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Minimizing the total completion time in single-machine scheduling with aging/deteriorating effects and deteriorating maintenance activities

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ABSTRACT

In a real manufacturing system, a machine may need multiple maintenance activities to improve its production efficiency due to the effects of aging or deteriorating. This paper considers scheduling with aging or deteriorating effects and deteriorating maintenance activities simultaneously on a single machine. We assume that the machine may be subject to several maintenance activities during the planning horizon. However, due to the restriction of budget of maintenance, the upper bound of the maintenance frequency on the machine is assumed to be known in advance. Moreover, we assume that the duration of each maintenance activity depends on the running time of the machine. The objective is to find jointly the optimal maintenance frequencies, the optimal maintenance positions, and the optimal job sequence for minimizing the total completion time. We show that all the problems studied are polynomially solvable.

1. Introduction

Most production scheduling assumes that a machine is continuously available during the planning horizon. However, in a real production system, the machine may not be available because of preventive maintenance, tool changes, or breakdowns. Scheduling with maintenance to improve the machine's efficiency has received increasing attention in the last two decades. During the maintenance, the machine is unavailable for processing jobs. This problem has been classified as machine scheduling with availability constraint. For a complete list of studies, the reader may refer to the comprehensive surveys by Schmidt [1] and Ma et al. [2].

Due to the practical experience in production systems, scheduling with considerations of the learning, aging, or deteriorating effects has been one of the most popular topics among researchers in recent years. The actual processing times of jobs may vary due to the learning, aging, or deteriorating effects. For details on this stream of research, the reader may refer to the comprehensive surveys by Alidaee and Womer [3], Cheng et al. [4], Bachman and Janiak [5], Janiak and Kovalyov [6], Janiak and Rudek [7], Biskup [8], Janiak and Rudek [9], and the recent book by Gawiejnowicz [10].

Additionally, in order to model a more realistic manufacturing setting, several studies have considered the aging or deteriorating effect and maintenance simultaneously in scheduling problems. Wu and Lee [11] studied a single-machine scheduling with an availability constraint under linearly deteriorating jobs and a resumable condition. The aim was to find an optimal schedule for minimizing the makespan. Ji et al. [12] investigated the same problem as was proposed by Wu and Lee [11] under a non-resumable condition with the objectives of minimizing the makespan and the total completion time. Lee and Wu [13] further studied multi-machine scheduling problems with deteriorating jobs and an availability

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constraint. Both the resumable and the non-resumable cases were studied with the objective of minimizing the makespan. Low et al. [14] considered a single-machine scheduling with an availability constraint to minimize the makespan under a simple linear deteriorating assumption. Lodree and Geiger [15] explored a single-machine scheduling with time-dependent processing times and a rate-modifying activity. The aim was to derive the optimal policy for assigning the rate-modifying activity in a sequence to minimize the makespan. Gawiejnowicz and Kononov [16] studied a single-machine scheduling with simultaneous considerations of time-dependent deteriorating jobs and availability constraint in a resumable situation to minimize the makespan. Yang et al. [17] investigated a due-window assignment scheduling problem on a single machine under a job-dependent aging effect and maintenance activity considerations simultaneously. The goal was to find jointly the optimal maintenance position, the optimal due-window position, and the optimal job sequence to minimize a total cost function.

Those papers which consider scheduling problems with the aging or deteriorating effect and the maintenance activity assumed that at most one maintenance activity is undertaken on each machine throughout the planning horizon. However, in a real production setting, a machine may need to be maintained more than once to improve its production efficiency. Therefore, a more realistic machine scheduling model should be taken into consideration associated with multiple maintenance activities for a machine. However, research on scheduling with simultaneous considerations of aging or deteriorating effects and multiple maintenance activities has not been studied until recently. Gawiejnowicz [18] considered two problems of scheduling a set of independent, non-preemptive and proportionally deteriorating jobs on a single machine, with constraints on availability of the machine or jobs. The objective was to minimize the makespan. Kuo and Yang [19] investigated a single-machine scheduling with a cyclic process of aging effects and multiple maintenance activities. They stressed the makespan problem with job-independent and position-dependent aging effects, respectively. Later, Zhao and Tang [20] extended the study of Kuo and Yang [19] to the case with job-dependent aging effects. Yang and Yang [21] studied a single-machine scheduling with the job-dependent aging effects under multiple maintenance activities and variable maintenance duration considerations simultaneously to minimize the makespan.

To the best of our knowledge, however, the scheduling with simultaneous considerations of aging or deteriorating effects and multiple maintenance activities for minimizing the total completion time has never been explored. Furthermore, apart from Kubzin and Strusevich [22,23], Mosheiov and Sidney [24], Yang et al. [17], and Yang and Yang [21], scheduling with variable maintenance duration has rarely been studied. In a real manufacturing system, however, the machine maintenance duration may depend on the running time of the machine in that the later maintenance activity is performed, the worse the machine conditions are, and a longer time is needed to perform the maintenance activity. This kind of maintenance activity can be considered as a deteriorating maintenance activity.

Consequently, this paper considers the scheduling with aging or deteriorating effects and multiple maintenance activities simultaneously on a single machine. The upper bound of the maintenance frequency on the machine due to the restriction of budget of maintenance is assumed to be known in advance. In addition, we assume that the duration of each maintenance activity depends on the running time of the machine. The objective is to find jointly the optimal maintenance frequencies, the optimal maintenance positions, and the optimal job sequence for minimizing the total completion time. We will show that all the problems studied can be optimally solved using polynomial time algorithms.

The remainder of this paper is organized as follows. In Section 2, we formulate the problems under study. In Section 3, we present several important preliminary properties if there is no maintenance scheduled in the sequence. In Section 4, we provide polynomial time solutions for all the problems studied. We conclude with the findings in the last section.

2. Problem formulation

The problem considered in this study can be formally described as follows: There are n independent jobs to be processed on a single machine. All the jobs are available simultaneously at time zero and preemption of jobs is not allowed. Due to the aging or deteriorating effects, maintenance may be performed on the machine to improve its production efficiency. In order to model a realistic manufacturing system, the machine may be subject to several maintenance activities during the planning horizon. We assume that the duration of each maintenance activity is a linear function of the running time of the machine and is denoted by $m_i = \alpha + \beta t_i$, where $\alpha > 0$ is the basic time of maintenance activity, $\beta \geq 0$ is the deteriorating maintenance factor, and t_i is the running time of the machine between the $(i-1)$th and ith maintenance activities of the machine. We further assume that a maintenance activity can be scheduled immediately after completing the processing of any job. After maintenance, the machine reverts to its initial condition and the aging or deteriorating effect starts anew.

The upper bound of the maintenance frequency on the machine due to the restriction of budget of maintenance is assumed to be known in advance. We denote by k_0 the upper bound of the maintenance frequency on the machine. Observe that $k_0 \leq (n-1)$. Moreover, we denote by k the maintenance frequency on the machine, where $k \leq k_0$. If the machine is subject to k times of maintenance, then there are $(k+1)$ groups of jobs in the job sequence. Let $G_1, G_2, \ldots, G_{k+1}$ denote the groups of jobs in the schedule. Then the group of jobs and maintenance sequence can be denoted as $\Pi = (G_1, M_1, G_2, M_2, \ldots, G_k, M_k, G_{k+1})$, where M_i represents the ith maintenance activity. Following Mosheiov [25], we denote by $P(n, k+1) = (n_1, n_2, \ldots, n_{k+1})$ the allocation vector of the number of jobs in each group, where $n_i \geq 1$ is the number of jobs in group G_i and $\sum_{i=1}^{k+1} n_i = n$. For a certain schedule, we denote by C_j and $\sum C_j$ the completion time of job j and the total completion time, for $j = 1, 2, \ldots, n$, respectively.