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A simulation-optimization approach for sales and operations planning in build-to-order industries with distant sourcing: Focus on the automotive industry

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ABSTRACT

Due to increasing globalization and distant sourcing, reconciling industrial constraints and sales requirements becomes very challenging for build-to-order industries facing an uncertain environment and demanding customers. The sales and operations planning (S&OP) is crucial for efficiently balancing production capacities with the volatile market demand. In this article, we propose an original S&OP model in order to improve the trade-off between the supply chain costs and the customer satisfaction. The problem is formulated as a multi-objective optimization model with ε-constraints and is solved by a simulation-optimization approach. Two classes of policies for managing the parts procurement and the flexibility offered to the sales function are presented. The model and the proposed solution are illustrated with the case study of Renault, a French global automobile manufacturer. Several policies and optimization algorithms are compared in terms of system performance and computation time. Managerial insights are derived based on these results.

1. Introduction

The globalization has significantly increased the procurement lead times. This makes supply chains more vulnerable to various disruptions like uncertain demand (Tang, 2006). The use of a traditional build-to-order strategy may be inefficient to deal with uncertainty and distant sourcing. Indeed, while customers are impatient and would not wait for a long time (Elias, 2002; Holweg, Disney, Hines, & Naim, 2005), the firm needs to procure parts several weeks beforehand because of distant suppliers. Therefore, part procurements are based on forecasts that are often unreliable, especially in the automotive industry (Childerhouse, Disney, & Towill, 2008; Elkins, Huang, & Alden, 2004).

A trade-off has to be made between two conflicting objectives: on one hand, the company needs more flexibility and shorter delivery times to satisfy customer demand. On the other hand, the production system asks for a stable production plan and higher visibility on the future demand. To make the supply chain more agile and flexible in an uncertain environment, several actions are possible (Stevenson & Spring, 2009): better integration of suppliers, modularity for product design, information sharing, etc.

In this paper, we focus on the sales and operations planning (S&OP) as means of flexibility. Grimson and Pyke (2007) define this process as the tactical production plan that links strategic perspectives to daily operations. The authors develop a framework for helping managers to evaluate the maturity of their S&OP processes. The S&OP has to take into account both the sales objectives and the industrial constraints. The S&OP is crucial to improve the trade-off between logistic costs and customer requirements. Recent literature reviews on S&OP are given in Grimson and Pyke (2007), Thomé, Scavarda, Fernandez, and Scavarda (2012) and Olhager (2013). Researchers show that the S&OP can improve significantly firms' performance and this topic becomes increasingly popular in industry. Thomé, Sousa, and Scavarda do Carmo (2013) analyse a sample of 725 manufacturers around the world and test different hypotheses on the impact of S&OP on the manufacturing performance. The authors argue that the integration of suppliers amplifies the positive impact of internal S&OP on the firm performance. For further details, we refer the readers to a recent literature review on the coordination framework of S&OP Tuomikangas and Kaipia (2014).

During the last decades, the automotive industry has largely evolved from mass production to mass customization with more individualized and sophisticated vehicles (Brabazon, MacCarthy, Woodcock, & Hawkins, 2010; MacCarthy, Brabazon, & Bramham, 2003). If the product variety represents an important competitive

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advantage (Ramdas, 2003), it also makes the supply chain more complex and can increase significantly the production costs (Scavarda, Reichhart, Hamacher, & Holweg, 2010; Stäblein, Holweg, & Miemczyk, 2011). To adapt efficiently their production capacities with the volatile and changing market demand, the automobile manufacturers strive to make their production systems more flexible and to implement build-to-order strategies in their supply chains (Howard, Powell, & Vidgen, 2005; Miemczyk & Holweg, 2004; Volling & Spengler, 2011). To improve the order fulfillment processes in the automotive industry, Brabazon, MacCarthy, and Hawkins (2007) and Brabazon et al. (2010) present an original method named virtual-build-to-order based on product reconfiguration.

For the automotive industry, Hahn, Duplaga, and Hartley (2000) describe the new mechanisms of Hyundai to coordinate sales and supply chain. The authors insist on the importance of a better synchronization and integration of sales and supply chain functions. Meyr (2004) describes the complex organizational issues in sales and operations planning and shows that the literature lacks comprehensive overviews for short and mid-term planning in the automotive industry. Bihlmaier, Koberstein, and Obst (2009) present a deterministic and a stochastic model for optimizing the tactical and strategic production planning with uncertainty in the automotive industry. The study of Tomino, Park, Hong, and Roh (2009) compares the production planning methods of Toyota, Nissan and Mitsubishi and shows how the automobile manufacturers have implemented a market flexible customizing system.

Our research studies a S&OP model, introduced in Lim, Alpan, and Penz (2014), for managing the conflicting objectives of sales and supply chain functions. The originality of this S&OP model lies on sales constraints and flexibility rates for partially controlling the order fulfilment process. Safety stocks are managed according to the flexibility given to the sales function. This planning method is particularly relevant for companies that face distant sourcing and unreliable forecasts. It helps reducing logistic costs while improving the customer satisfaction. A first investigation of this planning method using simulation is presented in Lim et al. (2014). The authors present a simulation model (re-used in this article) and tests the static rules for the sales constraints and flexibility rates to show their interest as an S&OP tool. Although simulation is a powerful tool to improve operations' efficiency and to incorporate uncertainties in real complex systems (Glover, Kelly, & Laguna, 1999), it can only test what-if scenarios, and hence, is not very convenient to find the optimal (or the best) solution. Similarly, the main drawback in Lim et al. (2014) is that the simulation model cannot tell the users which values are the best for the sales constraints and flexibility rates. The only way is to test all possible combinations and choose the best, which is time consuming and not applicable in industry. The optimization model is needed to this end. However, the optimization model alone will not work either since the problem is complex with several stochastic parameters. Therefore, in this article, we extend the research of Lim et al. (2014) by introducing optimal policies for managing parts inventory and sales flexibility in the S&OP. These policies are obtained via a simulation-optimization approach.

Simulation and optimization techniques can be combined in various manners (Ladier, Greenwood, & Alpan, 2015); optimization can be embedded into a simulation model and is used to deduce some decision rules to be applied in the simulation model or simulation can be embedded into an optimization model (see for instance, Almeder, Preusser, & Hartl (2009)). This latter is referred as the simulation-optimization approach in the literature. The simulation-optimization approach is a structured method to determine optimal parameter values, where the objective function is measured by a simulation model (Swisher, Hyden, Jacobson, & Schruben, 2000). This approach has been widely used for solving complex industrial problems, (see, among others, Rosen & Harmonosky (2005), Zeng & Yang (2009), Li, Gonzalez, & Zhu (2009), Keskin, Melouk, & Meyer (2010), Bilgen & Çelebi (2013), Sel & Bilgen (2014)) and is especially efficient to handle the stochastic and dynamic nature of such complex systems (see for instance, Safaei, Moattar Husseini, Farahani, Jolai, & Ghodsypour (2010)). There exists various techniques to search efficiently the best parameter values in simulation-optimization problems: random search (Andradóttir, 2006), metaheuristics (Alrefaei & Diabat, 2009; Haddock & Mittenthal, 1992; Ólafsson, 2006; Rosen & Harmonosky, 2005), gradient-based procedures (Fu, 2006), response surface methodology (Kleijnen, 2008; Neddermeijer, van Oortmarssen, Piersma, & Dekker, 2000), etc. And, for the simulation model, either discrete event or the agent-based simulation techniques are employed (see for instance, Nikolopoulou & Ierapetritou (2012), Sahay & Ierapetritou (2013)). In this research, we consider several random search techniques and a metaheuristic method (simulated annealing). For more information on the vast research area of simulation-optimization and its applications, we refer the readers to the literature reviews of, among others, Fu (1994), Swisher et al. (2000), Fu (2002), Swisher, Hyden, Jacobson, and Schruben (2004), Fu, Glover, and April (2005), Rani and Moreira (2010).

To the best of our knowledge, this article is the first that proposes a multi-objective simulation-optimization model for solving a S&OP problem with flexibility, uncertain demand and impatient customers (a challenging context faced by many companies at the moment). The main contribution is, first of all, the description and the implementation of an efficient method to compute the optimal policies for managing inventories and flexibility that can be offered to the Sales function in the S&OP, under the challenging context described above. We present a multi-objective optimization model with ε-constraints and we investigate two different classes of policies (static and linear). The static policies are introduced in Lim et al. (2014), the linear policies are novel and generalize the threshold policies given in Lim et al. (2014). The second contribution is the application of the method on the case study of Renault, a global automobile manufacturer. Numerical experiments on industrial data show that there are significant benefits of using linear policies instead of static ones. Moreover, the superiority of linear policies varies greatly depending on the problem characteristics. Based on this case study, we also provide managerial insights for decision makers and discuss the practical implementation of our solution. Even though the industrial focus in this article is the automotive industry, we believe that the proposed model could fit other build-to-order industries, having similar environment (such as volatile demand, distant sourcing, and impatient customers), and similar operational characteristics (such as the order fulfillment mechanism). We consider that the above-mentioned features are quite common to most of the build-to-order industries.

This article does not have the ambition to present new optimization techniques. The performance of the proposed algorithms is an important parameter at the implementation phase in an industrial context. Therefore, we also present the comparison of different optimization techniques and the generated solutions in terms of system performance and computation time.

The paper is organized as follows. Section 2 presents the problem, the notations and the mathematical model. Section 3 describes the simulation-optimization approach and the different optimization techniques employed in this article. Section 4 details the experimental design and the numerical results based on the Renault's case. Several managerial insights are derived from these results. Finally, the contribution of this paper and research perspectives are discussed in Section 5.