European Journal of Operational Research 000 (2015) 1–8

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

An approximate policy for a dual-sourcing inventory model with positive lead times and binomial yield

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ARTICLE INFO

Article history:
Received 14 January 2014
Accepted 26 January 2015
Available online xxxx

Keywords:
Inventory
Supply chain management
Applied probability
Yield uncertainty
Dual-index order-up-to policy

ABSTRACT

This paper studies the inventory system of a retailer who orders his products from two supply sources, a local one that is responsive and reliable, but expensive, and a global one that is low-cost but less reliable. The deliveries from the global source only partially satisfy the quality requirements. We model this situation with a dual-sourcing inventory model with positive lead times and random yield. We propose a dual-index order-up-to policy (DOP) based on approximating the inventory model with an unreliable supplier by a sequence of dual-sourcing models with reliable suppliers and suitably modified demand distributions. Numerical results show that the performance of this heuristic is close to that of the optimal DOP. Moreover, we extend the heuristic to models with advance yield information and study its impact on the total inventory costs.

1. Introduction

Rising in tandem with the prevalence of outsourcing activities, supply risk has recently attracted a great deal of attention from the OR research community. One important type of risk in outsourcing processes is the uncertainty regarding the order quantities that turn out to be usable at the buyer companies. This uncertainty is often referred to in the literature as yield uncertainty. Many factors may lead to yield uncertainty. When goods are transported from a global supplier, yield uncertainty is often related to damage that occurs during transportation due to humidity, collision and other reasons. Part of the goods received may also fail to pass the quality inspection of the buyers. For example, in the semiconductor industry, the yield rate may drop below 50 percent due to strict requirements on quality (Grasman, Sari, & Sari, 2007).

Yield uncertainty significantly increases the difficulty of inventory management. Often, big OEMs and retailers in Europe and the US, use responsive but more expensive local suppliers to mitigate the yield uncertainty caused by the low-cost global suppliers.

This paper focuses on the inventory system of a retailer who sources from two suppliers: one global and one local. Both suppliers have positive lead times. The global supplier is unreliable in the sense that his deliveries only partially satisfy the quality requirements. Thus, the goods need to pass quality inspection in order to be identified as usable items. Due to delays in quality inspection, the usable portion of an order is not known when the order is placed. In this paper we assume that failures of different units in an order are independent and that the failure probability is the same for all units. We are interested in the sourcing strategy that minimizes the average total inventory costs and in the impact of advance information about the quantity of the usable items on this strategy. To the best of our knowledge, this model has not been previously discussed in the OR literature.

Since the optimal policy for the simpler dual-sourcing model with positive lead times and full returns does not have a simple form (Whittemore & Saunders, 1977), we focus on finding a simple and efficient heuristic for our model. According to Veeraraghavan and Scheller-Wolf (2008), the dual-index order-up-to policy (DOP) performs close to the optimal policy in a dual-sourcing model with full returns. We therefore propose a DOP, establishing the order-up-to levels by using a sequence of dual-sourcing models with reliable suppliers and suitably modified demand distributions. We then show how to extend this heuristic to incorporate advanced information on the yield quantities.

1.1. Related literature

Yield uncertainty has attracted a great deal of attention in inventory management research in the past several decades. Three types of random yield have been considered in the literature: binomial yield (Inderfurth & Vogelgesang, 2013), stochastically proportional yield (Agrawal & Nahmias, 1997; Bollapragada & Morton, 1999; Henig & Gerchak, 1990; Huh & Nagarajan, 2010; Inderfurth & Transchel, 2007; Inderfurth & Vogelgesang, 2013; Li, Xu, & Zheng, 2008) and

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http://dx.doi.org/10.1016/j.ejor.2015.01.052
0377-2217/

interrupted geometric yield (Inderfurth & Vogelgesang, 2013). Binomial yield is used when failures of different units in a batch are independent and occur with the same probability. In situations where a random process affects whole batches, stochastically proportional yield is used instead. Models using interrupted geometric yield assume that good items are generated independently with a fixed probability until a failure occurs, and that thereafter all items are defective.

Most papers consider the effect of random yield in single-sourcing models with zero lead time. Henig and Gerchak (1990) studied the optimal policy and showed that it has an order point, but does not have the order-up-to structure. Bollapragada and Morton (1999) and Inderfurth and Transchel (2007) proved that the infinite-horizon periodic-review model can be reduced to a newsvendor problem. However, a closed-form solution cannot easily be found, since the 'demand distribution' in the newsvendor problem depends on the order quantities. Li et al. (2008) gave upper and lower bounds for the optimal reorder point and order quantity in an infinite-horizon model. Cheong and Song (2013) studied the value of the yield information in a newsvendor problem with stochastically proportional yield. They compared the ordering decisions and overall profits when different levels of yield information are available (i.e. no information at all, known expectation and variance of the yield factor and known distribution of the yield factor).

Since the optimal policy is difficult to find even when the lead time is neglected, numerous heuristics have been proposed. Bollapragada and Morton (1999) studied several myopic heuristics. Huh and Nagarajan (2010) found the optimal policy within the class of 'linear inflation rules' and proved that the average total cost is convex in the order-up-to level for any given inflation factor.

For positive lead times, Inderfurth and Vogelgesang (2013) proposed a linear inflation rule for which the optimal critical stock level is derived based on a normal approximation of the difference between the lead time demand and the yield of the pipeline orders. Inderfurth and Kiesmüller (2013) proposed two methods to derive optimal or near-optimal critical stock levels: one method based on modeling the on-hand inventory by a Markov chain and the other method based on fitting a normal or gamma distribution to the on-hand inventory.

Dual sourcing is often used in practice for balancing cost and service level or for mitigating yield uncertainty. Due to the complexity of the problem, however, the literature focusses on models with full returns. Whittemore and Saunders (1977) proved that when the difference between the lead times is larger than one, the optimal policy does not have a simple structure. For general lead times, Veeraraghavan and Scheller-Wolf (2008) proposed a dual-index order-up-to policy (DOP), and showed that the DOP performs close to the optimal policy. The main difficulty in finding the optimal order-up-to levels in a DOP is that, due to different lead times, the expedited inventory position may exceed its order-up-to level. The distribution of this excess, called the overshoot, is difficult to find. Veeraraghavan and Scheller-Wolf (2008) showed that for any given difference between the order-up-to levels, if the distribution of the overshoot were known, the optimal expedited order-up-to level could be found by solving a newsvendor problem. In order to find the distribution of the overshoot, they relied on simulations. Arts, van Vuuren, and Kiesmüller (2011) gave an approximation of the distribution of the overshoot, which is exact when the difference between the order-up-to levels is one or approaches infinity. Sheopuri, Janakiraman, and Seshadri (2010) generalized the DOP and studied three new policies which outperform the optimal DOP in their numerical experiments. Tagaras and Vlachos (2001) considered a heuristic which uses the order-up-to rule for the regular supplier and places orders with the expedited supplier only when the likelihood of a stockout is very high. Allon and Van Mieghem (2010) studied a continuous review model and proposed a tailored base-surge policy (TBS). This policy sources from the cheap, offshore supplier at a constant rate (to meet a *base* level of demand) and from the responsive, nearshore supplier only when on-hand inventory is below a certain level (to manage demand *surges*). They presented bounds on the optimal cost and an asymptotically optimal policy for a high-volume system. Janakiraman, Seshadri, and Sheopuri (2014) proved that the TBS policy is optimal for periodic review inventory systems in which demand follows a two-point distribution and the probability of a high demand is sufficiently small. Moreover, if demand can be represented as a sum of two random variables, the base and the surge demand, and the last one occurs with a small probability, the TBS policy performs close to the optimal. Chen, Feng, and Seshadri (2013) incorporated price-dependent demand in multi-period models with more than one unreliable suppliers and negligible lead times. They proved that for general demand models, there exists a time-dependent reorder point for each supplier such that a positive order is placed for almost every inventory level below the reorder point. They also studied sufficient conditions under which the optimal policies have a strict reorder point structure or the optimal order quantities are decreasing in the inventory level.

Other papers related to ours studied the optimal policies for the single-sourcing inventory systems in which the realized demand is known to the decision maker only after a certain number of periods (Bensoussan, Çakanyildirim, & Sethi, 2006; Bensoussan, Cakanyildirim, & Sethi, 2007a; Bensoussan, Çakanyildirim, & Sethi, 2007b; Bensoussan, Çakanyildirim, Feng, & Sethi, 2009; Bensoussan, Cakanyildirim, Sethi, Wang, & Zhang, 2011). In contrast, we focus on dual-sourcing models in which the usable quantities of the orders placed with the offshore supplier are not immediately known when the orders are placed.

1.2. Statement of contribution

We consider yield uncertainty in a dual-sourcing model with positive lead times, which to the best of our knowledge, has not been studied previously in the literature. For this model we propose a dual-index order-up-to heuristic. In order to account for yield uncertainty, we find the order-up-to levels based on a sequence of dual-sourcing models with full returns and suitably modified demand distributions. When compared to the optimal DOP, our heuristic gives promising results. We further extend our heuristic to models with advance yield information, and study its impact on the total costs.

The remainder of the paper is organized as follows. Section 2 formulates the dual-sourcing model with positive lead times and yield uncertainty, and gives some preliminary results on the DOP. Section 3 describes in detail our heuristic for the case where the yield becomes known only at the moment of delivery. Section 4 extends the heuristic to models with advanced information regarding the yield quantities. Section 5 presents numerical results on the performance of the proposed heuristic and on the importance of taking into account the yield uncertainty when designing inventory policies. This section also examines the impact of the advance yield information on the total inventory costs. Section 6 contains a summary of our results and concluding remarks.

2. Model and preliminaries on dual-index order-up-to policies

We consider an infinite-horizon periodic-review inventory model with two suppliers, one regular (denoted as 'r') and one expedited supplier (denoted as 'e'). The lead time l_r of the regular supplier is larger than the lead time l_e of the expedited supplier, while the per-unit ordering cost c_r of the regular supplier is lower than the cost c_e of the expedited one. Assume that there is no fixed ordering cost for either supplier and that c_r is paid for every ordered unit from the regular supplier. Moreover, the regular supplier has binomial random yield, which means that, out of an order X_n^r placed with him, only a random portion $B(X_n^r, p)$ turns out to be usable upon delivery, where p is the long-run average fraction of usable items. In Sections 2 and 3