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ScienceDirect
Computers & Operations Research 36 (2009) 325–328
computers & operations research
www.elsevier.com/locate/cor

A note: Common due date assignment for a single machine scheduling with the rate-modifying activity

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Available online 10 October 2007

Abstract

In this paper we study the single machine common due date assignment and scheduling problem with the possibility to perform a rate-modifying activity (RMA) for changing the processing times of the jobs following this activity. The objective is to minimize the total weighted sum of earliness, tardiness and due date costs. Placing the RMA to some position in the schedule can decrease the objective function value. Several properties of the problem are considered which in some cases can reduce the complexity of the solution algorithm.
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Keywords: Single machine scheduling; Common due date assignment; Earliness; Tardiness; Rate-modifying activity

1. Introduction

Scheduling problems with due date assignment decisions have received considerable attention due to the introduction of just-in-time concepts in modern manufacturing, logistics and supply chains. Among the scheduling problems considered within the just-in-time concept there are problems in which all the jobs have to be completed as close as possible to a common due date [1,2]. Such models correspond to systems in which, for some reason (appointment, technical constraints, etc.), several tasks are to be completed at the same time: for instance, in a shop several jobs form an order by a single customer, or the components of the product should be ready by the time of assembly. In food industry, the common due date model applies if some of the involved components have a limited life time (a "best before" time) and that determines a due date for the final product.

In many instances, the situation can be modeled by a single machine scheduling problem of minimizing earliness–tardiness and assignable common due date costs. In such a model, the decision maker not only takes sequencing and scheduling decisions, but also determines the optimal values of controllable parameters that specify the due date and the processing times of the jobs. Sometimes, in the situation of repairing or upgrading the machine, a *rate-modifying activity* (RMA) can be applied to the machine so as to change (usually to decrease) the processing times of the jobs. The time p_j of processing job j changes after the RMA to $\delta_j p_j$.

Panwalkar et al. [3] were the first to consider the common due date assignment in a single machine scheduling and to provide a polynomial-time algorithm for solving the problem. Lee and Leon [4] consider several problems of scheduling on a single machine with an RMA (minimizing makespan, flow-time, weighted flow-time and maximum

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0305-0548/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.cor.2007.10.008

lateness). In the paper on new results with rate modifications, Mosheiov and Sidney [5] study problems of minimizing makespan with precedence relations, minimizing makespan with learning effect and minimizing the number of tardy jobs.

In a recent paper, Mosheiov and Oron [6] address the problem of Panwalkar et al. with an RMA available and provide a polynomial-time algorithm to solve the problem for any $\delta_j > 0$. In our paper we consider several useful properties of this problem which allow us to reduce the runtime for solving some cases of the problem with $0 < \delta_j \leqslant 1$.

2. Scheduling with an RMA

Consider a scheduling situation when n jobs are to be processed on a single machine under the common due date d, which is to be assigned. Each job j, $j = 1, 2, \ldots, n$, becomes available at time zero and initially has a processing time p_j. Let C_j be the completion time of job j in a certain schedule s. Let $E_j = \max\{0, d - C_j\}$ and $T_j = \max\{0, C_j - d\}$ be earliness and tardiness of job j, respectively. There exists a possibility to perform an RMA with the duration t before some job. For each job j, let the positive value δ_j be a processing time modification coefficient. If job j is scheduled after the RMA then its processing time changes to $\delta_j p_j$. The objective is to determine a job schedule with the position of the RMA in it and assign a common due date to minimize

$$f(d, s) = \sum_{j=1}^{n} (\alpha E_j + \beta T_j + \gamma d),$$

where $\alpha > 0$, $\beta > 0$ and $\gamma > 0$ are earliness, tardiness and due date per unit penalties, respectively.

So, we have to find an optimal position m^* of the job before which the RMA is scheduled, an optimal schedule s^* of the jobs and an optimal due date d^* to minimize the total penalty $f(d, s)$.

Extending the standard scheme for the scheduling notation [7], we refer to our problem as

$$1|RMA, d_j := d| \sum (\alpha E_j + \beta T_j + \gamma d).$$

Mosheiov and Oron [6] consider the common due date assignment and scheduling problem $1|RMA, d_j := d| \sum (\alpha E_j + \beta T_j + \gamma d)$ and propose an $O(n^4)$ algorithm for solving this problem in the case that $\delta_j > 0$. The idea of the algorithm is the following. The problem is modeled as a *bipartite matching problem* which is solved for a given location of the RMA by the *Hungarian Method*. Placing the RMA at each of n possible positions and solving each of the corresponding problems in $O(n^3)$ time give a runtime of $O(n^4)$ for the algorithm.

3. Properties of an optimal schedule

We restrict the value of δ_j by $0 < \delta_j \leqslant 1$, which is natural for the maintenance operations, and prove properties which can reduce the runtime of the algorithm [6] in some cases of the problem.

Let $[j]$ denote the job in the position j. Panwalkar et al. [3] show that an optimal due date coincides with the completion time of some job, i.e., $d^* = C_{[K]}$, and provide the following formula for the optimal due date position K:

$$K := \lceil n(\beta - \gamma)/(\alpha + \beta) \rceil.$$

As shown in [6], this formula is also valid for the problem with an RMA.

The following lemma can be easily proved by interchanging adjacent jobs.

Lemma 1. *If in an optimal schedule the RMA is placed just before the job in position m and $m > K$, then in the sequence corresponding to the optimal schedule the jobs are in LPT order before the position $K + 1$ and in SPT order in all other positions, i.e., in positions j with $K < j < m$ and $m \leqslant j \leqslant n$.*

Here SPT (and, respectively, LPT) stands for *shortest* (and *longest*) *processing time*. Notice that for the jobs in positions j, $m \leqslant j \leqslant n$, the SPT order is considered with respect to $\delta_j p_j$; it can happen that $p_{[m-1]} > p_{[m]}$ and $p_{[m-1]} > \delta_{[m]} p_{[m]}$.

Placing the RMA at the end of a schedule (in other words, just before the position $n + 1$) means that the RMA is not scheduled at all.

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