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Two-stage scheduling on identical machines with assignable delivery times to minimize the maximum delivery completion time

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ABSTRACT

In this paper, we consider the two-stage scheduling problem in which n jobs are first processed on m identical machines at a manufacturing facility and then delivered to their customers by one vehicle which can deliver one job at each shipment. In the problem, a set of n delivery times is given in advance, and in a schedule, the n delivery times should be assigned to the n jobs, respectively. The objective is to minimize the maximum delivery completion time, i.e., the time when all jobs are delivered to their respective customers and the vehicle returns to the facility. For this problem, we present a $\frac{3}{2}$-approximation algorithm and a polynomial-time approximation scheme.

1. Introduction

Since Maggu and Das [13] first studied the scheduling problem with delivery coordination, the topic has attracted increasing attention of the scheduling research community. In order to be competitive, storage costs have to be reduced for enterprises. That is, all jobs are needed to be transported as soon as possible to another machine for further processing or to their customers. Thus, it is important for industry manufacturers to coordinate job production and job delivery. According to the transportation function, the problems on this topic can be classified into two types (see Lee and Chen [9]). The first type (type-1) involves intermediate transportation of the unfinished jobs from one machine to another for further processing. The second type (type-2) involves outbound transportation of the finished jobs from the machine(s) to their customer(s). In this paper, we study the scheduling problem with type-2 transportation.

Potts [15] first studied the single machine scheduling problem with release dates and delivery times to minimize the maximum delivery completion time. In this problem, there is a sufficient number of vehicles so that each finished job can be delivered individually and immediately to its customer. A $\frac{3}{2}$-approximation algorithm was presented in [15] for the problem. Hall and Shmoys [6] presented two polynomial-time approximation schemes for the same problem. Woeginger [19] studied a similar problem in the parallel-machine environment in which the jobs have a common release date.

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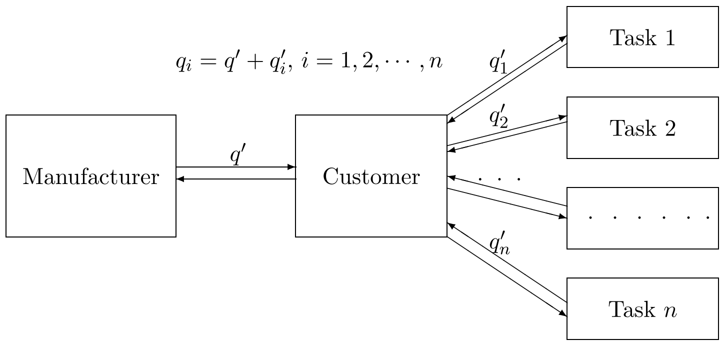

Fig. 1. The delivery structure of the studied scheduling problem.

Lee and Chen [9] studied several scheduling problems with type-2 transportation. In their problems, there are v vehicles with the same capacity c to transport all finished jobs. Soukhal et al. [17] and Yuan et al. [20] studied the two-machine flow-shop scheduling problem to minimize the maximum delivery completion time. They showed that the problem is binary NP-hard when $c = 2$ and is strongly NP-hard when $c \geq 3$ even if the jobs have the same processing time on the first machine and all jobs have the same transportation time. Lu et al. [12] considered the single-machine scheduling with release dates in which only a vehicle can be used to deliver all jobs to a single customer. They showed that the problem is strongly NP-hard for each fixed $c \geq 1$ and gave a heuristic with a tight worst-case performance ratio of $\frac{5}{3}$.

Chang and Lee [2] extended Lee and Chen's model in [9] and gave an algorithm with the worst-case performance ratio of $\frac{5}{3}$ by considering the situation where each job might occupy a different amount of physical space in a vehicle. He et al. [8] presented an improved approximation algorithm with the worst-case performance ratio of $\frac{53}{35}$. For the same problem, Lu and Yuan [10] provided a heuristic with the best-possible worst-case performance ratio of $\frac{3}{2}$. Lu and Yuan [11] also extended Chang and Lee's problem in [2] on an unbounded parallel-batch machine. They showed that the problem is strongly NP-hard and gave a heuristic with a worst-case performance ratio of $\frac{7}{4}$. For the scheduling problem on two parallel machines, Zhong et al. [21] presented an improved algorithm with the worst-case ratio of $\frac{5}{3}$ and Su et al. [18] proposed a heuristic with a worst-case performance ratio of $\frac{63}{40}$, except for two particular cases. Dong et al. [4] considered a two-machine open-shop problem with one customer. They gave two algorithms with worst-case performance ratios of 2 for the case $c \geq 2$ where each job might occupy a different amount of physical space and $\frac{3}{2}$ for the case $c = 1$, respectively. Chen et al. [3] presented a preemptive scheduling problem on identical machines, in which they showed that the problem is strongly NP-hard and gave an algorithm with the worst-case ratio of $\frac{3}{2}$. Pei et al. [14] investigated the setting in which the jobs are first processed in serial batches on a bounded serial batching machine at the manufacturer's site and then the batches are delivered to a customer by a single vehicle with limited capacity during the transportation stage, where the actual job processing time is a linear function of its starting time.

Scheduling under the assumption of *generalized due dates* (GDD) was first introduced by Hall [7]. Under the GDD assumption, there are n jobs and n due dates given in advance, but each due date does not belong to a specific job. In a schedule, the n due dates are assigned to the jobs in the way that the job completed first is assigned the earliest due date, the job completed second is assigned the second due date, and so on. A flexible version of the GDD assumption, called *assignable due dates* (ADD), was introduced in Qi et al. [16]. Under the ADD assumption, the n due dates given in advance can be assigned to the n jobs independently.

Inspired by the GDD assumption and the ADD assumption, we consider the scheduling with delivery coordination under the assumption of *assignable delivery times* (ADT). Under the ADT assumption, corresponding to the n jobs $J_1, \cdots, J_n$, we have n delivery times $q_1, \cdots, q_n$ given in advance. In a schedule, the n delivery times are assigned to the n jobs, respectively. Let $([1], \cdots, [n])$ be a permutation of $(1, \cdots, n)$ so that $q_{[1]} \geq \cdots \geq q_{[n]}$. When the objective function to be minimized is the maximum delivery completion time of jobs, by using the two-exchange argument, we can show that, under every machine environment, there is an optimal schedule so that the n delivery times are assigned to the n jobs in the following way: the job completed first is assigned the maximum delivery time $q_{[1]}$, the job completed second is assigned the second delivery time $q_{[2]}$, and so on. Then the ADT assumption can be also understood as the assumption of *generalized delivery times* (GDT).

The ADT assumption is also motivated by the following phenomenon in practical application: Apart from the processing and delivery of the jobs $J_1, \cdots, J_n$ from the customers, the manufacturer has n tasks $T_1, \cdots, T_n$ in the customer center. Such tasks T_i may include local transportation, repairing services, procurements, or collecting new orders. Suppose that the manufacturer has just one vehicle in working. Then a round of shipment of the vehicle consists of the following procedures: (i) deliver a processing completed job J_j to its customer in the customer center, (ii) execute a task T_i in the customer center, and (iii) return to the manufacturer. Suppose that, in a round of shipment, the time used in procedure (i) and (iii) is given by q' which is independent of J_j and T_i, and the time used in procedure (ii) is given by q'_i which is independent of J_j. Then the time used in this round of shipment of the vehicle is equal to $q_i = q' + q'_i$ which only depends on the task T_i. Therefore, we regard each q_i as a delivery time to be assigned. Fig. 1 may help the reader to understand the model easily.