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Order acceptance and scheduling with batch delivery

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ABSTRACT

We study an order acceptance and scheduling problem with batch delivery in a supply chain consisting of a manufacturer and a customer. The manufacturer can rejects some orders placed by the customer, and processes the others on parallel machines and then delivers them to the customer in batches. The objective is to minimize the weighted sum of the maximum lead time of the accepted orders and the total cost of rejecting and delivering orders. We develop two approximation algorithms for this NP-hard problem.

1. Introduction

Scheduling problems have been extensively studied in the literature under the assumption that the manufacturer needs to process all of the orders in the planning horizon. However, in many highly loaded make-to-order production systems, the manufacturers always reject the processing of some orders by either outsourcing them or rejecting them altogether (Shabtay, Gaspar, & Kaspi, 2013). Hence, order acceptance and scheduling (OAS) problem has attracted considerable attention from scheduling researchers as well as operation managers in the past decade. In traditional OAS models, it is implicitly assumed that once an order completes processing it is delivered to the customer without any transportation cost. However in recent years, the escalating oil prices and an imbalance of supply and demand for freight transport services have led to high transportation cost. As a result, the distribution management plays a more important role in the supply chain and the manufacturers have to schedule the production and distribution of orders in a coordinated and efficient manner.

In this paper, we consider an OAS model, in which the distribution process of orders is considered. In this model, the supply chain consists of a processing facility operated by the manufacturer and a customer. The manufacturer receives a set of distinct orders from the customer at the beginning of the planning horizon. Each order is either rejected with penalty cost, or processed in the processing facility and delivered to the customer. The manufacturer needs to determine (i) orders which will be accepted, (ii) how to schedule the accepted orders in the processing facility, and (iii) how to schedule the completed orders from the processing facility to the customer. As we know, customer service and cost are two major concerns of the decision maker. The delivery lead time of an order, i.e., the time between the placement of the order by the customer and its delivery to the customer, is an important factor of the performance of a supply chain, and the maximum lead time of the orders is a widely used function for measuring customer service performance of a supply chain (Chen & Pundoor, 2006). Therefore, the objective of our problem is to minimize the weighted sum of the maximum lead time of the accepted orders and the total cost of rejecting and delivering orders.

Remaining sections of this paper are organized as follows. In Section 2, we review related literature. In Section 3, we define our problem precisely and give some optimality properties. We then develop algorithms for the problem in Section 4. Finally, we conclude the paper in Section 5.

2. Literature review

OAS problem has been studied extensively in the scheduling literature and excellent literature reviews on OAS are provided by Slotnick (2011) and Shabtay et al. (2013). Bartal, Leonardi, Marchetti-Spaccamela, Sgall, and Stougie (2000) is the first to

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investigate OAS models with parallel machine configuration. In this model, each order is either accepted and then processed by one of the machines, or rejected and then a rejection penalty is paid. The objective is to minimize the makespan of the accepted orders plus total penalty cost for the rejected orders. They showed that the model with single machine configuration is easy but with parallel machine configuration is NP-hard. Hence, they proposed a heuristic with the worse-case ratio of $2 - 1/m$ for the identical parallel machine case. Recently, Ou, Zhong, and Wang (2015) proposed an $O(n \log n + n/\varepsilon)$ heuristic with the worst-case ratio of $1.5 + \varepsilon$ for the model, where $\varepsilon > 0$ can be any small given constant. In recent years, several models with different constraints on identical parallel machines were studied with fixed and variable processing times. We refer the reader to books by Gawiejnowicz (2008) and Agnetis, Billaut, Gawiejnowicz, Pacciarelli, and Souhal (2014) for more details on scheduling problems with variable job processing times. Li and Yuan (2010) introduced several models with deteriorating jobs to minimize the scheduling cost of the accepted jobs plus the total penalty of the rejected jobs. They proposed two fully polynomial-time approximation schemes for the models under consideration. Gerstl and Mosheiov (2012) considered that the processing times of jobs are position-dependent and introduced efficient algorithms for the models. Wang, Huang, Hu, and Cheng (2015) considered that each order has a revenue value in the model with two identical parallel machines. Ou and Zhong (2016) dealt with a model in which the number of orders to be rejected is limited to be no greater than a given value so as to maintain a predefined high service level. Zhang, Xu, and Du (2016) found that there exists a communication delay between any two jobs connected in the precedence network and then proposed a 3-approximation algorithm for the model. Furthermore, some models with other machine configurations are investigated recently. Zhang, Lu, and Yuan (2015) studied the model in a two-machine open-shop environment and designed two algorithms for the model. Jiang and Tan (2016) proposed a 2-approximation algorithm for a model with unrelated parallel machines. Agnetis and Mosheiov (2016) introduced a polynomial time solution procedure for the model with proportionate flowshops configuration. However, to the best of our knowledge, little attention is paid on OAS model with job delivery coordination.

Obviously, the model studied by Bartal et al. (2000) can be viewed as a special case of our problem, in which each order is required to be delivered in a separate batch with no transportation cost and transportation time. However, in our problem, several orders are allowed to be formed into the same batch in order to reduce the transportation cost. The transportation cost of a batch is independent on the number of orders included in it. In other words, the transportation cost of a batch is fixed no matter whether the batch is full or not. For a given solution of our problem, the number of delivery batches may be decreased if some more orders are rejected and it may not be increased if some more orders are accepted. Hence, the decision on order acceptance will be significantly affected by the batch delivery of orders in our problem, which makes our problem more complex.

3. Problem description and preliminaries

In this section, we define our problem, represented by P hereafter, mathematically and introduce some optimality properties satisfied for the problem.

Given a set of n distinct orders placed by a customer at time 0, $N = \{1, 2, \ldots, n\}$, and a set of m identical parallel machines available at time 0 in the processing facility, $M = \{1, 2, \ldots, m\}$. Each order $j \in N$ is either rejected at w_j units of rejection penalty cost, or processed by one of the machines once without interruption. It takes p_j units of processing time to process order j on each machine, for $j \in N$. Completed orders need to be delivered to the customer in batches after processing, we assume that partial delivery of an order is not allowed. There are enough homogeneous vehicles stationed at the processing facility at time 0. Each vehicle will be used at most once and each delivery batch will be transported by an available vehicle. Moreover, each vehicle has a capacity limit; it can carry up to b orders in one batch. We assume that each order takes up the same amount of capacity of a batch. The delivery cost of a batch from the processing facility to the customer is f. Since all the accepted orders are delivered to the same customer and the shipping time of any batch is the same, we assume without loss of generality that the delivery time is 0. For a given solution Π of the problem, we define:

$A(\Pi) =$ the order set containing all accepted orders,
$R(\Pi) =$ the order set containing all rejected orders,
$D_j(\Pi) =$ the lead time of order $j \in A(\Pi)$, which is the time when order j is delivered to the customer since all the orders are given at time 0,
$D_{max}(\Pi) =$ the maximum lead time of order $j \in A(\Pi)$, i.e., $D_{max}(\Pi) = \max\{D_j(\Pi) | j \in A(\Pi)\}$, and
$TC(\Pi) =$ the total cost for delivering orders.

The problem is to find a solution such that the weighted sum of the maximum lead time of the accepted orders and the total cost of rejecting and delivering orders, i.e., $\alpha D_{max}(\Pi) + (1-\alpha)(\sum_{j \in R(\Pi)} w_j + TC(\Pi))$, is minimized, where $\alpha \in (0, 1)$ is a constant representing the decision maker's relative preference on customer service level and total cost.

In the following, we present some preliminary results about the structure of an optimal solution. Since these results are straightforward, we omit the proofs.

Lemma 1. *There exists an optimal solution for problem P in which all of the following hold:*

(1) *There is no inserted idle time between the orders processed on each machine in the processing facility.*
(2) *The departure time of each delivery batch is the completion time of the last order included in the batch.*
(3) *The accepted orders are delivered in the nondecreasing sequence of their processing completion times.*

Lemma 2. *There exists an optimal solution for problem P in which all the delivery batches, except possible one, are full. More precisely, if $u > 0$ orders are accepted, then $\lceil \frac{u}{b} \rceil$ batches are used to deliver these accepted orders, where $\lceil \frac{u}{b} \rceil$ is the smallest integer not less than $\frac{u}{b}$.*

Note that only solutions that satisfy the above properties are considered further.

4. Approximation algorithms

Evidently, the classical NP-hard parallel-machine makespan minimization scheduling problem $P_m||C_{max}$ (Garey & Johnson, 1979) is a special case of problem P when $f = 0$ and $w_j = +\infty$ for $j \in N$, which means that problem P is also NP-hard. As we know, the design and analysis of approximation algorithms is an appealing topic of research for these NP-hard problems and the quality of approximation algorithms is measured by their worst-case performance ratios (Quibell & Strusevich, 2014). Hence in this section, we will develop two approximation algorithms for problem P and analyze their worst-case performances.