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Collaborative production planning with production time windows and order splitting in make-to-order manufacturing ☆

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ABSTRACT

In this paper, we study a generalized production planning problem, that simultaneously investigates the two decisions that play critical roles in most firms, namely, production planning and order splitting and assignment. The problem takes into consideration the production time windows and capacities. We formulate the integrated problem as a linear mixed-integer program with a minimized total cost. A particle swarm optimization-based approach is developed to address the problem. Extensive computational experiments show that the proposed approach outperforms a commercial optimization package. Some managerial insights are also explored and reported. Finally, concluding remarks and future research directions are provided.

1. Introduction

Increasing incentives in a competitive market impels companies to undertake collaborative decision-making activities that will help to achieve their cost-minimization or profit-maximization objectives. The core partial decision faced by a company is the production planning problem. In this paper, we address a generalized production planning problem, that simultaneously considers several important decision activities under complicated constraints and limitations in real situations.

This study originated from our collaboration with the business division of an iron and steel company in China. The business division originally consisted of a headquarter and several distribution centers. It was mainly responsible for handling customer orders such as procurement, order quantity allocation, distribution and inventory of the products. Due to the increasing market competition, various value-added services are provided to improve customer satisfaction. For example, based on the shapes of the customers' products, steel sheet cutting and bending processes are carried out by the company instead of the customers. Moreover, a make-to-order strategy is used to provide "the right item in the right quantity at the right time at the right place for the right price in the right condition to the right customer" (Van Lear & Sisk, 2010). Thus, manufacturing facilities are integrated to the division, and, the managers realize the importance of integrated decision-making activities, in which, production planning is a basic operational decision. In comparison with the classical production planning decision, managers face a more complicated setting that includes the constraints of production time windows, production capacities, balanced production loads among manufacturing facilities as well as the decisions of production planning, order splitting and assignment.

The main contributions of our study are summarized as follows: (a) from the modeling perspective, we present a mixed integer program to formulate a generalized production planning problem that considers order splitting and assignment, production time windows, production capacity, and utilization of the manufacturing facilities; (b) from the algorithm perspective, we develop an efficient particle swarm optimization-based (PSO) approachto solve the model by introducing a new way of representing the solutions and then decomposing the model into two tractable submodels. The proposed approach outperforms commercial optimization software in the formulation of the problem. The advantages of the PSO algorithm such as quick convergence, easy implementation, and few parameters to adjust (Sun, Liu, & Lan, 2010; Goksal, Karaoglan, & Altiparmak, 2012; Martins, Fuchs, Pando, Luders, & Delgado, 2013) motivate us to develop the PSO-based algorithm to address the problem. Moreover, PSO has been successfully applied in the fields of combinatorial optimization problems such as the production planning problems, the vehicle routing problems, and the scheduling problems. Mostly PSO gets better results with less computational effort compared to other methods (Hu, 2011); and (c) some interesting managerial insights

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are reported, which will help the managers to make suitable production decisions.

The rest of the paper is organized as follows. A comprehensive review on production planning problem is presented in Section 2. The problem is stated and mathematically formulated in Section 3. A particle swarm optimization-based approach to address the model is proposed in Section 4. Numerous computational experiments are reported in Section 5, and, the managerial insights of the problem are explored. Finally, the conclusions are drawn and the future research directions are outlined in Section 6.

2. Literature review

Production planning problems have been extensively studied by the academic and industrial research communities since their introduction more than five decades ago (Karimi, Fatemi Ghomi, & Wilson, 2003; Jans & Degraeve, 2007; Jans & Degraeve, 2008). Classical production planning problems determine a cost-minimizing production schedule that considers setup cost, production and inventory holding cost when the time-varying demands are known in advance. In recent years, numerous extensions of the classical problems have been studied (Pochet & Wolsey, 2006; Brahimi, Dauzere-Peres, Najid, & Nordli, 2006b; Buschkühl, Sahling, Helber, & Tempelmeier, 2010), in which, various additional constraints (such as production capacity and time windows) and decisions (such as order splitting and assignment) are integrated into the classical production planning problems according to the real-life applications. For a review of production planning problems, their extensions, and solution approaches, please refer to Robinson, Narayanan, and Sahin (2009) and Buschkühl et al. (2010). In the rest of this section, we focus our attention on the literature with respect to time windows and order splitting.

Time windows play an important role in the study of make-to-order manufacturing (Azevedo & Sousa, 2000; Mestry, Damodaran, & Chen, 2011). Since Lee, Çetinkaya, and Wagelmans, 2001 first studied the uncapacitated production planning problem with delivery time windows, relevant papers associated with delivery time windows have continuously emerged (Lee et al., 2001; Hwang & Jaruphongsa, 2006; Wolsey, 2006; Jaruphongsa & Lee, 2008; Hwang, Jaruphongsa, Çetinkaya, & Lee, 2010). In addition, production time windows (Dauzère-Pérès, Brahimi, Najid, & Nordli, 2002; Brahimi, Dauzère-Pérès, & Najid, 2006a; Wolsey, 2006; Hwang, 2007; Brahimi, Dauzere-Peres, & Wolsey, 2010; Hwang et al., 2010; Absi, Kedad-Sidhoum, & Dauzère-Pérès, 2011) have appeared in the study of production planning. Delivery time window means that orders must be delivered within a given time interval. However, all of the demands can still be processed as early as the first period of the planning horizon, and the holding cost is considered to be null if a demand is satisfied within its corresponding time window (Absi et al., 2011). Production time window is the time interval during which the order must be produced (i.e., the order cannot be produced before its release period). The general case of the latter where there is no restriction on the production time windows is solved by a pseudo-polynomial dynamic programming algorithm (Dauzère-Pérès et al., 2002). Hwang, 2007 also proposed a dynamic programming algorithm to solve a problem with a concave production cost in $O(T^5)$, a problem that is called customer specific (CS). An interesting special case of the problem is called non-customer specific (NCS) where two time windows cannot be strictly included. NCS can be solved in polynomial time (Dauzère-Pérès et al., 2002; Wolsey, 2006).

Normally, order splitting emerges with the supplier selection decisions in the research of production planning problems. It determines which suppliers to select and the order-splitting ratio among the selective suppliers in each production period. Basnet and Leung (2005) proposed a multiperiod lot sizing with supplier selection problem to decide what products to order in what quantities with which suppliers in which period. An enumerative search algorithm and a heuristic were presented to address the problem. Liao and Rittscher (2007) applied a genetic algorithm to address a multi-objective single-item lot sizing problem, which integrates supplier selection, order-splitting ratio, procurement lot sizing, and carrier selection. Ding, Benyoucef, and Xie (2009) studied a production–distribution network design problem that includes both supply chain configuration and related operational decisions such as order splitting, transportation allocation, and inventory control. Cheng and Ye (2011) addressed an order-splitting problem among parallel suppliers and presented a single-period bi-objective model with two criteria: (i) minimizing total cost and (ii) minimizing the deviation of production load rates between any two selected suppliers.

However, a few studies integrate production planning and order splitting under the constraints of time windows and production capacity. For example, Azevedo and Sousa (2000) mentioned that order splitting and assignment are main tasks in an order insertion problem with production time windows. These tasks plan the production of an incoming customer order in a multi-site and multi-period make-to-order production system. However, their proposed mathematical formulations did not consider these tasks. Jaruphongsa and Lee (2008) also studied a dynamic lot-sizing problem with delivery time windows and container-based transportation costs. Two polynomial-time algorithms were proposed for the two special cases of the problem where delivery order splitting is allowed. Both of the above mentioned studies treated order-splitting activities as input parameters instead of decision variables.

3. Problem statement and formulation

We consider a multi-item capacitated production planning problem in make-to-order manufacturing. The schematic diagram of the studied system is illustrated in Fig. 1. The customers place the orders to a company that has several plants to perform the production activities. Each order only includes one item. The order information, which includes demand quantity of the item, its release time, and due time, is known in advance. The basic process of order treatment is as follows: when an order's release time is reached, it is divided into suborders for processing and then assigned to the corresponding plants. At the due time of each order, the items must be completed and shipped to the company and then the corresponding customers.

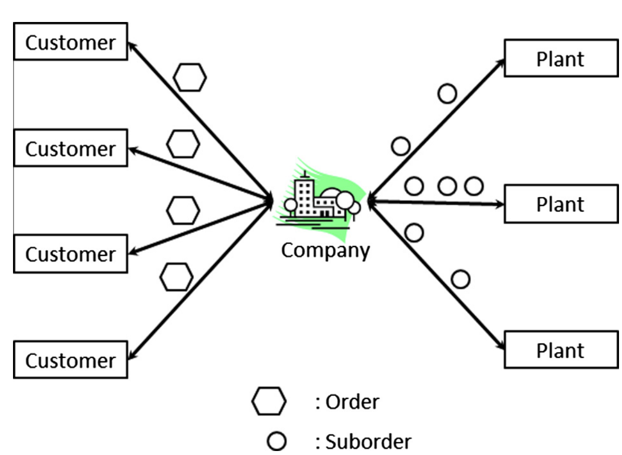

Fig. 1. Schematic diagram of the system.