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Integrated inventory management and supplier base reduction in a supply chain with multiple uncertainties

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ABSTRACT

This paper considers a manufacturing supply chain with multiple suppliers in the presence of multiple uncertainties such as uncertain material supplies, stochastic production times, and random customer demands. The system is subject to supply and production capacity constraints. We formulate the integrated inventory management policy for raw material procurement and production control using the stochastic dynamic programming approach. We then investigate the supplier base reduction strategies and the supplier differentiation issue under the integrated inventory management policy. The qualitative relationships between the supplier base size, the supplier capabilities and the total expected cost are established. Insights into differentiating the procurement decisions to different suppliers are provided. The model further enables us to quantitatively achieve the trade-off between the supplier base reduction and the supplier capability improvement, and quantify the supplier differentiation in terms of procurement decisions. Numerical examples are given to illustrate the results.

1. Introduction

Manufacturer-oriented supply chain systems are concerned with the effective management of the flow and storage of goods in the process from the procurement of raw materials from the suppliers to the delivery of finished goods to the customers. Here the flow refers to transporting materials and the storage refers to holding inventory. One of the key challenges in supply chain management is how to appropriately tackle and respond to a variety of uncertain factors such as supply uncertainty and disruption (Lu, Huang, & Shen, 2011; Snyder et al., 2012), imperfect production or defective items (Pal, Sana, & Chaudhuri, 2013; Sana, 2010), unreliable machines (Pal et al., 2013; Song & Sun, 1998); stochastic processing times (Buzacott & Shanthikumar, 1993; Song, 2013), and random demands (Masih-Tehrani, Xu, Kumara, & Li, 2011).

Traditionally, procurement policy about lot sizing decisions for raw materials was often separated from the production control systems so that the complexity and interplay of the functional areas like procurement, inventory, production and scheduling are decomposed and reduced. Such treatment is useful to simplify the management problem, and may be appropriate in situations with loose connections between functional areas. However, from a systemic viewpoint, it may lead to sub-optimal solutions and the system may perform far away from the optimum. In the last two decades, much attention has been paid to the coordination between procurement management and production management along the development of the supply chain management concept (e.g. Arshinder, Kanda, & Deshmukh, 2008; Goyal & Deshmukh, 1992; and the references therein). This paper will consider the optimal integrated procurement and production problem for a manufacturing supply chain with multiple suppliers in the presence of multiple uncertainties such as uncertain material supplies, stochastic production times, and random customer demands. In the following, we review and classify the relevant literature into two groups. The first group focuses on the sourcing (procurement) problems among multiple suppliers under supply uncertainty; and the second group focuses on the integrated inventory management for production systems subject to two or multiple types of uncertainties.

With respect to the first group, Snyder et al. (2012) described several forms of supply uncertainty including: disruptions, yield uncertainty, capacity uncertainty, lead-time uncertainty, and input cost uncertainty; however, the boundaries among these forms are often blurry. Sourcing from multiple suppliers is an important strategy to deal with the supply uncertainty. The general sourcing (ordering) problem is to determine from how many and which suppliers to source the commodity (or raw material) and in what quantities in order to minimise total expected cost. A significant number of studies have been conducted in this area in the last

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two decades (cf. the review papers: Ho, Xu, & Dey, 2010; Minner, 2003; Qi, 2013; Thomas & Tyworth, 2006; Snyder et al., 2012). More specifically, Lau and Zhao (1993) considered an inventory system with two suppliers subject to stochastic lead times and demands. They presented a procedure to determine the optimal order-splitting policy (i.e. the total order quantity, reorder point and proportion of split between two suppliers). Anupindi and Akella (1993) studied a dual sourcing problem with stochastic demand and supply uncertainty (e.g. random disruption and yield uncertainty). They proved that the optimal ordering policy has three action regions depending on the on-hand inventory level. Agrawal and Nahmias (1997) developed a mathematical model to optimise the number of suppliers with yield uncertainty. They assumed that the yield from an order is the placed order size multiplied by a normal random variable, which implies that larger orders have higher yield variance. Such effect favours smaller orders from many suppliers. On the other hand, more suppliers incur additional fixed costs associated with each supplier such as qualifying new suppliers, supplier development, and more logistics problems. Their model is able to find the optimal number of suppliers that balances these two competing objectives. Berger, Gerstenfeld, and Zeng (2004) examined the single versus multiple sourcing problem from the risk management viewpoint and presented a decision-tree based optimisation model to evaluate the performance of the two procurement approaches. Here the risks refer to catastrophic events that affect many/all suppliers, and unique events that affect only a single supplier. Berger and Zeng (2006) extended the above decision-tree approach to considering unpredictable operations interruptions caused by all suppliers failing to satisfy the buyer's demand so that the optimal size of the supply base can be determined. Ruiz-Torres and Mahmoodi (2007) also utilised the decision tree approach to determine the optimal number of suppliers taking into account various levels of supplier failure probability and possible procurement cost savings gained from using less reliable suppliers. Dada, Petruzzi, and Schwarz (2007) formulated a newsvendor model for the procurement decisions from multiple unreliable suppliers in which demand is stochastic and supply uncertainty can reflect disruptions, yield uncertainty, and capacity uncertainty. They showed that if a given supplier is not used, then no more expensive suppliers than this supplier should be used. Federgruen and Yang (2008, 2009) examined the supplier selection and diversification issues in the similar inventory system to that of Dada et al. (2007), but with different cost structures.

Burke, Carrillo, and Vakharia (2007) contrasted the preference of single versus multiple supplier sourcing strategies in a single period, single product sourcing decisions under demand uncertainty. They showed that single sourcing strategy is preferred only when supplier capacities are large relative to the product demand and when the manufacturer does not obtain diversification benefits. In other cases, the multiple sourcing strategy is preferred. Jokar and Sajadieh (2008) considered a multiple sourcing inventory system with stochastic lead-times and constant demand under the reorder point-order quantity inventory control policy on a continuous-review scheme. They presented a mathematical model that is able to determine the optimal number of identical suppliers and quantify the difference between multiple-sourcing and sole-sourcing strategies. Sarkar and Mohapatra (2009) formulated a model with a decision tree-like structure to determine the optimal size of supply base by considering the risks of supply disruption caused by different types of events. Masih-Tehrani et al. (2011) showed that risk diversification is preferred in a multi-manufacturer-one-retailer system with stochastically dependent supply capacities, and indicated that if the retailer ignores the effect of dependent disruptions it would overestimate the fill rate and tend to order more than the optimum. Lu et al. (2011) considered the optimal sourcing policy in a supply chain with product substitution and dual sourcing under random supply failures. Mirahmadi, Saberi, and Teimoury (2012) used a decision tree approach to determine the optimal number of suppliers taking into account the supply risk and the associated costs (e.g. cost of supplier development, missing discount in volume, loss due to supply postponement). Silbermayr and Minner (2012) presented a semi-Markov decision process for the optimal sourcing problem with multiple suppliers in which demands, lead times and supplier availability are all stochastic. They showed that the optimal sourcing strategy (depending on the on-hand inventory, the outstanding orders and the supplier availability statuses) is rather complex. Pal, Sana, and Chaudhuri (2012a) addressed a multi-echelon suppler chain with two suppliers in which the main supplier may face supply disruption and the secondary supplier is reliable but more expensive, and the manufacturer may produce defective items. Arts and Kiesmuller (2013) studied a serial two-echelon periodic-review inventory system with two supply modes, and showed that dual-sourcing can lead to significant cost savings in cases with high demand uncertainty, high backlogging cost or long lead times.

With regard to the second group that addresses production-inventory control in the presence of uncertainties, a rich literature existed. The earliest relevant research could date back to early 1960s, e.g. Clark and Scarf (1960) studied the multi-stage or multi-echelon inventory systems with random demand and deterministic lead-time. When two or more types of uncertainties are modelled, the optimal production and inventory policies are often addressed within a single-stage, two-stage, or three-stage context. In the following, we mainly select the relevant literature considering two or multiple uncertainties with an emphasis on stochastic lead times.

Hadley and Whitin (1963) addressed a single-stage inventory management problem and identified the optimal inventory control policies for some special cases with restrictive assumptions, e.g. orders do not cross each other and they are independent. Zipkin (1986) characterized the distributions of inventory level and inventory position in continuous-time single-stage models with stochastic demand and lead times. Bassok and Akella (1991) investigated the optimal production level and order quantity with supply quality and demand uncertainty. Song and Zipkin (1996) studied a single-stage system with random demand and Markov modulated lead-times, and were able to characterise the optimal inventory control policy. Berman and Kim (2001) examined the optimal dynamic ordering problem in a two-stage supply chain with Erlang distributed lead-times, exponential service times and Poisson customer arrivals. They showed the optimal ordering policy has a monotonic threshold structure. Berman and Kim (2004) extended the above model to including revenue generated upon the service considering both exponential and Erlang lead times. He, Jewkes, and Buzacott (2002) considered a two-echelon make-to-order system with Poisson demand, exponential processing times, and zero lead times for ordering raw materials, and explored the structure of the optimal replenishment policy. Yang (2004) studies a periodic-review production control problem where both the raw material supply and product demand are exogenous and random. He was able to establish the partial characterisation of the optimal policies under both strict convex and linear raw material purchasing/selling costs. Simchi-Levi and Zhao (2005) investigated the safety stock positioning problem in multistage supply chains with tree network structure with stochastic demands and lead times, in which a continuous-time base-stock policy is used in each stage to control its inventory. Mukhopadhyay and Ma (2009) considered the optimal procurement and production quantity for a remanufacturing company with uncertain market demand. Song (2009) investigated the optimal integrated ordering and production control in a supply chain with a single supplier and multiple uncertainties. Muharremoglu and Yang (2010)