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Pareto optimization for the two-agent scheduling problems with linear non-increasing deterioration based on Internet of Things ☆

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HIGHLIGHTS

- We study two-agent scheduling problems with linear non-increasing deterioration.
- We solve two Pareto optimization scheduling problems in polynomial time.
- Experimentation results show the efficiency of the presented.

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ABSTRACT

The Internet of Things (IoT) enables these objects to collect and exchange data and it is an important character of smart city. Multi-agent scheduling is one necessary part of Internet of Things. In this paper, we investigate the Pareto optimization scheduling on a single machine with two competing agents and linear non-increasing deterioration, which is Multi-agent scheduling problems often occurred in the Internet of Things. In the scheduling setting, each of the two competing agents wants to optimize its own objective which depends on the completion times of its jobs only. The assumption of linear non-increasing deterioration means that the actual processing time of a job will decrease linearly with the starting time. The objective functions in consideration are the maximum earliness cost and the total earliness. Two Pareto optimization scheduling problems are studied in this paper. In the first problem, each agent has the maximum earliness cost as its objective function. In the second problem, one agent has the maximum earliness cost as its objective function and the other agent has the total earliness as its objective function. The goal of a Pareto optimization scheduling problem is to find all Pareto optimal points and, for each Pareto optimal point, a corresponding Pareto optimal schedule. In the literature, the two corresponding constrained optimization scheduling problems are solved in polynomial time under the assumption that the inverse cost function of each job is available. In this paper, we extend these results to the setting without the availability assumption. Furthermore, by estimating the number of Pareto optimal points, we show that the above two Pareto optimization scheduling problems are solved in polynomial time. Hence, our results have much more theoretically meaningful constructs. Experimentation results show that the algorithms presented in this paper are efficient.

1. Introduction

A smart city uses digital technologies or information and communication technologies (ICT) to enhance quality and performance of urban services, to reduce costs and resource consumption, and to engage more effectively and actively with its citizens. A smart city may also be more prepared to respond to challenges than one with a simple transactional relationship with its citizens. The Internet of Things (IoT) is the network of physical objects or things embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data. Internet of Things is an important character of smart city. So Internet of Things has great meaning for smart city. Two excellent comprehensive review papers about Internet of Things can be referred to Atzori et al. [1] and Zanella et al. [2]. Multi-agent scheduling is one

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necessary part of Internet of Things. In this paper, we investigate two Multi-agent scheduling problems and give thorough analysis.

Two-agent scheduling has received increasing attention in the last decade. In their pioneering research on two-agent scheduling, Baker and Smith [3] and Agnetis et al. [4] addressed the scheduling models in which two agents, each with a set of its own jobs, compete for the usage of shared processing resource and each agent has its own criterion to be minimized. The objective functions considered in their research included the maximum of regular functions (e.g., makespan or maximum lateness), the total (weighted) completion time, and the number of tardy jobs. Baker and Smith [3] focused on minimizing a linear combination of the objectives of the two agents on a single machine. Yuan et al. [5] followed the line and made some revision for the incorrect contents which occur in Bake and smith [3]. Agnetis et al. [4] studied the constrained optimization problem and the Pareto optimization problem on various machine settings. Ng et al. [6] considered the two-agent scheduling problem in which one agent wants to minimize the total completion time under the restriction that the number of the other agent's tardy jobs is bounded. Cheng et al. [7,8] and Agnetis et al. [9] extended the two-agent setting of Agnetis et al. [4] to the multi-agent setting and analyzed the complexity of the related problems they studied. Lee et al. [10] studied a multi-agent scheduling problem on a single machine in which each agent wants to minimize the total weighted completion time of its own jobs and presented a new standard to measure the objectives of all the agents. Wan et al. [11] considered the two-agent scheduling problems on one machine or two identical machines with controllable processing times for various objectives including the total completion time plus compression cost, the maximum tardiness plus compression cost, the maximum lateness plus compression cost and the total compression cost subject to deadline constraints. Leung et al. [12] studied a scheduling environment with $m \geq 1$ identical parallel-machines and two agents, and generalized the results of Agnetis et al. [4] by including the total tardiness objective, allowing for preemption, and considering jobs with different release dates. Mor and Mosheiov [13] studied the problem of minimizing maximum (or total weighted) earliness cost of one agent, subject to an upper bound on the maximum earliness cost of the other agent. Kovalyov et al. [14], Li and Yuan [15], and Fan et al. [16] investigated the two-agent scheduling problems on the serial-batching or parallel-batching model.

Scheduling with deterioration was first introduced by Gupta and Gupta [17] and Browne and Yechiali [18]. Since then, scheduling models with deteriorating jobs were growing rapidly and have been extensively studied from a variety of perspectives, such as [19–27]. Alidaee and Womer [28] and Cheng [29] gave comprehensive reviews for scheduling with deteriorating jobs. Liu et al. [30,31] discussed a new two-agent scheduling model with time-independent processing times. Liu et al. [32] studied the two-agent group scheduling problems with deterioration on a single machine. Wu et al. [33] considered a single-machine problem which has been proved to be strongly NP-hard in Ng et al. [6] with learning effects, where the objective is to minimize the total weighted completion time of jobs from the first agent under the condition that there is no tardy jobs of the second agent.

In this paper, we adopt the assumption of non-increasing deterioration introduced by Ho et al. [22]. In this scheduling model with deterioration, we have n jobs $J_1, J_2, \ldots, J_n$ to be scheduled in a single machine. Each job J_j has a normal processing time a_j. Set $a_{\min} = \min\{a_1, a_2, \ldots, a_n\}$ and let $k \geq 0$ be a constant so that $k(t_0 + \sum_{j=1}^{n} a_j - a_{\min}) < 1$, where t_0 is the required starting time of the first job in a schedule. Then, the actual processing time of each job J_j is given by $p_j = a_j(1 - kt)$, where t is the starting time of job J_j.

Under the above deteriorating model introduced by Ho et al. [22], Yin et al. [34] studied several single-machine two-agent scheduling problems to minimize earliness penalties. Their work is closely related to our research. Following the notations adopted in [34], we can formulate the single-machine two-agent scheduling with linear non-increasing deterioration as follows.

Two agents A and B, each with a set of nonpreemptive jobs, compete to processing its own jobs on a common machine in order to minimize its own objective function. Let $\mathcal{J}^A = \{J_1^A, J_2^A, \ldots, J_{n_A}^A\}$ and $\mathcal{J}^B = \{J_1^B, J_2^B, \ldots, J_{n_B}^B\}$ denote the job sets of agent A and agent B, respectively. $\mathcal{J}^A \cap \mathcal{J}^B = \emptyset$. Let $\mathcal{J} = \mathcal{J}^A \cup \mathcal{J}^B$ and $n = n_A + n_B$. For each $X \in \{A, B\}$, the jobs in $\mathcal{J}^X$ are called X-jobs. The normal processing time and due date of job J_j^X are denoted by a_j^X and d_j^X, $j = 1, 2, \ldots, n_X$, respectively. $a_{\min} = \min\{a_j^X : 1 \leq j \leq n_X, X \in \{A, B\}\}$ is used to denote the minimum value of the normal processing times of all jobs. All jobs are available at time 0 and a feasible schedule processes the jobs without overlap. Suppose that the first job starts at a time $t_0 \geq 0$ in a feasible schedule, we have a given constant k with $k(t_0 + \sum_{j=1}^{n} a_j - a_{\min}) < 1$. The actual processing time p_j^X of job J_j^X, which is a non-increasing linear function of its starting time, is given by

$$p_j^X = a_j^X(1 - kt), \quad j = 1, 2, \ldots, n_X,\ X \in \{A, B\},$$

where $t \geq t_0$ is the starting time of job J_j^X.

Generally, we must set a common deadline by which all the jobs have to be processed completely. Otherwise, we may trivially execute all the jobs sufficiently late to induce no earliness cost. Let D denote the common deadline of all the jobs with $D \geq \sum_{J_j^X \in \mathcal{J}} a_j^X$.

A feasible schedule is an assignment of starting times to the jobs of $\mathcal{J}$ in which there is no overlapping among the jobs of both agents. Let S be a feasible schedule of the jobs. We use $C_j^X(S)$ and $E_j^X(S)$ to denote the completion time and the earliness of job J_j^X in S, respectively. Then $E_j^X(S) = \max\{0, d_j^X - C_j^X(S)\}$. If there is no confusion, we simply write C_j^X and E_j^X for $C_j^X(S)$ and $E_j^X(S)$, respectively. Let $f_j^X(\cdot)$ be a nondecreasing function of the earliness of job J_j^X. Then, $f_{\max}^X = \max\{f_1^X(E_1^X), f_2^X(E_2^X), \ldots, f_{n_X}^X(E_{n_X}^X)\}$ is regarded as the maximum earliness cost of the agent $X \in \{A, B\}$.

Let f^A and f^B be the objective functions of agent A and agent B, respectively. By the three-field notation introduced by Graham et al. [35], together with the notation introduced by Agnetis et al. [4], the two constrained optimization scheduling problems can be denoted by

$$1|p_j^X = a_j^X(1 - kt)|f^A : f^B \leq U$$

and

$$1|p_j^X = a_j^X(1 - kt)|f^B : f^A \leq U,$$

and the Pareto optimization scheduling problem can be denoted by

$$1|p_j^X = a_j^X(1 - kt)|f^A \circ f^B.$$

The work in Yin et al. [34] related to our research can be summarized as follows.

- Under the assumption that the inverse function of $f_j^X(\cdot)$ is available for $X \in \{A, B\}$ and $1 \leq j \leq n_X$, Yin et al. [34] showed that, for problem $1|p_j^X = a_j^X(1 - kt)|f_{\max}^A : f_{\max}^B \leq U$, an optimal schedule can be obtained in $O(n_A^2 + n_B \log n_B)$ time, and an optimal and Pareto optimal schedule can be obtained in $O(n_A^2 + n_B^2)$ time.
- Under the assumption that the inverse function of $f_j^B(\cdot)$ is available for $1 \leq j \leq n_B$, Yin et al. [34] showed that, for problem $1|p_j^X = a_j^X(1 - kt), d_j^A = d^A|\sum E_j^A : f_{\max}^B \leq U$, an optimal schedule can be obtained in $O(n_A \log n_A + n_B \log n_B)$ time, and an optimal and Pareto optimal schedule can be obtained in $O(n_A \log n_A + n_B^2)$ time.

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