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An optimal vendor-buyer cooperative policy under generalized lead-time distribution with penalty cost for delivery lateness

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ABSTRACT

This paper presents an integrated inventory model for a single-vendor and single-buyer where lead-time is a stochastic variable with general distribution function. The vendor delivers goods at a fixed lot size to the buyer who has a constant demand rate. Storage is permitted on both parties, but a penalty cost is assessed when the vendor delivers the shipment late beyond a threshold time. The problem is formulated as a nonlinear cost model which needs to be minimized to arrive at an optimal policy for reorder point, order quantity, and number of shipments from the vendor to buyer, to cooperatively operate the joint contract. The solution procedure involves both closed form solution and iterative search procedure for this multi-dimensional problem. Numerical examples are presented for uniform, exponential and normally distributed lead-times to demonstrate the solution methodology as well as a precursor test for special cases. The model presented here are applicable for numerous two-stage supply chain systems including retail businesses, assembly and production houses, where two parties of the supply chain are tied to their common goal of achieving minimum total cost of inventory operation.

1. Introduction

In today's supply chain environment, the successful implementation of Just-in-time (JIT) inventory requires a mutual cooperation between the vendor and buyer to cut down the expected inventory system cost by raising service level, reducing losses, gaining quick response capability, and improving competitiveness. Supply chain has received more attention by firms, so companies are recognizing inventories to be more efficient through better coordination. This research deals with a supply chain consisting of two layers which are one vendor and one buyer. The buyer places his order to the vendor, and then the vendor produces the requested order in lots and delivery shipment sizes to the buyer. In traditional inventory polices, the vendor will optimize his shipments independently while the buyer will do so for his own ordering strategy. As a consequence, their individual optimal policies may not match. To solve this problem, many researches have been conducted related to the integrated vendor-buyer cooperation where the joint relevant cost of vendor and buyer has been optimized. It will be cost-effective from mutual perspectives to determine the ordering and shipment policies for the vendor-buyer's integrated total cost optimization instead of operating with their individual plans (Sajadieh and Jokar, 2009).

The vendor-buyer joint cooperative policy for optimizing such a system is motivated from a situation where they are geographically located in the near proximity so that mutual coordination can be materialized quite effectively and efficiently. Another perspective of this problem is of ardent need to address when the products meant for some special events such as Christmas, Thanksgiving, New Year's Eve, Independence Day, graduation day and many such local, national and international festivities. For a non-festive time, the problem of such cooperation is relatively simpler and follows fewer binding constraints, but for a festive occasion this joint cooperative policy ushers to some other operational or controlling issues to run the system smoothly so that no party is at the losing end. One practical example is festive products, where an integrated inventory model can be applied. The values of festive products decrease drastically after the event; even more, those products would be valueless after a certain time. Few obvious examples are the commencement ties that are worn by graduates, centennial souvenirs, festival attires and other similar products.

In such events or festive cases, the demand is known because the buyer (a store) has already predicted it before the order is placed and the order is replenished by a vendor (which is a supplier in this situation). If the vendor is geographically dispersed, especially if it involves international transportation, the lead-time is stochastic which means the supplier could provide the buyer with the products in

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variable times. Moreover, these seasonal or festive products have to be shipped well in advance before the event so that it is not late to replenish the buyer's stock before the event date, or a penalty cost is assessed due to the sudden fall in demand and decrease of the product value after event, resulting in buyer's profit or goodwill loss. The lead time distribution is one of the creeping factor in this type of replenishment lateness problem. It is expected that the products should arrive before the event or target date so that the buyer (in this case a retailer) stack them to sell. If the shipment does not arrive in time, the buyer loses expected profit. Because of the stochastic nature of the lead time, there is a possibility that the shipment will arrive later than the event or target time. So in order to discourage such a costly lateness, the buyer imposes a high penalty to the vendor for late arrival of the products. This penalty scenario is quite common in garments products that are imported in high volume from distant countries (e.g., Far East, Southeast Asia, and Central America) that produce them at low cost; Wal-Mart and department stores are typical examples of such transactions. A lump-sum penalty cost is deposited by a vendor with the buyer at the time of contract and is forfeited when the replenishment falls through, but is honored when delivery is made in time; in the latter case the vendor's account is credited with the full amount in addition to the price of the order quantity.

Several researches focused on deterministic lead time while developing joint-economic lot sizing (JELS) models, whereas some researches considered lead time as a decision variable. Recent literatures which consider probabilistic nature of lead time are also reported here.

1.1. Deterministic lead time

Most joint-economic lot sizing (JELS) models deal with deterministic lead time. Zhang et al. (2007) extended the integrated inventory model of Woo et al. (2001) for a single-vendor and multi-buyers with the consideration of zero lead time. Yu et al. (2012) proposed an integrated inventory model for single-manufacturer and multi-retailers under consignment policy with uniform and exponential demand distributions. Hariga et al. (2013) also developed scheduling and lot sizing models for the single-vendor multi-buyer problem under consignment stock partnership. Uthayakumar and Rameswari (2013) extended Huang (2010) by assuming deterministic lead time as a part of decision variable and allowing quality improvement investment. Zhao et al. (2016) optimized the inventory policy for a multi-stage supply chain with time-varying demand. Avinadav et al. (2015) dealt with different risk attitudes for consignment contract between single retailer and multiple developers of mobile applications. Lee et al. (2016) investigated vendor-managed inventory systems with stock-out cost sharing under limited storage capacity.

1.2. Controllable lead time

Some research works considered lead time as a controllable variable. Liao and Shyu (1991) created an integrated model between a vender and a buyer by decomposing lead-time into components, each one being crashed differently to reduce the lead-time cost. Subsequently Ben-Daya and Raouf (1994) extended Liao and Shyu's (1991) work by considering lead-time and order quantity to be decision variables. On the other hand, Pan and Yang (2002) extended an integrated vendor-buyer model of Banerjee (1986) and Goyal (1988) by incorporating controllable lead-time. Hoque and Goyal (2006) extended a vendor-buyer model of Pan and Yang (2002), and Ben-Daya and Raouf (1994) with controllable lead-time and based on equal/unequal sized of batch shipments to minimize the joint total cost. Hsu and Huang (2009) extended the joint economic total cost (JETC) model of Banerjee and Banerjee (1994) for determining the lead time, and inventory policy so that the expected total system cost is minimized. Li et al. (2012) also created integrated inventory models for a vendor and a buyer with multi-product to minimize the inventory cost for both the supplier (vendor) and retailer (buyer), while length of lead time was considered as a decision variable. While Taleizadeh et al. (2012) extended integrated inventory models of Ben-Daya and Hariga (2004) and Taleizadeh et al. (2010) assuming multi-product and multi-constraint, where demand follows uniform distribution, and the lead-time is variable. Jha and Shanker (2013) develop an integrated production-inventory model between a vendor and multiple buyers, where demand is normally distributed, and the lead-time can be reduced by adding crashing cost. Yi and Sarker (2013a) developed optimal consignment models for production and replenishment policy with controllable lead time. This model was improved later to accommodate the buyers' space limitation (Yi and Sarker, 2013b).

1.3. Uncertain lead time

Some research articles also considers probabilistic nature of the lead time by introducing the probability distribution function of lead time in their joint-economic lot sizing (JELS) model. Sajadieh and Jokar (2009) relaxed the assumption of deterministic lead-time in the existing vendor-buyer joint models. They addressed this integrated system with uniformly distributed lead time variability, but their research does not address many other practical problems under exponential, normal or other distributions of the lead time. Taleizadeh et al. (2011) developed a model for multi-product case where cooperation is made between multi-vendor and multi-buyer, assuming that the demand of each product is stochastic and follows a uniform distribution, and lead-time varies linearly with respect to order quantity of the buyer. Chaharsooghi and Heydari (2010) developed a coordination model for decentralized supply chain consisting of one buyer and one supplier while both demand and lead times are uncertain. However, late delivery penalty cost assessing mechanism is not incorporated in their model. Zhou et al. (2012) developed an integrated inventory model for multi-supplier and single-buyer with a milk-run delivery network considering a stochastic lead time within a finite-range and a capacity constraint. Bushuev and Guiffrida (2012) discussed about optimal positioning of supply chain delivery window in a serial supply chain by minimizing the expected penalty cost due to early and late delivery for the general form of a delivery time distribution. However, they did not show the vendor-buyer joint cooperative policy and any mechanism for controlling the tangible contract between vendor and buyer for sharing the late delivery penalty cost. When the demand is stochastic the situation becomes complicated. Yi and Sarker (2014) proposed an operational consignment stock policy under normally distributed demand with controllable lead time and buyers' space limitation.

1.4. Problem identification

Several research publications mentioned above extended different dimensions of the joint-economic lot sizing (JELS) problems. However, most of them are limited to either deterministic or controllable lead time. Even though some research articles (Sajadieh and Jokar, 2009; Chaharsooghi and Heydari, 2010; Bushuev and Guiffrida, 2012) focused on probabilistic lead time distributions, those models with simple specific distributions or absence of late delivery penalty cost assessing mechanism limit their applicability in wider range. A JELS model with lead time under *generalized probability distribution function* can capture a wide range of applications in general. Moreover, the provision for late delivery penalty cost along with a controlling factor for defining the delivery latitude can be a good mechanism for the collaboration of cost sharing between two parties (vendor and buyer). Hence, in this work, the lead time is assumed to follow a generalized probability distribution. A model for a vender and a buyer with probabilistic lead time and penalty cost for late delivery to the buyer is presented in this paper where the objective is to find optimal order quantity, reorder point, and the number of shipments to