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Total tardiness minimization in permutation flowshop with deterioration consideration

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ABSTRACT

In this paper, we consider a permutation flowshop scheduling problem with deteriorating jobs. The objective is to minimize the total tardiness of all jobs. A branch-and-bound algorithm incorporating with a dominance property and a lower bound is developed. Furthermore, two metaheuristic algorithms, the simulated annealing algorithm, and the particle swarm optimization method, are proposed. Finally, computational studies are given.

1. Introduction

The job processing times are assumed to be known and fixed in classical scheduling. This assumption, however, might not be suitable in many realistic industrial processes. For example, the time to do the cleaning assignments increases if it is processed at a later time. Alidaee and Womer [1], Cheng et al. [2], and Gawiejnowicz [3] provided the surveys of deteriorating jobs.

Recently, Li et al. [4] considered the total absolute differences in completion times on a single machine. They showed that the optimal schedule is V-shaped. They provided some properties of an optimal schedule, and proposed two heuristic algorithms for the problem. Zhao and Tang [5] considered a single machine due-window assignment problem. Cheng et al. [6] proposed a deterioration model and derived the solutions for some single machine problems. Toksari [7] considered the makespan problem with learning and deterioration effects and unequal release times on a single machine. They established a branch-and-bound and a heuristic algorithm to seek for the optimal and near-optimal solutions. Cheng et al. [8] studied a single machine scheduling problem with deteriorating jobs and the setup time. They proposed a branch-and-bound algorithm for the maximum tardiness problem. Gawiejnowicz and Kononov [9] considered the single-machine makespan problem. They assumed that the machine has non-availability periods in which the time of each period are known. They proved that the problem with a single non-availability period is ordinarily NP-complete. Zhao and Tang [10] considered deteriorating jobs scheduling with two types of disruption. Ji and Cheng [11] considered a single machine problem with an availability constraint where the jobs are resumable. They showed that the makespan problem is NP-hard in the ordinary sense. Rudek and Rudek [12] studied some single-machine scheduling problems with the aging effect, in which the processing time of the job is given as a non-decreasing function of the machine wear. Liu et al. [13] proposed a heuristic algorithm for the parallel machine scheduling problem with deteriorating jobs. Rudek et al. [14] considered multiprocessor scheduling

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problems, where each job must be executed simultaneously by the specified number of processors. Cheng et al. [15] studied a single-machine scheduling problem for assigning the common due-window, in which the deteriorating jobs and the maintenance activity are considered. Bai et al. [16] considered the group scheduling problems with deterioration and learning effects on a single machine. Wang and Wang [17] studied the single-machine scheduling problems to minimize the makespan and the total completion time, in which the precedence constraints and position-dependent processing times are considered. Wei et al. [18] showed some single-machine scheduling problems remain polynomial solvable if the processing time of a job is a function of its starting times and its resource allocation.

Most of the research with deteriorating jobs focuses on single-machine problems. Often, jobs consist number of operations to be done serially in many manufacturing systems [19–23]. The deteriorating jobs scheduling is relatively unexplored in the flowshop environment. Wang and Xia [24] addressed no-wait or no-idle flow shop scheduling problems. They showed that the problems to minimize makespan or weighted sum of completion time are more complicated than the classical ones. Lee et al. [25] considered the total completion time problem on permutation flowshop environment. Wang and Liu [26] considered the two-machine total completion time problem. They derived the optimal solution for some special cases, provided a branch-and-bound and a heuristic algorithm for the general case. Sun et al. [27] studied the permutation flow shop scheduling problems on no-idle dominant machines. They provided the optimal solutions for the makespan and the total completion time problems. Lee et al. [28] studied a two-machine flowshop problem with blocking where the objective is to minimize the makespan. Rudek [29] studied a two-machine flowshop makespan problem with learning consideration, in which the computational complexity was proved. Ng et al. [30] considered a two-machine flowshop problem where the objective is to minimize the total completion time. They derived a branch-and-bound and a heuristic algorithm. Wang et al. [31] considered the makespan problem with a simple linear deterioration on a three-machine permutation flowshop. They derived the optimal solution for some special cases, and provided a branch-and-bound and a heuristic algorithm for the general case. Zhao and Tang [32] considered two types of precedence constraints in two-machine scheduling problems with deteriorating jobs. Bank et al. [33] proposed a branch-and-bound algorithm to minimize the total tardiness in two-machine flowshop environment, in which the processing time of a job depends on its waiting time.

In this paper, we consider a permutation flowshop total tardiness scheduling problem with the deterioration consideration. Recently, Vallada et al. [34] provided a comprehensive review of the heuristic algorithms. To the best of our knowledge, Kim [35] and Chung et al. [36] were among a few authors who studied the optimal schedules for the classical total tardiness problem. Lee and Chung [37] considered the total tardiness problem with learning effect. They proposed a branch-and bound algorithm which can solve problems with up to 18 jobs. In addition, they proposed a simulated annealing algorithm to obtain heuristic solutions. For more information about learning effect, reader can refer to Jaber [38]. In this paper, we develop a branch-and-bound and two meta-heuristic algorithms where jobs might deteriorate. The rest of the paper is organized as follows. In the next section we formulate the problem. In Section 3, we construct a branch-and-bound algorithm using an elimination rule and a lower bound. In Section 4, two heuristic algorithms are developed. In Section 5, computational experiments are conducted. A conclusion is given in the final section.

2. Problem description

There are a set of n jobs $J = \{J_1, ..., J_n\}$ to be processed on a set of m machines $M = \{M_1, ..., M_m\}$. Each job J_j has m operations $O_{1j}, O_{2j}, \ldots, O_{mj}$ where operation O_{ij} must be processed on machine M_i, $i = 1, 2, \ldots, m$. Operation $O_{i+1,j}$ can be processed only after operation O_{ij} is completed. In this paper, we consider the permutation flowshop case where the job sequence is the same in all the machines. The due date of J_j is d_j. The actual processing time p_{ij} of J_j on M_i is a function which depends on its starting time in a schedule, i.e.

$$p_{ij} = a_{ij} + b_i t, \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n,$$

where a_{ij} is the informal processing time, $b_i > 0$ is the job deterioration rate on M_i and t is its starting time.

For a given schedule S, let $C_{ij}(S)$ denote the completion time of job J_j on machine M_i, $T_j(S) = \max\{0, C_{mj}(S) - d_j\}$ denote the tardiness of J_j. Meanwhile, $C_{i[r]}(S) = (1 + b_i)\max\{C_{i[r-1]}(S), C_{i-1[r]}(S)\} + a_{ij}$ denote the completion time of job J_j if it is scheduled in the rth position on M_i, and $T_{[r]}(S)$ denote the tardiness of the job scheduled in the rth position. The objective is to find a schedule that minimizes the total tardiness of all jobs. That is, we want to find a schedule S^* such that $\sum T_j(S^*) \leqslant \sum T_j(S)$ for any schedule S.

3. A branch-and-bound algorithm

The classical total tardiness problem in the permutation flowshop is known to be NP-hard [22]. In this section, we will provide a branch-and-bound algorithm to derive the optimal solution.

3.1. Dominance property

Chung et al. [36] presented a dominance property for the classical total tardiness problem. In this subsection, we derive the result with the deterioration effect [36].