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The impact of liner shipping unreliability on the production–distribution scheduling of a decentralized manufacturing system

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ABSTRACT

Liner shipping uncertainty affects global supply chains reliability seriously. The pressure from downstream forces the make-to-order manufacturer to face high penalty cost due to stochastic shipping lead-times. A new risk-averse model is proposed aimed at improving production scheduling reliability integrated with shipment assignments in terms of total operating cost. The closed form of the risk cost of job-shipment assignment under given reliability levels is formulated, which verifies the effects of shipping uncertainty on the production scheduling and operating cost. The computational and statistical evaluation demonstrate our approach can compensate the amplification effects of the high penalty level and shipping uncertainty.

1. Introduction

Globalization and the development of emerging markets have led an increasing number of manufacturers/suppliers to create decentralized production networks for reducing the production cost and increasing the production efficiency while meeting the market demands. When placing an order, customers expect a high service level, which can be achieved by efficient and timely delivery of products. Certainly, an efficient delivery service wins more customers. However, achieving customer satisfaction, as well as controlling the overall cost, is a critical issue.

In the global supply chain involving maritime transport, the integration of production and distribution in multi-factory production networks is highly important. The regularly expected shipping schedules and the long shipping lead-time limit the processing time of the manufacturers significantly, affecting the production assignment, scheduling, and storage. In addition, the carriers (shipping companies) are the crucial members connecting the manufacturers with their customers. They usually publish the expected shipping schedules several months in advance so that shippers can make appropriate decisions. When the actual schedules deviate from the published ones, not only the shippers (manufacturers) but also their customers face uncountable losses because of the delays.

However, in reality, the schedule unreliability is a common problem in the shipping industry. Both internal and external factors, which are not in the control of the shipping companies, bring about negative impacts on the timely arrivals of vessels. As reported by Notteboom (2006), the actual vessel schedule reliability can be as low as 50% for many shipping routes compared with their expected schedules. In a recent report by Drewry (2015), the statistics showed that only 49% to 55% of ships in three key East–West trade routes arrived within 24 h of the expected time of arrival (ETA), whereas the average deviation from the ETA was 1.9 days and

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2.1 days in January 2015 and February 2015, respectively. The situation has not improved much. As reported by Drewry (2016), the universal average on-time performance of the shipping schedule reliability in February 2016 was 62.7%, and for Asia–Europe trade, it was less than 60%. The main source of the schedule unreliability arises from the congestion of vessels in ports and the unexpected low handling efficiency at ports/terminals. In recent years, many researchers have focused on the shipping routing design problems with uncertainties in the shipping operations. Shipping schedules were redesigned or the shipping speed was controlled from time to time to minimize the cost of fuel consumption as well as improve the service reliability (Qi and Song, 2012; Wang and Meng, 2012). Many studies have been conducted on the vessel schedule recovery problems aimed at handling disruption events in liner shipping (Brouer et al., 2013; Li et al., 2015a). Except for disruptive events, the regular uncertainties (port-related uncertainties) were also considered in the work of Li et al. (2016) in which a real-time schedule recovery method was developed for the shipping companies. Although some studies considered the customer service levels as the constraints in the fleet deployment and route scheduling problems, their priority was the profitability of the shipping companies. When a trade-off cannot be achieved between the profitability of the shipping company and the shipping service reliability, the shipping companies have to sacrifice the schedule reliability for controlling the total cost.

Almost all the existing studies discuss the shipping unreliability from the perspective of the shipping companies. Studies for identifying the impact of shipping uncertainties on the production–distribution scheduling and the operating cost from the perspective of the shippers (manufacturers) are quite limited. Therefore, we address this issue in this study.

This study seeks for a new risk-averse method for the make-to-order manufacturer who faces liner shipping uncertainty but commits to deliver the finished orders to its global customers on time. It not only enriches the literature on stochastic production–distribution scheduling, but also enriches the studies on supply chain risk management at operational level. Firstly, a stochastic programming involving random variables in both objective function and constraints is proposed for an integrated multi-factory production–distribution scheduling problem under liner shipping uncertainty. A new objective function aimed at minimizing the value-at-risk (VaR) of the whole system is proposed so as to measure the risk cost coming from both earliness and tardiness. The general closed form for the individual VaR is formulated and applicable to arbitrary probability distribution. Therefore, the deterministic equivalent counterpart is developed and can be solved by the exact algorithm. Some managerial insights are obtained with these data. The solutions of the expected value method are used as the benchmark for the proposed model in terms of different shipping market situations, uncertainty levels, and penalty levels. The impacts of the changes in these three factors on the VaR of the manufacturer and the performance of the proposed model are determined by conducting numerical experiments and statistical analysis. The superiority of the proposed method is further demonstrated by comparison with a β-quantile buffer method.

This paper is divided into the following sections. Section 2 reviews some recent relative studies. Section 3 details the concept of the proposed risk-averse approach, problem background and formulation. Section 4 presents the modeling of the proposed VaR based method and the development of its deterministic equivalent counterpart, i.e., the individual probabilistic constrained integer programming (IPCIP). Section 5 explains the numerical experiments, which are used to validate the effectiveness and superiority of the proposed model. Comprehensive numerical experiments and statistical analysis for the performance evaluation of the proposed model are presented in Section 6. Section 7 discusses the conclusions.

2. Literature review

The coordinated production and distribution problems have drawn more and more attention in the last two decades. In order to meet customized needs and stay competitive in the market, more and more companies are adopting the make-to-order business mode. In this way, the finished orders are usually delivered to their customers directly, or shortly after production, without inventory. Therefore, as the key functional activities in the supply chain, production and distribution become intimately linked. The majority of the existing literature for integrated production and distribution scheduling problems was modelled in a single-factory production network, and focused on the single machine (Condotta et al., 2013; Rasti-Barzoki and Hejazi, 2013, 2015; Tang et al., 2014; Cheng et al., 2015; Gao et al., 2015; Cheng et al., 2017; Karaoğlan and Kesen, 2017; Koç et al., 2017) and parallel machine manufacturing environment (Liu and Lu, 2016; Joo and Kim, 2017; Kergosien et al., 2017). In terms of the distribution part, the common delivery method is batch delivery with direct shipping, counted on the fleet owned by the manufacturer.

With the rapid development of the third-party logistics companies (3PL), some researchers started to consider the production scheduling problem integrated with 3PL, especially in the increasing trend of make-to-order business modes (Wang and Lee, 2005; Stecke and Zhao, 2007; Huo et al., 2010; Azadian et al., 2015; Li et al., 2015b; Guo et al., 2017). Usually, 3PL companies provide more flexible selections in term of transportation cost, time, and provide sufficient vehicles responsible for picking up customers orders at the appointed date and time. However, in reality, dominated transportation modes cannot be avoided in the global supply chain involving long-distance shipping, i.e. air, sea, rail transportation.

A handful of studies considered the production scheduling with dominated transportation modes under simple machine configurations, i.e., single machine and identical parallel machines. Li et al. (2005) studied an integrated assembly scheduling with air transportation. Different available time, capacity, shipping lead-time with different price was involved for each flight. The problem was solved by a decomposition method. The objective for the first sub-problem was to minimize the total transportation cost as well as earliness and tardiness penalties. The second sub-problem was to minimize the average waiting cost at the machine. Later, Li et al. (2006) further studied the problem with consideration of the process delays coming from the production part. The scenario that the machine would not be available at the beginning, until some given time, was considered in the sub-problem of assembly scheduling. The objective was changed into minimizing the delivery costs due to adjustment of air transportation allocation. The problem was solved by a decomposition method. Wang et al. (2005) studied a mail processing and distribution scheduling problem with a fixed