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A single-machine scheduling with a truncated linear deterioration and ready times

Chin-Chia Wu [a], Wen-Hsiang Wu [b], Wen-Hung Wu [c], Peng-Hsiang Hsu [c], Yunqiang Yin [d,*], Jianyou Xu [e]

[a] Department of Statistics, Feng Chia University, Taichung, Taiwan
[b] Department of Healthcare Management, Yuanpei University, Hsinchu, Taiwan
[c] Department of Business Administration, Kang-Ning Junior College, Taipei, Taiwan
[d] School of Sciences, East China Institute of Technology, Fuzhou, Jiangxi 344000, China
[e] College of Information Science and Engineering, Northeastern University, Shenyang 110819, China

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ABSTRACT

Recently, machine scheduling problems with deteriorating jobs have received interestingly attention from the scheduling research community. Majority of the research assumed that the actual job processing time is an increasing function of its starting time. However, no job can remain undeteriorated indefinitely in real life situations. This paper considers a single-machine scheduling problem with a truncated linear deteriorating effect and ready times. By the truncated linear deteriorating effect, it means that the actual processing time of a job is a function of its starting time and a control parameter. The objective is to minimize the makespan. A mixed integer programming model and a branch-and-bound algorithm coupled with several dominance properties and two lower bounds are developed to search for the optimal solution. In addition, an ant colony and a Tabu search algorithm where each is refined by the three improvements are also proposed for a near-optimal solution, respectively. A computational experiment is then conducted to evaluate the impacts of the used parameters on the performances of the proposed algorithms.

1. Introduction

In many real-life production settings a job processed later usually takes more time than when it is processed earlier. For instance, such a problem arises in steel production, where ingot batches must be preheated by gas to the required temperature in soaking pits before they can be hot-rolled by a blooming mill (critical machine) [16,20]. In these cases, accomplishing a task might need more time as time passes along. Scheduling in such settings is known as ‘‘scheduling deteriorating jobs’’ or ‘‘time-dependent scheduling’’.

Gupta and Gupta [16] and Browne and Yechiali [3] independently initiated the research on scheduling with deteriorating jobs or time-dependent processing times. Since then, machine scheduling problems with time-dependent processing times have received considerable interest in the scheduling research community. For example, Sundararaghavan and Kunnathur [27] proposed optimal and heuristic algorithms to minimize the makespan and the total weighted completion time, respectively. Chen [4] considered a single-processor scheduling model where the execution time of a task is a linearly decreasing function of its starting time, and presented an $O(n^2)$-time dynamic programming algorithm to minimize the number of late

* Corresponding author.
E-mail address: yunqiangyin@gmail.com (Y. Yin).

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tasks. Cheng and Ding [7] considered a family of scheduling problems for a set of start-time-dependent tasks with release times and linearly increasing/decreasing processing rates on a single machine to minimize the makespan. Bachman et al. [2] proved that minimizing the total weighted completion time is NP-hard when the processing time is a linear function. Ng et al. [23] investigated three proposed single-machine scheduling problems with deteriorating jobs where their objective function was to minimize the total completion time. Cheng and Ding [8] proposed a piecewise-linear model where each job was assumed to have a normal processing time, but to be deteriorated as a step function when its starting time is beyond a given deterioration date. Cheng et al. [9] addressed a set of non-preemptive jobs on single- or multi-machines scheduling problems without idle times where the processing time of a job was modeled as a piecewise non-increasing function of its start time. Cheng and Ding [10] showed the feasibility for several single-machine time-dependent-processing scheduling problems under the assumption that deadlines, processing rates and identical initial processing times were known. Wu et al. [32] proposed optimal and near-optimal solutions for a single-machine deterioration job problem where the objective function was to minimize the total weighted completion time. Wang et al. [28] provided the optimal and near-optimal solutions for the total completion time problem in a two-machine flow shop. Moreover, under dominating-machine assumption, Wang and Xia [29] showed that the problems to minimize the makespan or total weighted completion time was still polynomially solvable. Wang et al. [30] considered single-machine scheduling problems with deteriorating jobs which were related by a series–parallel graph.

In addition, Shiau et al. [26] proposed a branch-and-bound and heuristic algorithm for a two-machine linear deterioration flowshop problem where the objective was to minimize the mean flow time. Moreover, Wang et al. [31] showed that single-machine group scheduling problems were polynomially solvable where the objectives were to minimize the makespan and the total completion time under the model specified by $p_{ij}(t) = a_{ij} - b_{ij}t$. For more applications, we refer the reader to Alidaee and Womer [1] and Cheng et al. [6], and Gawiejnowicz [15].

It is noted that the majority of the research assumed that the actual processing time of a job is an increasing function of its starting time. However, no job can remain undeteriorated indefinitely in real-life situations. For example, a set of ingots has to be produced in a steel mill. After being heated in a blast furnace, ingot liquid metal is poured into steel ladles and next into ingot moulds, where it solidifies. After the ingot stripper process, the ingots are segregated into batches and transported into the soaking pits, where they are preheated up to a certain temperature. Finally, the ingots are hot-rolled on a blooming mill. If the temperature ingot, while waiting in a buffer between the furnace and the rolling machine, has dropped below a certain degree, then the ingot needs to be reheated to the temperature required for rolling (see Kunnathur and Gupta [22], Ng et al. [23], and Rinnooy Kan [25]) where "the rolling machine has dropped below a certain degree" means the deteriorating effect with a limit. This case motivates a consideration of the deteriorating effect with an upper limit. Janiak [19] also pointed out that in many industries in steel and copper plants there are problems of sequencing jobs on machines with simultaneous allocation of constrained resources. In many such production processes, there usually has only one critical machine, for example, a very expensive one, on which processing sequencing jobs is essential. Another motivation is inspired by the observation that there is a drawback in the linear deteriorating effect model, i.e. $p^A_{jt} = p_j(1 + bt)$, marked in blue color in Cheng and Ding [7]. That is, the actual processing time of a given job approaches to a huge value precipitously as a number of jobs increases. For example, given $n = 20$, starting time $t_0 = 0$, deteriorating effect $b = 0.02$, and the processing times and ready times of n jobs require 60 and zero, respectively. In addition, the control variable c and truncated parameter β were specified by 2 and 1950 based on the pretests. As shown in Fig. 1, the behavior of the actual job processing time is approaching a huge value as n increases. As a third motivation, Gawiejnowicz [15] pointed out that most heuristic algorithms for time-dependent scheduling problems constructed the final schedules in a step-by-step manner, but only a few authors proposed

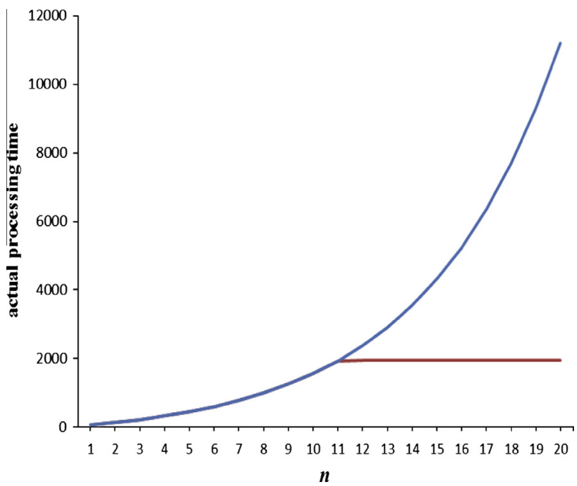

Fig. 1. The behavior of proposed model with or without a truncated parameter.