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Discrete Optimization

On-line supply chain scheduling for single-machine and parallel-machine configurations with a single customer: Minimizing the makespan and delivery cost

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ABSTRACT

This paper investigates minimization of both the makespan and delivery costs in on-line supply chain scheduling for single-machine and parallel-machine configurations in a transportation system with a single customer. The jobs are released as they arrive, which implies that no information on upcoming jobs, such as the release time, processing time, and quantity, is known beforehand to the scheduler. The jobs are processed on one machine or parallel machines and delivered to the customer. The primary objective of the scheduling is time, which is makespan in this case. The delivery cost, which changes due to the varying number of batches (though the cost for each batch is assumed to be the same) in delivery, is also concerned. The goal of scheduling is thus to minimize both the makespan and the total delivery cost. This scheduling involves deciding when to process jobs, which machine to process jobs, when to deliver jobs, and which batch to include jobs. We define 10 problems in terms of (1) the machine configuration, (2) preemption of job processing, (3) the number of vehicles, and (4) the capacity of vehicles. These problems ($P1, P2, \ldots, P10$) have never been studied before in literature. The lower bound for each problem is first proved by constructing a series of intractable instances. Algorithms for these problems, denoted by $H1, H2, \ldots, H10$, respectively, are then designed and a theoretical analysis is performed. The results show that $H1$, $H2$, $H6$, and $H7$ are optimal ones according to the competitive ratio criterion, while the other algorithms deviate slightly from the optimum. We also design the optimal algorithm for a special case of $P5$. A case study is provided to illustrate the performance of $H5$ and to demonstrate the practicality of the algorithms.

1. Introduction

In a large-scale manufacturing and/or service operation, jobs are processed on machines in a factory or shop and delivered via a transportation system to customers in different locations. Two performance measures for such operations are time and cost. The cost includes both job processing costs and delivery costs, and time refers to the time interval between the time when a customer places an order and the time when the customer receives the ordered product. For customers, both the cost and time are a concern, and a low cost and short time are always desired. Scheduling for such an operation involves deciding when to process products and when to deliver products so that shorter time and lower cost may be achieved.

In supply chain scheduling, information such as future jobs, job release times, job processing times, and job quantity may not be known in advance, or scheduling runs as the demand occurs, which is called an on-line environment. Algorithms for the supply chain problem in an on-line environment are called on-line algorithms and must schedule jobs as they arrive (also called current jobs). On-line algorithms are evaluated using so-called competitive analysis instead of complexity analysis (Borodin & El-Yaniv, 1998; Pruhs, Sgall, & Torng, 2004). Algorithms with complete information of jobs for supply chain scheduling are called off-line algorithms, among which there are optimal ones. Let $\mathcal{P}$ be an on-line problem, of which $\mathcal{I}$ is an instance. Let $\mathcal{A}(\mathcal{I})$ be the result of the on-line algorithm for $\mathcal{I}$, and let $\mathrm{OPT}(\mathcal{I})$ be the optimal result of the corresponding off-line algorithm. If $\frac{\mathcal{A}(\mathcal{I})}{\mathrm{OPT}(\mathcal{I})} \leq r$ for all $\mathcal{I}$ and $r \geq 1$, $\mathcal{A}$ is called an r-competitive algorithm. Furthermore, the on-line algorithm has competitive ratio $\mathcal{R}_{\mathcal{A}} = \inf\{r \geq 1, \frac{\mathcal{A}(\mathcal{I})}{\mathrm{OPT}(\mathcal{I})} \leq r,$ for all $\mathcal{I}\}$, where inf denotes the infimum. For an on-line problem, if no on-line algorithm can achieve a competitive ratio of less than

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L, we say that L is the lower bound of that on-line problem. If an algorithm has competitive ratio L, we call this on-line algorithm optimal.

Machine configuration is another factor in supply chain scheduling. Here we consider single-machine and parallel-machine configurations in this paper. In the case of parallel machines, there are m identical machines, and a particular machine and a particular job are however exclusively related at any time. Several results have been published for the on-line problem of classical parallel-machine scheduling to minimize the makespan. If preemption of job processing is allowed, the 1-competitive on-line algorithm can be designed according to Hong and Leung (1992), whereby the McNaughton algorithm is applied whenever there is a new job. The McNaughton algorithm finds the shortest preemption schedule on parallel machines (McNaughton, 1959). If preemption of job processing is not allowed, the longest processing time (LPT) rule can generate a $\frac{3}{2}$-competitive schedule. According to the LPT rule, the job with the longest processing time is processed whenever there are idle machines (Chen & Vestjens, 1997).

Hall and Potts (2003) defined a supply chain scheduling problem and solved some basic off-line problems. Note that off-line refers to the situation that the job release information is given to the scheduler before scheduling. The difference between supply chain scheduling and classical scheduling problems is that in the former case, products may not be delivered immediately owing to transportation costs; instead, products may be held for arrangement into a batch for delivery. Therefore, supply chain scheduling involves deciding not only when and on which machine to process a product, but also when and in which batch to deliver the product. When there is more than one customer and the number of transportation vehicles is finite, the products in one batch may belong to different customers, so an appropriate delivery route should also be considered. Chen (2005) studied eight off-line supply chain scheduling problems, of which four have a routing problem; however, the author assumed that the number of customers is constant and solved the routing problem by permutation. If the number of customers is variable, the routing problem is strongly NP-hard (Christofides, 1976) and the problem reduces to the traveling salesman problem (TSP), so the permutation based approach will not work.

Averbakh and Xue (2007) considered on-line single-machine supply chain scheduling in which preemption of job processing is allowed and the total flow time and total delivery cost are minimized. The authors developed an on-line optimal algorithm for the case of a single customer and an on-line approximate algorithm for the case of more than one customer. They later considered an on-line supply chain scheduling problem with constraints on vehicle capacity and designed an on-line optimal algorithm for the single customer case (Averbakh, 2010). Chen (2010) reviewed the supply scheduling problem and modified a three-field notation for the classical scheduling problem to a five-field notation for supply chain scheduling.

In recent years, the supply chain scheduling problem has been the focus of much attention. Lee, Lei, and Dong (2013) considered a supply chain scheduling problem with capacitated multistage operations to minimize weighted tardiness. They proposed a method for iterative solution of the upstream problem under a given production quantity. The supply chain scheduling in a semi-on-line environment was first studied by Averbakh and Baysan (2012) to minimize the sum of the total flow time and the total delivery cost. The authors designed an algorithm with competitive ratio $\frac{2D}{D+P}$, where D is the cost of a shipment and P is a lower bound for all processing times. Rasti-Barzoki, Hejazi, and Mazdeh (2013) investigated supply chain scheduling for a single-machine or two-machine flow to minimize the total weighted number of tardy jobs and delivery costs. The structural properties were explored to develop a new branch-and-bound algorithm; and computational tests were conducted to show the performance. A three-tier supply chain scheduling model with three objective functions was proposed by Tang, Jing, and He (2013). They designed an improved ant-colony optimization algorithm and demonstrated that the method was better than those for other methods. Ivanov and Sokolov (2013) studied a new dynamic model of supply chain scheduling under a process modernization, which can be represented as a special case of the scheduling problem with dynamically distributed jobs. They explored optimality conditions and structural properties with discrete optimization techniques. Koc, Toptal, and Sabuncuoglu (2013) considered a supply chain scheduling problem with two vehicles for delivery under different delivery policies. Meisel, Kirschstein, and Bierwirth (2013) were the first to include production set-ups and production quantity, cargo consolidation, and capacity bookings for transportation in a supply chain scheduling model. A branch-and-cut method with heuristics was applied, and a case study demonstrated the performance. A supply chain scheduling problem with a third-party logistics provider was studied by Agnetis, Aloulou, and Fu (2014). They considered different transportation modes and investigated the complexity of the problems. Different techniques have been introduced in this domain. Bashir, Badri, and Talebi (2012) considered the supply chain scheduling problem as a production–distribution network, and described several hypothetical cases to show the planning process. Ivanov, Dolgui, and Sokolov (2012) studied supply scheduling problems combined with control theory, and proposed corresponding real-time policies. Different schemes have been introduced to search for a better solution in a shorter time, including an intelligent algorithm (Meinecke & Scholz-Reiter, 2014; Ullrich, 2013), the Taguchi method (Hajiaghaei-Keshteli, Aminnayeri, & Ghomi, 2014), and a piecewise linear model (Baghalian, Rezapour, & Farahani, 2013).

However, little research has considered the makespan as the objective function. In addition, to the best of our knowledge there have been no studies of the problem with different vehicle characteristics and machine configurations in an on-line environment. To reduce knowledge gap was the motivation for our study.

Here we propose and define 10 on-line supply chain scheduling problems for single-machine and parallel-machine configurations for a single-customer and different vehicle characteristics. For all these problems, the objective functions are the makespan and the delivery cost. There are no related work for these supply chain scheduling problems in the existing literatures. Furthermore, consideration of the vehicle characteristics (or tool more generally) in supply chain scheduling represents the first step toward tackling more realistic application problems.

The remainder of the paper is organized as follows. The 10 problems are first defined and their lower bounds are investigated. Then an on-line optimal or approximate algorithm is developed for each problem. To show the effectiveness of the algorithm developed, a simulated experiment is presented and the results are discussed. The paper concludes with a summary of the contributions from this study and suggestions for future work.

2. Problem formulation

Suppose there are n jobs $\mathcal{J}_1, \ldots, \mathcal{J}_n$ with processing time $p_1, \ldots, p_n$ that are released on-line at time $r_1, \ldots, r_n$, respectively, and that the manufacturer has a single machine or m identical machines. After jobs are processed, they are transported to the customer in vehicles, for which there is a delivery cost. A schedule should specify what machine a job is assigned to and when a job is processed and transported. A completed job should be packed in a batch, and the schedule should also decide which jobs are packed in which batches. Furthermore, delivery may not be carried out immediately, which means that there may be a waiting time for a processed product before it is delivered.

Let I be an instance (i.e., a particular problem). We give the following notations: