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Accelerating Benders decomposition approach for robust aggregate production planning of products with a very limited expiration date

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ABSTRACT

The price of products with a very limited expiration date reduces dramatically after a certain period, say a season. Thus, overproduction or deficiency of such products will end in loss of profit. This study determines aggregate production planning (APP) of products with a very limited expiration date, such as seasonal clothing, New Year gifts, yearbooks and calendars using postponement policy with uncertain conditions. In order to apply the concept of postponement for these products, three types of production activities including direct production, semi-finished production and final assembly are taken into account. Additionally, a robust optimization model is expanded to deal with the inherent uncertainty of the model parameters. Moreover, since the proposed problem is NP-hard, a Benders decomposition algorithm is developed by using two efficient acceleration inequalities to tackle large-scale computational complexity. Finally, a set of real data from a calendar producing company in Tehran called "NIK Calendar" are used to validate the model and show the efficiency as well as convergence of the developed Benders decomposition algorithm. The computational results clearly show efficiency and effectiveness of the devised algorithm.

1. Introduction

Production planning is one of the most important issues in production systems that aim at effective planning and coordination of all production activities in such a way as to optimize the companies' goals. Production planning purposes include determining the optimal amount of production, inventory and other important parameters of production to meet variable demands in a certain planning period (Ramezanian, Rahmani, & Barzinpour, 2012). In fact, production planning is a decision-making process about the resources that an organization needs to carry out operations in the future, in a way that the allocation of these resources to production is as required and also with the least expenditure costs. APP, decision-making and long-term planning for a certain period of time in such matters as the total production volume, the shortage, the number of employees, various methods of providing and capacity leveling are conducted with a group perspective and in the general level (Mirzapour Al-e-hashem, Malekly, & Aryanezhad, 2011).

The present study analyzes aggregate production planning of products with a very limited expiration date, such as seasonal clothing, New Year gifts, yearbooks and calendars that New Year specifications are printed on them. As the end of the life cycle of these products approaches (as of the end of the year, before the New Year), their demand increases dramatically. Therefore, the demand for these products is very sensitive to time, which makes their production planning and inventory control difficult. On the other hand, storing these products during production sale can result in less revenue, because these products cannot be profitable after a certain date. In order to deal with the limited expiration date properties, postponement strategy has been used to solve the problem of production planning for such products in terms of limited resources and growing demand. Postponement means that the product stays in the middle of production line, e.g., it has passed the first phase of production and according to various cases (e.g., color, size and type of product) production activities such as blending, packing, color work and final assembly will be postponed until the next phase. Indeed, until the time that orders are achieved, the next production phases are postponed (Aviv and Federgruen (2001a, 2001b), Van Hoek (2001)). There is little research on determination of aggregate production planning of these products. Accordingly, the present study can solve production planning problem in companies producing products with a

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very limited expiration date, such as seasonal clothing, New Year gifts, yearbooks, and calendars that New Year specifications are printed on them, such as “NIK Calendar” company who manufactures different types of calendars and phonebooks in Tehran.

It is suggested that the products production process evaluated by applying the postponement be divided into two manufacturing processes consisting of final and semi-finished production. Thereupon, three types of production activities including direct production, semi-finished production and final assembly will be taken into account. Nonetheless, the proposed model characterizes that (1) how much final product must be produced directly from raw materials (direct production); (2) how much semi-finished product must be made from raw materials (semi-finished production); and (3) how much final product must be produced from semi-finished products (final assembly); in which the resources be well-used to visit any significant growth in demand. In addition, by using this model, all of the costs will be minimized simultaneously, including the costs of setup, production, labor, inventory, hiring and laying-off.

Demand for products with a very limited expiration date and many of the cost parameters in the APP are mainly uncertain in the real-word environments. Moreover, as economic scenarios are taken into account, changes in uncertain data don’t have significantly effect on an optimized production planning (Leung, Tsang, Ng, & Wu, 2007c). Thus, in order to account the inherent uncertainty of the model parameters, different economic scenarios have been considered and then a robust optimization model have been applied (Mulvey, Vanderbei, and Zenios (1995) technique) for optimizing the production problem of such products for multi-site productions under uncertain conditions. This paper contributes to the literature in five directions. First, we use postponement policy for the production of products with a very limited expiration date. Second, since the inherent uncertainty of the model parameters, a robust optimization method is utilized. Third, the proposed model incorporates production planning under a multi-site manner into the problem to make it more realistic. According to Ramezanian et al. (2012), issues regarding APP, are strongly NP-hard and nowadays meta-heuristic methods such as genetic algorithms are used to solve them, which do not guarantee obtaining an accurate and optimum general answer. Therefore, it can be argued that the addressed problem in this study is one of the NP-hard problems and an efficient algorithm will be required to tackle its computational complexity. Hence, as fourth innovation, we develop a powerful Benders decomposition algorithm (BDA) using two efficient inequalities to accelerate the convergence of algorithms in order to solve the addressed NP-hard problem in a large scale. Fifth, real data is applied to study the application of the developed model in an actual case study.

The rest of this study is organized as follows. Section 2 presents a brief overview of APP field as well as production of products with a very limited expiration date. In Section 3, mathematical modeling of the production planning is presented. Section 4 introduces the proposed solutions including the accelerated Benders decomposition algorithm (ABDA) on a large scale. In Section 5, performance of the model and efficiency of the proposed solution, with regard to data collected from a manufacturer of calendars in Tehran are examined and tested. Eventually, conclusions and some avenue for future researches are presented in Section 6.

2. Literature review

The issue under review is a multi-site and multi-product aggregate production planning (APP) with postponement strategy. APP is defined as a long-term capacity planning under a planning horizon of 6–18 months. The postponement of the production means activities such as blending, packing and final assembly will be postponed until the next phase. In fact, until the time that orders are achieved, the next phase of production will be postponed. In this section, we aim to provide more related studies to our work briefly. For comprehensive reviews on production planning problems, the interested readers can refer Mula, Poler, Garcia-Sabater, and Lario (2006) and Fahimnia, Farahani, Marian, and Luong (2013).

An early contribution was provided by Garg and Tang (1997), who examined two kinds of postponement in the production process as well as the importance of diversity of demand and the relative scope of delivery time in determining the suitable time of postponement. Pagh and Cooper (1998) explained that the main benefit of postponement policy is decrement or complete deletion of uncertainty and risk in production and logistical operations. Aviv and Federgruen (2001b) investigated the profit of postponement, where distributions were considered to be unfamiliar. Van Hoek (2001) surveyed the related literature of postponement policy as well as obtained postponement positions in production planning.

A fuzzy model for production planning was extended by Wang and Fang (2000). They proved that dissolutions in the shape of fuzzy numbers prepare a greater flexibility to manage production in a fuzzy situation. Baykasoglu (2001) stated that an APP takes into account costs minimization, levels of inventory, alteration in level of workforce, production wages in overtimes, alteration in the rate of production, the number of setups, factory and workforce downtime, benefit maximization and customer services with a higher priority. Wang and Fang (2001) devised a four-objective model, which demand, machine time as well as costs were considered under uncertainty. Høyland and Wallace (2001) proposed a model to formulate risk aversion in random linear programming and considered utility function as piecewise linear curve. A nonlinear robust optimization model was extended, in which the objective function was a risk-averse concave function (Bai, Carpenter, & Mulvey, 1997). Jang, Jang, Chang, and Park (2002) proposed three decompose formulation types and a genetic algorithm for production planning and distribution operations. Park (2005) introduced a more integrated approach by developing a single mixed integer formulation and an innovative two-phase solution for the model.

Leung and Ng (2007a) developed a model of goal programming models to solve APP for products with a very limited expiration date and postponement policy. Continuing their study, they also developed a stochastic programming model for production planning of products with a very limited expiration date using postponement policy (Leung & Ng, 2007b). Leung et al. (2007c) added the robust optimization model to literature for APP problem in uncertain conditions. They determined optimal production planning using Mulvey et al. (1995) technique to minimize costs such as costs of production, inventory, and workforce. Also, the robust model is expanded for production planning of perishable products with uncertain conditions (Leung, Lai, Ng, & Wu, 2007d). Leung and Chan (2009) studied a goal programming model for APP with resource utilization constraint with the goal of maximizing profit, minimizing repair costs, and maximizing the use of production capacity of China factory.

Mirzapour Al-e-hashem et al. (2011) proposed a multi-objective robust optimization model for multi-product and multi-site aggregate production planning in the supply chain under uncertain conditions. In their proposed model, they divided workforce into several skill levels; considered the possibility for workforce upgrade to a higher level; and solved the model using Mulvey et al. (1995) technique. Ghasemy Yaghin, Torabi, and Fatemi Ghomi (2012) examined the APP in a two-stage supply chain with pricing, and used a combined fuzzy multi-objective approach related to fuzzy goal programming method to resolve the issue. Jose Alem and Morabito (2012) analyzed cutting matter in production of wooden chair manufacturing industry with a robust