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Single machine group scheduling with time dependent processing times and ready times

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ABSTRACT

In this paper we investigate a single machine scheduling problem with time dependent processing times and group technology (GT) assumption. By time dependent processing times and group technology assumption, we mean that the group setup times and job processing times are both increasing functions of their starting times, i.e., group setup times and job processing times are both described by function which is proportional to a linear function of time. We attempt to minimize the makespan with ready times of the jobs. We show that the problem can be solved in polynomial time when start time dependent processing times and group technology are considered simultaneously.

1. Introduction

Traditional scheduling problems usually involve jobs with constant, independent processing times (Janiak et al. [12], Wang and Wei [30]). In practice, however, we often encounter settings in which the job processing times vary with learning effect (Cheng et al. [5,6], Lee et al. [18,19], Rudek [21], Sun et al. [22,23], Wang et al. [31], Wu et al. [35], Yeh et al. [40], Yin et al. [41]) and deterioration effect (Alidaee and Womer [1], Cheng et al. [2] and Gawiejnowicz [7]). Scheduling problems involving deterioration effect (time dependent processing times) appears, e.g., in scheduling maintenance jobs, steel production, national defense, emergency medicine or cleaning assignments, where any delay in processing a job is penalized by incurring additional time for accomplishing the job. Extensive surveys of different scheduling models and problems involving jobs with start time dependent processing times can be found in Alidaee and Womer [1], Cheng et al. [2] and Gawiejnowicz [7]. More recent papers which have considered scheduling jobs with deterioration effects include Cheng et al. [3,4], Gawiejnowicz [8], Gawiejnowicz et al. [9], Hsu et al. [11], Janiak and Kovalyov [13], Kang and Ng [15], Lee et al. [17], Wang [24], Wang et al. [25–28], Wang and Sun [29], Wei and Wang [33], Wu and Lee [34], Wu et al. [36–38], Yang and Wang [39], Yin et al. [42], and Xu et al. [43].

On the other hand, many manufacturers have implemented the concept of group technology (GT) in order to reduce setup costs, lead times, work-in-process inventory costs, and material handling costs. In GT scheduling, it is conventional to schedule continuously all jobs from the same group. Group technology that groups similar products into families helps increase the efficiency of operations and decrease the requirement of facilities (Janiak et al. [14], Liaee and Emmons [16], Potts and Van Wassenhove [20], Webster and Baker [32]).

It is natural to study the situations where scheduling with group technology and start time dependent processing times (time-dependent scheduling) are combined. For the case of the setup time of each group is a fixed constant: Wang et al. [27]

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considered single machine group scheduling in which the actual processing time of a job is a general linear decreasing function of its starting time. For the makespan minimization problem and total completion time minimization problem they showed that some problems can be solved in polynomial time. Wang et al. [25] and Xu et al. [43] considered the single machine scheduling problems with group technology and release times. Wang et al. [25] considered a simple linear deterioration function and Xu et al. [43] considered a proportional linear deterioration function.

For the case of the setup time of each group is a linear deterioration function of its starting time: Since longer setup or preparation might be necessary as food quality deteriorates or a patient's condition worsens, Wu et al. [37] considered a situation where the setup time groups and jobs in each group deteriorate as they wait for processing, i.e., group setup times and job processing times are both described by a simple linear deterioration function. They proved that the single machine makespan minimization problem and the total completion time minimization problem can be solved in polynomial time. Wang et al. [28] considered single machine scheduling where group setup times and processing times of jobs are both described by a proportional linear deterioration function. For the makespan and the total completion time minimization problems, they proposed a polynomial time solution, respectively. Wu and Lee [34] considered a situation where group setup times and job processing times are both described by a linear deterioration function. They showed that the makespan minimization problem remain polynomially solvable. For the sum of completion times problem, they showed that the problem remains polynomially solvable for a special case. Wang et al. [26] considered a situation where the group setup times and processing times of jobs are both described by a general linear deterioration function. They proved that the single machine makespan minimization problem can be solved in polynomial time.

In reality, longer setup or preparation might be necessary as food quality deteriorates or a patient's condition worsens. In this paper, we consider the single machine scheduling with ready times of the jobs under the group technology assumption and starting time-dependent setup times. The remaining part of the paper is organized as follows. In the next section, a precise formulation of the problem is given. The problem of minimization of the makespan is given in the Section 3. The last section contains some conclusions.

2. Problem formulation

The single machine group scheduling problem with group setup times can be stated as follows: We consider n non-preemptive jobs to be grouped into m groups and to be processed on a single machine. The jobs in the same group are consecutively processed and a setup time is required if the machine switches from one group to another and all setup times of groups for processing at time $t_0 > 0$. Let J_{ij} denote the jth job in group G_i, $i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n_i$, $r_{ij} > 0$ denote the ready (arrival) time of job J_{ij}, where n_i denotes the number of jobs belonging to group G_i (i.e., $n_1 + n_2 + \ldots + n_m = n$). As in Wang et al. [28], we consider the following proportional deterioration model, i.e., the actual processing time of job J_{ij} is

$$p_{ij} = \alpha_{ij}(a + bt),$$

where α_{ij} is the deterioration rate of job J_{ij} and t is its starting time. As in the above proportional model, we also assume that the setup time of group G_i is a proportional deterioration model, i.e., the actual setup time of group G_i is

$$s_i = \delta_i(a + bt),$$

where δ_i is the deterioration rate of the group G_i. Our objective is to find the optimal group sequence and the optimal job sequence within each group to minimize the maximum completion time of all jobs, i.e., the makespan.

For a given schedule π, let $C_{ij} = C_{ij}(\pi)$ denote the completion time of job J_{ij}, and $C_{\max} = \max\{C_{ij} | i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n_i\}$ represent the makespan of a given schedule. Using the three-field notation schema in scheduling problems (Graham et al. [10]) the makespan minimization problem is denoted as $1|r_j,\ p_{ij} = \alpha_{ij}(a + bt),\ s_i = \delta_i(a + bt),\ GT|C_{\max}$.

3. The makespan minimization problem

In the following section, we will prove that the single machine makespan minimization scheduling problem with deteriorating jobs and ready times of the jobs is polynomially solvable.

Lemma 1. *For the problem $1|r_j,\ p_j = \alpha_j(a + bt)|C_{\max}$, the optimal job sequence can be obtained by sequencing the jobs in the nondecreasing order of r_j.*

Proof. Suppose that $\pi = [S_1, J_i, J_j, S_2]$ and $\pi' = [S_1, J_j, J_i, S_2]$ are two job sequences, where S_1 and S_2 denote a partial sequence (note that S_1 and S_2 may be empty) and the difference between π and π' is a pairwise interchange of two adjacent jobs J_i and J_j. In addition, denote by A as the completion time of the last job of S_1 in sequence π (π'). Then the completion times of jobs J_i and J_j under π are

$$C_i(\pi) = \max\{A, r_i\} + \alpha_i(a + b\max\{A, r_i\}) = \max\left\{\left(A + \frac{a}{b}\right)(1 + b\alpha_i), \left(r_i + \frac{a}{b}\right)(1 + b\alpha_i)\right\} - \frac{a}{b} \quad (1)$$