calculated using the results of the first phase. Finally, an improvement procedure is used to improve the schedule obtained in the second phase. The computational results showed that the ATCS heuristic outperformed the dispatching rule proposed by Raman et al. [5]. The ATCS heuristic was adapted for the problem with identical parallel machines by Lee and Pinedo [7].

A survey of machine scheduling problems involving setup considerations is given by Allahverdi et al. [8]. Potts and Kovalyov [9] review the literature on problems that integrate scheduling and batching decisions. This literature review includes some scheduling problems with setup times, more specifically scheduling models with job families. The single machine total weighted tardiness problem with no setups has received considerable attention. A recent survey of the state of the art in weighted and unweighted tardiness scheduling can be found in [10].

In this paper, we present several heuristic algorithms based on the beam search technique. These algorithms include the classic beam search procedures, with both priority and total cost evaluation functions, as well as the more recent filtered and recovering variants. Previous implementations of the beam search approach use fixed beam and filter widths. We consider the usual fixed width algorithms, and also develop new versions that use variable beam and filter widths. In these versions, the number of beam or filter nodes is determined at each level of the search tree, based on the quality of the competing nodes. The proposed algorithms are compared with the three-phase heuristic solution procedure presented by Lee et al. [6].

The remainder of the paper is organized as follows. In Section 2, we describe the beam search approach and its several variations. The fixed and variable width alternatives are discussed in Section 3. The proposed heuristic procedures and their implementation details are presented in Section 4. The computational results are reported in Section 5, and some concluding remarks are given in Section 6.

2. The beam search approach

Beam search is a heuristic method for solving combinatorial optimization problems that consists in an adaptation of the branch-and-bound algorithm (for a description of the branch-and-bound algorithm for scheduling problems, see for instance Brucker [11]). In the beam search method, only the most promising nodes at each level of the search tree are retained for further branching, while the remaining nodes are pruned off permanently. Since only a few nodes are