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Integrated operations scheduling with delivery deadlines ☆

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ABSTRACT

An integrated scheduling problem of supply and distribution operations in a make-to-order supply chain is considered. The supply chain consists of contracted suppliers, capacitated processing centers, and many demand points. Processing centers customize and/or configure semi-finished products supplied by suppliers to finished products in terms of the requirements of demand points: order quantity and delivery deadline. The problem is to find the assignment of both suppliers and demand points to processing centers and the schedules for supply and distribution operations such that the total costs of shipping and penalty that unfulfilled customer orders incur are minimized, subject to network capacity and deadline constraints. In this paper, a heuristic algorithm is developed, based on partial relaxation and median threshold, which makes it possible to avoid dealing with the generalized assignment problem, a strongly NP-hard problem, in the solution process. Computational tests are performed over test cases randomly generated to assess the performance of the proposed algorithm. As compared to the use of commercial optimization package, CPLEX, computational results show that the proposed algorithm is able to find a good near-optimal solution to this problem with remarkably less computational time.

1. Introduction

The trend of globalization and rising fuel price has brought more challenges to supply chain management. Due to the rise on oil price, there has been an increase of more than 50 percent in transportation costs over the past five years; inventory, in turn, has risen by more than 60 percent from 2002 to 2006 as a result of increasing transportation costs (Simchi-Levi, Peruvankal, Mulani, Read, & Ferreira, 2012). As globalization increases, lead time is also becoming longer and longer so that many companies are exposed to different types of risks. Intensified competition and heightened requirements of customers are forcing companies to significantly reduce inventory costs on one hand and to improve responsiveness on the other. Cost and customer service have become even more critical in global supply chain operations in today's fast-changing, complex environment. To reduce inventory costs, many companies attempt to hold very little inventory so that inventory holding costs are negligible. To be more responsive, companies have been trying to achieve shorter lead times. Shorter lead times, however, incur higher distribution costs because more delivery shipments and faster transportation modes may have to be used. In such cases, a tighter integration of supply and distribution operations is required to achieve a desired service level at minimum total cost, with little or no idle time of supply and distribution operations, and with little or no inventory of intermediate and finished products.

Motivated by the applications in lumber industry, a scheduling problem of integrated supply and distribution operations (**ISDO**) was presented by Wang and Lei (2012), in an effort to improve operations efficiency and effectively manage lead time. The supply chain associated with the scheduling problem is three-stage supply and distribution network with contracted suppliers, processing centers and demand points. Suppliers ship semi-finished products to a given set of capacitated processing centers (PCs) for further processing. PCs comply with the requirements that demand points specify to customize and/or finally configure semi-finished products to finished lumber products. Then the finished lumber products are distributed to demand points dispersed geographically by or before the deadlines that demand points request. Due to constraints of delivery deadline and network capacity, orders of certain demand points may be unfulfilled, which leads to penalty costs. Additionally, partial delivery is unacceptable as each demand point adopts single sourcing strategy to reduce purchase costs. The problem is to determine the assignment of both suppliers and demand points to PCs and find the operations schedules so

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as to minimize the total shipping and penalty costs while satisfying service level requirements.

Since a detailed discussion on **ISDO** problem was provided by Wang and Lei (2012), the focus of this paper is on solution approaches determining a close-to-optimal operational schedule for the scheduling problem. In fact, **ISDO** problem is difficult to solve because of its combinatorial nature, so most related work in the literature tends to employ heuristics to find a near-optimal solution to **ISDO** problem. In general, the heuristics for solving **ISDO** problem in the literature can be classified into two categories. The research in the first category aims to decompose **ISDO** problem into several sub-problems which are in general solvable in polynomial time. A feasible solution to original problem can then be found and improved by combining the optimal solutions to sub-problems. Wang and Lei (2012) investigated a capacitated supply and distribution network scheduling problem with delivery deadlines. The three efficiently solvable cases of the operations scheduling problem were taken into account: (a) identical order quantities; (b) designated suppliers; and (c) divisible customer order sizes. For each case, they designed a decomposition-based algorithm and proved their computational complexity, respectively. Lei, Liu, Ruszczynski, and Park (2006) developed a two-phase algorithm to solve an integration problem of production, inventory, and distribution with non-instantaneous traveling times. The first phase found a feasible solution to the original problem by solving a direct shipment problem between manufacturing facilities and customers. The second phase used heuristics to improve the solution obtained in the first phase. Dawandel, Geismar, Hall, and Sriskandarajah (2006) solved a transportation scheduling problem in a supply chain with a short shelf-life product by a two-phase heuristic, where the first phase applied a genetic algorithm to permutate customers and the second phase used Gilmore Momory algorithm to obtain an integrated schedule by combining the subsequences of customers. Kaminsky and Kaya (2009) considered a combined scheduling problem of make-to-order and make-to-stock supply chains. They presented different heuristic algorithms to find appropriate inventory levels for make-to-stock products and for scheduling lead time quotations, respectively. Manoj, Sriskandarajah, and Wagneur (2012) considered the problem of whether coordinating the two stages that are adjacent in a production system was beneficial. They analyzed conflicting costs when the optimal schedule for the other stage was employed, evaluated the computational tractability of the individual problems at each stage, and showed that individual problems were able to be solved in polynomial time. Finally a genetic algorithm was designed for solving the problem.

Compared to the first category, works in the second category intend to solve **ISDO** problem in an integrated fashion by first reducing original problem to an easily solvable problem through relaxing some constraints, and then improving the solution obtained by relaxed problem to a near-optimal one. There are several early studies of this category in the literature (e.g., Cohen & Lee, 1988, Chandra & Fisher, 1994, Fumero & Vercellis, 1999, Hall, Lesaoana, & Potts, 2001, Kreipl and Pinedo, 2004). Recent research on the operations scheduling problem of **ISDO** is also extensive. Chen and Vairaktarakis (2005) studied a joint scheduling problem of minimizing a convex combination of distribution cost and customer service level, where some efficient algorithms were provided to highlight the advantages of integrated scheduling over the sequential model. Lapierrea and Ruizb (2007) studied an coordination problem of procurement and distribution operations in hospital logistics and proposed a tabu search metaheuristic to solve this problem with two modeling approaches including many decision regarding operations decision. Li and Vairaktarakis (2007) developed efficient heuristics and approximation schemes for an integrated scheduling problem with two machines and bundling operations to minimize the total costs of transportation and customers' waiting. Sawik (2009) analyzed a multi-objective integrated scheduling problem in a customer-driven supply chain by applying both monolithic and hierarchical approaches, and showed that monolithic approach was advantageous over hierarchical method through computational studies. Zegordi and Nia (2009) considered a two-stage supply chain where order assignment and the integration of production and distribution are both involved. They designed a genetic algorithm based algorithm and proved that the algorithm performed well. Zhong, Chen, and Chen (2010) proposed and proved a tight, polynomial-time heuristic algorithm with the performance ratio of 2 in order to solve an integrated scheduling problem of production and distribution operations with committed delivery dates. Gaudreault, Frayret, Rousseau, and D'Amours (2011) studied the coordination of process planning and operations scheduling through using a single model so that simultaneous implementation of process planning and scheduling is achieved. Rasti-Barzoki and Hejazi (2013) studied an operations scheduling problem with due date assignment, production, and batch delivery in a make-to-order supply chain. They presented a three-stage heuristic algorithm based on the structure of optimal solution and carried out computational experiments to show the efficiency of their algorithm. Mokhtari and Abadi (2013) dealt with a scheduling problem with a single stage considering scheduling both in-house production or outsourcing. The objective of this study is to jointly schedule in-house and outsourcing production at the same time so as to minimize the sum of the total weighted completion time and outsourcing cost. Liu, Zhang, Zhu, and Rao (2014) presented a multi-objective scheduling model to schedule logistics tasks and resources for fourth party logistics and developed an improved nondominated sorting genetic algorithm to achieve a joint optimization of cost and time of logistics activities between tow adjacent activities and two sequential activities.

Although the scheduling problem of **ISDO** has been extensively studied in the literature, none of the existing algorithms can be directly applied to our model. Compared to those in the literature, **ISDO** studied is a more complex problem and has some fundamental differences. First, many relevant works consider minimizing either lead times or total costs in supply, production, and distribution operations. However, our objective is to not only minimize the total costs of scheduling supply and distribution operations and penalizing unsatisfied demand points, but also consider the constraints of network capacity and delivery deadlines. Second, most related studies focus on allocating supplies from production facilities, inventory, and distribution centers to demand points, while our model also needs to assign capacitated suppliers to serve the needs of the distribution centers (i.e., PCs in our case). Third, the interaction between assigning suppliers and demand points to PCs and delivering on time results in additional complexities for solving this problem. The integration scheduling of supply and distribution operations requires simultaneous optimization of assigning suppliers and demand points to PCs and scheduling supply and distribution, with a focus on minimizing the total costs of shipping and penalty. This is difficult since the simultaneous assignment of suppliers and demand points to PCs is also subject to network capacities, processing times, shipping times, and delivery deadlines.

To solve **ISDO** problem under study, an approximation algorithm belonging to the second category is developed by using partial relaxation and median threshold. When certain constraints are relaxed, **ISDO** problem can be reduced to a combination of two NP-hard problems: generalized assignment problem and supplier selection problem, both of which are computationally difficult. To avoid solving NP-hard problems, at the beginning of the proposed algorithm, **ISDO** problem with multiple sourcing is first solved to