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Uncertainty propagation in a supply chain or supply network

Shabnam Rezapour, Janet K. Allen *, Farrokh Mistree

The Systems Realization Laboratory, The University of Oklahoma, Norman, OK 73019, USA

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ABSTRACT

A supply chain is characterized by uncertain demands (demand-side uncertainty) and uncertainties associated with the performances of the production facilities (supply-side uncertainty). In this paper, a method is proposed to plan production in a supply chain with a multi-echelon supply process with unreliable production facilities working in markets with uncertain demand. In such a system it is necessary to consider the global and cumulative effects on the performance of the entire supply chain. We introduce the salient features of uncertainty propagation in supply chains and demonstrate their impact quantitatively using a test problem from the automotive industry.

1. Frame of reference

Today companies are improving their competitiveness by reducing production costs, by higher productivity, by improving quality through concentrating on their core competencies and by improving their flexibility to respond to rapidly changing customer expectations. All these requirements disperse previously centralized production systems into a network of core-competency-centered companies called “Supply Chains” (SC) or, more accurately, “Supply Networks” (SN). Along with all the advantages of SCs/SNs, decentralization reduces their controllability and makes them more vulnerable to uncertainties. This highlights the importance of uncertainty management in SC/SN to predict, control and mitigate the negative effects of uncertainty on SN performance. Uncertainty management capability of a SC/SN are mainly reflected in one of its performance metrics, the service level. Recently service level has become an important competition factor and many companies attempt to improve their market share by providing better service levels. For example, two well-known book retailers, Amazon and Barnes and Noble, who share more than 85 percent of online sales, initiated competition by promising the same business day delivery in different parts of the country. Blockbuster, a well-known company in the video rental industry, advertises its high fill rate and backs its promise up with a free rental guarantee. The same is happening in the fast food industry, Domino’s, for example, guarantees 30-min delivery or free delivery. Black Angus restaurants advertise free lunch if the customer’s order is not provided in 10 min. Retailers such as Lucky emphasize their short checkout times. Well Fargo Bank guarantees less than five minutes wait for its customers or gives them a $5 reward. Airline companies advertise based on their percent age of on-time arrivals. Several independent internet sites provide information about the company performance such as their service level warranties, back-up chargeback agreements, etc. Moreover, specifying a delivery window is common in business-to-business settings. Thus, service is becoming one of the most important competition factors. Service level is the capability of a company to balance demand and supply quantities. This balancing is not easy in reality because both demand and supply processes are stochastic. By assuming perfect production systems, supply side uncertainty has usually been ignored in the extensive service level literature. But in reality there is no perfect production system. Increasing the

* Corresponding author. Tel.: +1 405 550 3969; fax: +1 405 325 7555.
E-mail addresses: shabnam.rezapour@ou.edu (S. Rezapour), janet.allen@ou.edu (J.K. Allen), farrokh.mistree@ou.edu (F. Mistree).

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rate of production increases the likelihood of machinery and labor failures leading to a higher rate of non-conforming items produced (Sana, 2010). Decentralized and multi-echelon production systems of SCs/SNs amplify the probability of non-conformation. These trends demand more accurate approaches to determining appropriate service levels in the SCs/SNs. In this paper, by considering supply-side uncertainties and their propagated effects on the final supply quantities, we to respond to this new need of the business environment which, as will be shown later, is mainly ignored in the service level literature.

There are several uncertainties in a SC/SN. They can be classified as: (i) operational uncertainties, e.g., uncertain customer demand, uncertain supply quantity, uncertain raw material prices, etc. These uncertainties are expected and they occur frequently and have significant probabilities; (ii) unexpected disruptions with very low probabilities and very extensive effects such as earthquakes, floods, hurricanes, terrorist attacks, or economic crises such as currency fluctuations or strikes (Tang, 2006). In this paper we concentrate on the operational demand and supply quantity uncertainties which are common in the SC/SN context. There has been much work in the literature on operational uncertainties in the SCs/SNs. Many researchers only consider demand-side uncertainty (Sabri and Beamon, 2000; Miranda and Garrido, 2004; Shen and Daskin, 2005; Daniel and Rajendran, 2006; Romeijn et al., 2007; Ko and Evans, 2007; Shen and Qi, 2007; You and Grossmann, 2008; Schütz et al., 2009; Pan and Nagi, 2010; Park et al., 2010; Cardona-Valdés et al., 2011; Hsu and Li, 2011). In our problem, in addition to demand-side uncertainty, different supply-side uncertainties are also considered. Difficulties with supply in one entity can disrupt production schedules in all subsequent entities of the SC/SN leading to a delay in respond ing to customers' demands. Poor service levels lead to lost sales and long-term demand attenuation. Hence, it is imperative to develop strategies to mitigate the negative effects of supply-side uncertainties, especially in SCs/SNs with multiple supply echelons. The method presented here not only significantly improves the service level estimation in SCs/SNs, but also improves system reliability for preserving the service level and improving competitive capabilities. We assume that production systems in the SC's/SN's echelons are accompanied by stochastic percentages of wastage and nonconforming output making their supply quantities uncertain.

Supply-side uncertainty management in SC/SN has a rich literature about disruptions that affect operational uncertainty (Santoso et al., 2005; Listes and Dekker, 2005; Azaron et al., 2008; Yu et al., 2009; Chen et al., 2011; Li et al., 2010; Xanthopoulos et al., 2012; Baghalian et al., 2013). There are few works in the field of operational supply-side uncertainty in SC/SN. Chopra et al. (2007) consider product flow planning in a SN consisting of a buyer and two suppliers. The first supplier is cheaper, but unreliable and the second supplier is completely reliable, but more expensive. Demand in the markets is assumed to be deterministic. In this paper, supply-side uncertainty is considered and the necessity of decoupling operational and disruption supply risk is highlighted. Disruption is modeled by scenarios and operational supply uncertainty is considered as a random variable with a given distribution function. Schmitt et al. (2010) consider optimal ordering and the required amount of the reserve product of a two-echelon SN of a firm and its suppliers. One supplier is unreliable whereas the second is completely reliable and available but more expensive. They compare single-periods and multi-periods and discuss the advantages of considering multi-periods. Dada et al. (2007) consider a company with several potential suppliers both reliable and unreliable and decisions about supplier selection and order splitting are made to maximize the company's expected profit. Ross et al. (2008) consider the ordering policy of a firm with a Poisson arrival demand and a single sup plier with a random supply process. Supply and demand processes have time-dependent probabilities. They set a time varying order ing policy to decrease the total cost of the system. Li et al. (2010) develop a model for inventory management of a SN with an unreliable supplier and a retailer. They investigate the impact of supply-side uncertainty and customer differentiation on minimizing average annual cost.

In existing research, the SC's/SN's supply process is usually restricted to one echelon and uncertainty in the facility performance of that echelon. However in actuality, most SCs/SNs have longer production chains/networks involving several echelons of suppliers of suppliers, suppliers, component manufacturers, assemblers and so on. To fill the gap, we con sider a SC/SN with a multi-echelon supply process producing and supplying a product to a market with uncertain demand. The SC's/SN's multi-echelon supply process includes production facilities' with uncertain production systems. In such a complex

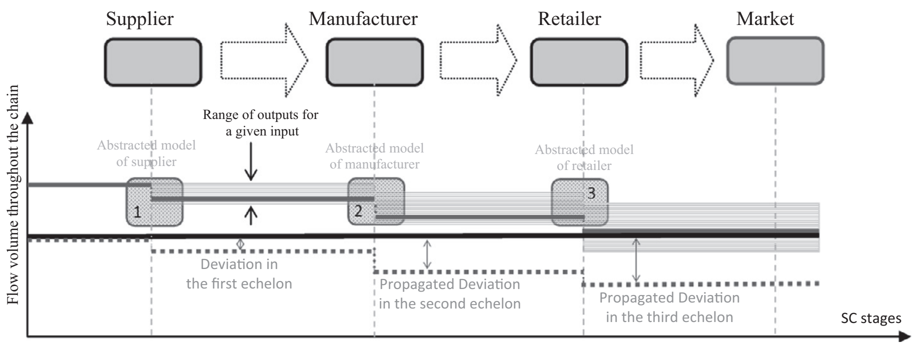

Fig. 1. Uncertainty propagation in a sample SC. Black line: Product flow planned in a deterministic model; Dashed line: Product flow that is happening in reality; Grey line: Solution of reliable model expected to be obtained in this paper.