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Integrated scheduling of production and rail transportation

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ABSTRACT

Nowadays, the most used, efficient and inexpensive mode of transportation between supply chain partners is the rail transportation. To the best of our knowledge, there is no research reported to date, which addresses the problem of synchronization of production and rail transportation. In this work, an integrated production and transportation model, which considers rail transportation, is firstly developed to deliver the orders from a facility to the customers (warehouses). The problem is to determine both production schedule and rail transportation allocation of orders to optimize customer service at minimum total cost. Different destinations of the trains, trains' capacities, and different transportation costs are the main aspects of the work which are considered. In order to tackle such an *NP*-hard problem, a heuristic, two metaheuristics and some related procedures are developed. Besides, Taguchi experimental design method is utilized to set and estimate the proper values of the algorithms' parameters to improve their performance. For the purpose of performance evaluation of the proposed algorithms, various problem sizes are employed and the computational results of the algorithms are compared with each other. Finally, we investigate the impacts of the rise in the problem size on the performance of our algorithms.

1. Introduction

Production is a key function within a supply chain. Traditional scheduling models just focused on the determination of schedules for production such that some performance measures are optimized. The coordination between the production schedule and the delivery plan had not been considered in those models. They implicitly assume that there are ample resources available for delivering finished works to their destinations without any delay. However, in reality, the number of conveyances is limited and they may need to serve more than one customer location to increase their utilization.

Recently, the coordination of activities along different partners of a supply chain has received a lot of attention in production and operations management. Rather than considering production scheduling in isolation, several researchers in this decade have designed models that integrate several of the operational functions to optimize customer service at minimum total cost (Potts & Strusevich, 2009). Rearrangement or interruption of production schedules, idle time, tardiness penalties, and unnecessarily high inventories often drive up costs considerably (Ullrich, 2013). In order to reduce total logistics cost, production and delivery operations need to be well coordinated, first within single companies and then within whole supply chains (Manoj, Gupta, Gupta, & Sriskandarajah, 2008). One of the most interesting issues in supply chain management is the coordination of production and delivery schedules. In many production systems, finished products are delivered from a factory to multiple distribution centers, warehouses, or customer locations by delivery conveyances. The decision maker wants to minimize the total production and distribution costs of a product regarding to customer's satisfaction. So, integrated production and distribution planning have received a lot of attention throughout the recent years and its economic advantages are well documented (Amorim, Gunther, & Almada-Lobo, 2012). Besides, it has been the subject of significant debates, both in academia and industries. The main reasons of the integration are increasing levels of global competition, creating a more demanding customer, demand driven markets and the emergence of just in time delivery.

Generally, researches in this area are mainly focused on road transportation and there has been a relative neglect of other transportation modes while there are sizable sectors of industry such as air and rail transportation. Here, because of the importance of rail transportation in distribution systems, we aim to study the problem of integration of production and rail transportation scheduling to achieve accurate scheduling minimizing total cost. The main difference between rail or air transportation with road transportation is the fixed departure time of the formers. Also the difference between rail and air transportation is that, in the rail transportation a train can transfer the orders of multiple customers which

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are in the same pass in the railway (like a tree in a graph). In freight rail transportation, orders and trains may have different destinations, so the orders should only be allocated to the trains with the same destinations or pass through the orders' destinations. So, we should ensure that by allocating an order to a destination with a train in the railway, we do not neglect the farther destinations' orders. Because this type of coordination is firstly discussed in the literature, we explain the reasons which motivate us to work on this subject in Section 3.

We study an integrated production and delivery scheduling problem for a facility faced by a make-to-order company and utilized rail transportation to deliver its orders to the customers (warehouses). At the beginning of a planning horizon, the company has accepted a set of orders and committed a delivery date for each order. The company needs to process these orders on a dedicated production line and deliver the finished orders to the respective customers by the pre-planned trains with their corresponding capacities and traveling times. The problem is to determine a production schedule for the accepted orders and to allocate the orders to the available trains for delivering each completed order subject to the constraint that all the orders are completed and delivered to their customers on the respective committed delivery dates. In this system, earliness and tardiness penalties happen at both production site and at the warehouses.

The 'departure time earliness' cost happens as a result of the need to store the order at the production facility or waiting charges at the rail station. Also there is an extra cost corresponding to charter trains considered as 'departure time tardiness' when shipping in a scheduled train is missed or there is no scheduled train for a specific time interval. Delivery penalties are incurred by delivering an order either earlier or later than the committed due date to customers. The 'delivery tardiness' cost includes customer dissatisfaction, contract penalties, loss of sales, and potential loss of reputation for manufacturer and retailers. If the arrival time of allocated orders in rail transportation model is earlier than its due date, retailers encounter the storing cost of orders which is considered as 'delivery earliness' cost. In this paper, we schedule both the production and allocate the trains in a way to minimize the total cost.

Likes previous related works, which presented new approaches and models about coordination in supply chain, e.g. Rostamian Delavar, Hajiaghaei-Keshteli, and Molla-Alizadeh-Zavardehi (2010), Li, Ganesan, and Sivakumar (2005), Li, Vairaktarakis, and Lee (2005), Li, Ganesan, and Sivakumar (2006), Li, Sivakumar, and Ganesan (2008), we utilized metaheuristics and heuristics which are relevant to the nature of the problem, too. We utilize the GA with SA which are different in the search approach. The GA is a population based algorithm where the SA is not. While SA creates a new solution by modifying only one solution with a local move, GA also creates solutions by combining two different solutions. Comparing these two algorithms, in fact, is to consider two different search methods in metaheuristics.

The remainder of the paper is organized as follows. The next section is devoted to the literature review of related topics. In Section 3, the relation between industry and rail freight transportation is discussed. In Sections 4 the assumptions are detailed and the mathematical model is formulated. In Sections 5 and 6, the proposed algorithms are explained and also the Taguchi experimental design and comparison of the computational results are detailed in Section 7. Finally, in Section 8, the paper is concluded and suggestions for the future research are proposed.

2. Literature review

In the supply chain literature, most researchers have focused on the production–distribution, from strategic, tactical, or operational perspectives. Research on integrated scheduling models of production and distribution is relatively recent, but is growing very rapidly. In many applications including make-to-order or time-sensitive (e.g., perishable, seasonal) products, finished orders are often delivered to customers immediately or shortly after the production. Therefore, the need for integration between supply chain partners is inevitable for these products.

Supply chain models that focus on integrating production and distribution operations (that is, on manufacturer–customer levels of the supply chain) are known in the recent literature under the name of integrated production–distribution problems (Chen & Vairaktarakis, 2005; Pundoor & Chen, 2005; Russell, Chiang, & Zepeda, 2008). The authors refer the readers to see the related papers in integrated analysis of production–distribution systems (Armentano, Shiguemoto, & Løkketangen, 2011; Ashoka Varthanana, Muruganb, & Mohan Kumarc, 2012; Chen, 2004, 2010; Chen & Vairaktarakis, 2005; De Matta & Miller, 2004; Erenguc, Simpson, & Vakharia, 1999; Goetschalckx, Vidal, & Dogan, 2002; Melo & Wolsey, 2010; Sarmiento & Nagi, 1999). In most production–distribution systems, finished jobs are delivered from a facility to the warehouses (customers) by vehicles such as trucks. There have been considerable researches conducted in production–transportation integration with emphasis on the road transportation and vehicle routing problem (Chang & Lee, 2004; Chen & Lee, 2008; Lee & Chen, 2001; Tang & Liu, 2009; Wang & Cheng, 2006; Xuan, 2011; Zhong, Dosa, & Tan, 2007).

The literature on production–distribution is vast ranging in multiple parameters. According to an outstanding review in this research area written by Chen (2010), there are five delivery methods considered in the previous paper published as production–distribution works. The last delivery modus which is mentioned in the paper, is a delivery method with fixed departure dates. This way gains lots of attention in today's world, but few papers have been published about it. Over 70% of the companies worldwide now rely on third party logistics (3PL) providers for their daily distribution and other logistics needs (Langley, van Dort, & Sykes, 2006). The statistics about using the 3PL shows the rapid growing of using this method of delivery in real world, but only about ten papers have been written about the integration of production and this method of delivery. To the best of our knowledge, the transporters which are considered in the previous papers for fixed departure dates are cars and airplanes.

There is a few research on production scheduling considering vehicles with fixed departure dates. Most of them use air transportation. Li, Sivakumar, Mathirajan, and Ganesan (2004) studied the synchronization of single machine scheduling and air transportation with single destination. The overall problem is decomposed into air transportation problem and single machine scheduling problem. They formulated two problems and then presented a backward heuristic algorithm for single machine scheduling. They extended their previous work to consider multiple destinations in air transportation problem (Li, Ganesan, et al., 2005; Li, Vairaktarakis, et al., 2005). They also proposed a forward heuristic and a backward heuristic for single machine (Li et al., 2006). Li et al. (2008) extended their work by considering parallel machines in production and using simulated annealing (SA) based heuristic algorithm to solve the problem. Zandieh and Molla-Alizadeh-Zavardehi (2008) also proposed some mathematical models for both production and transportation problems with different delivery assumptions (with delivery tardiness and without delivery tardiness) regarding due window. Zandieh and Molla-Alizadeh-Zavardehi (2009) extended their work by considering various capacities with different transportation cost and also charter flights (commercial flights). Besides, Rostamian Delavar et al. (2010) proposed two genetic algorithm (GA) approaches to determine both production schedule and air transportation