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A multiple sourcing inventory model under disruption risk

Lena Silbermayr[a],*, Stefan Minner[b]

[a] Dept of Business Administration, University of Vienna, Vienna A-1210, Austria
[b] TUM School of Management, Technische Universität München, Munich, Germany

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ABSTRACT

Interruptions in supply can have a severe impact on company performance. Their mitigation and management is therefore an important task. Reasons for interruptions can be machine breakdowns, material shortages, natural disasters, and labour strikes. Sourcing from multiple suppliers is a strategy to deal with and reduce supply disruption risk. We study a supply chain with one buyer facing Poisson demand who can procure from a set of potential suppliers who are not perfectly reliable. Each supplier is fully available for a certain amount of time (ON periods) and then breaks down for a certain amount of time during which it can supply nothing at all (OFF periods). The problem is modeled by a Semi-Markov decision process (SMDP) where demands, lead times and ON and OFF periods of the suppliers are stochastic. The objective is to minimize the buyer's long run average cost, including purchasing, holding and penalty costs. In a numerical study, we investigate the trade-off between single and multiple sourcing, as well as keeping inventory and having a back-up supplier. The results illustrate the benefit from dual souring compared to single sourcing and show the influence of the suppliers' characteristics cost, speed and availability on the optimal policy. Further, the value of full information about the supplier status switching events is analyzed and the performance of the optimal policy is compared to an order-up-to-*S* policy. As the optimal policy is very complex, a simple heuristic providing good results compared to the optimal solution is developed.

1. Introduction

For successful supply chain management, a buyer has to consider that suppliers may not always be available. Temporary supply interruption can occur due to machine breakdowns, labour strikes, natural disasters, terror events etc. As these disruptions can have a severe impact on the supply process, a buyer may source from more than one supplier to protect against supply risk. One example for a supply disruption where a dual sourcing strategy resulted in high cost savings is the Nokia–Ericsson case in 2000, where a fire shut down Philips' semiconductor plant in New Mexico which supplied both buyers Nokia and Ericsson for several weeks. Due to the disruption, Ericsson lost $400 million, while Nokia managed to source from alternative suppliers, minimizing the negative impact of the disruption (Latour, 2001). In April 2010, the car manufacturer BMW had to stop production in three German plants because electronic components, normally airshipped, could not be delivered due to the ash cloud over Europe (Friese et al., 2010). Recently, the earthquake in Japan in March 2011 caused companies around the world to rebuild their supply chains to cope with supply disruption and search for new suppliers to avoid running out of components that had been previously obtained from Japan (Hookway and Poon, 2011). These real life examples show that buyers can reduce the risk of supply shortfalls by sourcing from multiple suppliers when the supply process is subject to failure.

Our approach incorporates a multiple sourcing inventory system with stochastic demand, lead times and reliability of the suppliers, varying in cost, speed, and reliability. In order to compute the optimal decisions regarding supplier selection and reorder quantities for each state of the system, we formulate a semi-Markov decision process (SMDP) under Poisson demand, exponentially distributed lead times and exponentially distributed periods where a supplier is available (ON) and unavailable (OFF). A state consists of the buyer's inventory level, the outstanding orders, and the availability of the suppliers. As suppliers typically differ in service and cost, we investigate the optimal sourcing strategies depending on supplier characteristics like cheap/expensive, fast/slow, and reliable/unreliable.

This paper is organized as follows: In Section 2 we review relevant literature. In Section 3 we give a detailed description of the model assumptions and the semi-Markov decision process (SMDP) formulation. In Section 4 we present numerical results discussing the optimal sourcing strategy dependent on the states of the inventory system for the dual sourcing case. In Section 5 we summarize the results and give concluding remarks.

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* Corresponding author. Tel.: +43 1 4277 37959; fax: +43 1 4277 37954.
E-mail addresses: lena.silbermayr@univie.ac.at (L. Silbermayr), stefan.minner@tum.de (S. Minner).

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2. Literature

Comprehensive literature reviews on sourcing strategies and the optimal number of suppliers are provided by Elmaghraby (2000), Minner (2003) and Thomas and Tyworth (2006). Tang (2006) discusses supply risk management strategies in detail. A recent overview on supply disruption literature is provided in Snyder et al. (2012).

Although the problem of inventory systems with random supply is widely discussed, the majority is restricted to the single supplier case where no alternative source is available. Meyer et al. (1979) discuss a production–storage system with constant demand subject to stochastic failure and repair processes and give an expression for the average inventory level in the single supplier case. Moinzadeh and Aggarwal (1997) discuss an unreliable bottleneck production–storage system with random disruptions and positive set-up cost. They develop properties of the policy parameters, minimizing expected total cost. Parlar (1997) considers a continuous-review inventory problem with random demand and random lead-time where supplier availability is modeled as a Markov process. Using renewal reward theory, he constructs the average cost function of the underlying problem. Mohebbi and Hao (2006) consider a continuous review inventory system with Erlang-distributed lead times and lost sales.

Supply disruption models that include more than one supplier are discussed in Parlar and Perry (1996) and Gürler and Parlar (1997). Parlar and Perry (1996) consider order-quantity/reorder-point inventory models for single, dual, and multiple suppliers where the ON and OFF periods are exponentially distributed. They propose a suboptimal ordering policy in the two supplier cases where the parameters are determined numerically and show that as the number of suppliers becomes large, the objective function of the multiple supplier problem reduces to that of the classical EOQ model. Gürler and Parlar (1997) analyze an inventory model with two suppliers, where the distributions of the ON and OFF periods are Erlang and general. Both models are restricted by the assumption that demand is constant and that the suppliers have identical cost structures which often is not the case in reality.

Anupindi and Akella (1993) deal with two uncertain suppliers with different reliabilities and the effects on the inventory policy of the buyer in a single- and a multi-period case. Supply uncertainty is modeled in various ways. First, they model each supplier delivering an order of the buyer for a given probability; otherwise, he has to deliver the order in the consecutive period. Second, they consider yield uncertainty where the suppliers deliver a random fraction of the ordered quantity. They find that the optimal ordering policy depends on the current inventory: Either order nothing if the inventory is large, order only from the cheap supplier if the inventory is moderate or order from both suppliers if the inventory is small. Tomlin (2006) investigates an infinite-horizon model with random supply where the buyer can source from an unreliable and a reliable but more expensive supplier using a Markovian model. He shows that inventory is preferred over supplier diversification if the supply disruptions are relatively short and frequent.

Dada et al. (2007) discuss the multiple supplier newsvendor problem, where supply and demand are uncertain. The suppliers are either unreliable, and supply is strictly less than the required amount with some probability or perfectly reliable. They conclude that from the buyer's perspective the quantity ordered is higher than in the standard newsvendor setting where supply is certain. Another conclusion is that the size of the selected supplier's order is dependent on whether he is reliable or not. Federgruen and Yang (2008) also consider a newsvendor framework procuring from multiple sources, where each source faces a random yield factor and some fixed cost showing the optimality of a cost based supplier selection policy.

Chopra et al. (2007) consider a dual-sourcing, single-product, single-period, inventory model with a primary, cheap but unreliable supplier and a perfectly reliable but more expensive supplier for a risk-neutral retailer. Giri (2011) analyses the model settings of Chopra et al. (2007) from a risk-averse retailer point of view. He shows that the order quantities from the primary supplier are lower in the context of a risk-averse retailer than in the risk-neutral case. Abginehchi and Larsen (2012) study a lost sales inventory system with two non-identical suppliers assuming Poisson demand, Erlang distributed replenishment lead times and no more than one outstanding order for each supplier. Their problem is modeled as a semi-Markov decision process where the decision maker decides to use dual sourcing with order splitting, dual sourcing with emergency order, or single sourcing.

3. Problem formulation

We consider a single item inventory system where a buyer facing stochastic demand can source from $k \in K$ potential suppliers which are subject to temporary disruptions. The availability status of a supplier is subject to changes and the respective times are called ON and OFF periods. The lengths of these periods are exponentially distributed with mean $1/\mu_{\text{ON}}^{k}$ and $1/\mu_{\text{OFF}}^{k}$, respectively. The set of suppliers K is the union of the set of available and unavailable suppliers, $K^{\text{ON}} \cup K^{\text{OFF}} = K$. The availability of a supplier k, the fraction of time where the supplier is operating without any disruptions, A_k is defined as $A_k = \mu_{\text{OFF}}^{k} / (\mu_{\text{OFF}}^{k} + \mu_{\text{ON}}^{k})$.

If a supplier is ON and fully available, the buyer can order any desired quantity from the supplier without capacity restrictions. Whenever a supplier switches to OFF, this supplier is interrupted and no orders can be placed. Nevertheless, the orders on the way to the buyer, placed prior to a disruption, are not affected and will arrive after the corresponding lead time of that supplier. The replenishment lead times are exponentially distributed with a mean $1/\mu_L^k$, $k \in K$. The lead times can be interpreted as the time required to process an item. Each item is handled separately and thus the lead times are independently and identically random variables which also implies order crossovers.

Customers arrive at the buyer according to a Poisson-process with rate λ. Demands are satisfied immediately if the buyer has physical inventory on hand. We consider a lost sales model and a backorder model. In the lost sales case, unsatisfied demand is lost and subject to a penalty cost p. In the backorder case, unsatisfied demand is backordered and subject to a backorder cost b per unit per time unit until the backorder is satisfied. Further, inventories are subject to holding cost h (independent of past procurement cost) per unit per time unit. The unit procurement costs are c_k, $k \in K$.

3.1. State of the system and possible decisions

The state of the system is described by the buyer's net inventory s, the number n_k of outstanding orders with each supplier, and the status v_k of the respective supplier. Thus, the state space of the semi-Markov decision process (SMDP) is defined as

$$I = \{(s, n_1, ..., n_K, v_1, ..., v_K)\}, \tag{1}$$

where $v_k = 1$ indicates that supplier k is ON and $v_k = 0$ that supplier k is OFF.

The states of the system are reviewed at random epochs when either a demand arrives or the availability status of a supplier changes. At these random epochs, decisions have to be made. The buyer decides whether to place a new order, the order quantity, and which suppliers to assign the order to. Thus, the action a at a certain decision epoch is defined as $a = (a_1, ..., a_K)$, where a_k is the