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Optimal vendor investment for reducing defect rate in a vendor–buyer integrated system with imperfect production process

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ABSTRACT

This paper investigates a single-vendor single-buyer integrated production-inventory model with stochastic demand and imperfect production process. It is assumed that there is an inspection activity on the part of the buyer with a fixed screening rate greater than the demand rate. The vendor invests money in order to improve the production process quality and reduce the number of defectives. The expected annual integrated total cost is derived under the n-shipment policy and an iterative procedure is suggested to determine the optimal decisions. The benefit of investment in reducing the defect rate is illustrated by way of numerical examples. It is observed that, the higher the defect rate, the more beneficial the investment. Numerical studies further explore that an increased demand requires an increased investment to optimize the total cost.

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1. Introduction

Inventory management is one of the key components of any business that can be controlled by a business manager to efficiently and successfully operate in the fiercely competitive modern global market. Therefore, it is very important to build inventory models that are sensitive and responsive to the dynamic real life market situations. The economic order quantity (EOQ), first proposed by Ford Whitman Harris (1913), is the most fundamental result which has generated whole new directions of research in inventory management since its inception.

Integration of vendor's and buyer's individual problems in a supply chain has been a point of interest of many supply chain researchers during the past few decades. This is because integrated policy has the ability to offer customers shorter lead-time and lower inventory cost. It also helps to determine problem areas along the process enabling businesses to take decisive action and further reduce cost to improve the final price. Improved customer satisfaction and loyalty is a byproduct of an integrated supply chain because the end customers experience improved on-time delivery. It also makes the system as a whole more robust enabling both the vendor and the buyer to be more flexible in dealing with sudden disruptions.

In the literature of single-vendor single-buyer integrated inventory model, it is often assumed that the demand is deterministic and shortages are not allowed. Ben-Daya and Hariga (2004) extended this by taking the annual customer demand to be stochastic and thereby allowing shortages. The production process was however taken to be perfect. Even though production process is often considered to be perfect, but in reality, it is extremely unlikely that a production process is 100% defect-free. Even in models that do consider imperfect production process (Huang, 2004), the process quality is not assumed to be a control parameter. Porteus (1986) suggested that the process quality can be improved by making an investment in the production process in terms of buying new equipment, improving machine maintenance and repair, worker training, etc. Also, controlling process quality is an important tool in the hands of the decision maker as it is expected to lead to the production of smaller batch sizes of better quality products. In an integrated model, since the production is controlled by the vendor who has to pay warranty cost for defective items, it is beneficial to him, in particular, and to the supply chain as a whole, to invest in reducing the number of defective items produced. This control of process quality by the vendor affects production yield rate of non-defective items which, in turn, influences other important decisions such as the vendor's production lot size and the number of shipments delivered from the vendor to buyer. Evidently these decisions are directly related to the total cost incurred by the supply chain as a whole. Consequently, the process quality and the optimal policy need to be determined jointly in order to minimize the total cost associated with the supply chain. This also provides added advantages

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of reduced warranty cost and perhaps most importantly provides better quality products to the buyer. Also, a buyer is more likely to place an order to a vendor who has a reputation for producing better quality items. To incorporate the issue of quality improvement, it is assumed that the vendor makes an investment to reduce the defect rate of the production process.

For integrated models with imperfect production process, it is very likely that the buyer performs some sort of inspection activity before selling the products to the customers. Ignoring this inspection/screening period or assuming it to be negligible is not very practical. Therefore, we assume that the buyer performs an error-free and non-destructive screening in a non-negligible finite period. At the end of the screening period, all the defective items in each lot are returned to the vendor at the time of the next delivery.

This paper, therefore, extends the existing literature by investigating an integrated single-vendor single-buyer production-inventory model with stochastic demand, an imperfect production process and a non-negligible finite screening period. Since it is assumed that the vendor makes an investment in improving the process quality, therefore, the defect rate is assumed to be an additional control parameter together with the number of shipments from the vendor to the buyer, the safety stock factor and the buyer's order quantity.

The rest of the paper is organized as follows: Section 2 presents a brief review of related literature. The proposed model is formulated in Section 3 and the solution procedure is outlined in Section 4. Section 5 illustrates the developed model with numerical examples. The paper is concluded in Section 6 with some remarks and future research directions.

2. Literature review

In the recent past, several researchers have shown that both the buyer and the vendor can better achieve their goals through strategic cooperation with each other. Goyal (1976) was the first to develop an integrated inventory model for a single-supplier single-buyer problem. Banerjee (1986) generalized Goyal's model and developed a joint economic lot-size model where the vendor produces on a lot-for-lot basis to meet the buyer's order under deterministic conditions. Goyal (1988) extended Banerjee's model suggesting that the vendor's economic production quantity per cycle should be a positive integer multiple of the buyer's purchase quantity. Since then a lot of research (Ha and Kim, 1997; Hill, 1997, 1999; Pan and Yang, 2002; Ouyang et al., 2006) has been devoted to the study of integrated vendor–buyer model under various assumptions. Recently researchers such as Ben-Daya and Hariga (2004), Hsiao (2008), and Glock (2009, 2012) have also made some advances in the integrated model under stochastic demand. However, most of them did not consider the issue of process quality and its relation to the production shipment schedule in terms of the number and the size of batches transferred from the vendor to the buyer.

Porteus (1986) was the first to incorporate the concept of imperfect production process into a basic EOQ model. He introduced the concept of making an investment to improve the process quality in terms of reducing the probability of the production process going out-of-control. Lee and Rosenblatt (1987) considered process inspection during production for detecting and restoring out-of-control systems. Researchers such as Rosenblatt and Lee (1986), Scwaller (1988), Ben-Daya and Hariga (2000) and the references therein have also addressed the issue of imperfect production in inventory models. Goyal and Cárdenas-Barrón (2002) proposed a practical approach to the economic production quantity (EPQ) model with imperfect items. A majority of these researches, however, focused on determining the optimal policy solely from the buyer's or the vendor's point of view. Zhang and Gerchak (1990) considered a joint lot sizing policy and inspection policy in an EOQ model with imperfect items. Salameh and Jaber (2000) investigated a joint lot sizing and shipment policy assuming a random percentage of units to be defective and the defective items be sold at the end of the screening period as a single batch. Huang (2004) developed an integrated vendor–buyer inventory model for items with imperfect quality and equal shipment size in a deterministic framework, assuming that the number of defective items followed a given probability density function. He also assumed that the vendor treated the defective items as a single batch at the end of the buyer's 100% screening process. Shortages or any investment was however not considered. Ouyang et al. (2006) investigated an integrated model with imperfect production but did not consider any investment, re-order point or shortages. Lin (2013) assumed that, on the arrival of an order, the buyer performed a non-destructive and error-free screening process. The screening rate was fixed and the process was gradual so as to render the screening time non-negligible. At the end of the screening period, all the defective items in each lot were discovered and returned to the vendor at the time of the next delivery. This led to the buyer having two types of holding cost for defective and non-defective items. However, in any of the above mentioned papers, the production process quality was not treated as a control parameter and any investment on part of the vendor to improve the production process was not considered. Ouyang et al. (2007) developed a stochastic integrated model with investment in process quality but neglected the length of the inspection period. Shu and Zhou (2014) proposed an integrated single-vendor single-buyer model in which the products are sold with free minimal repair warranty. The integrated total cost is minimized by optimizing the number of shipments, the shipment quantity, the setup cost and the process quality. However, in this paper the demand is assumed to be deterministic and shortages are not allowed. Moreover, there is no consideration of inspection/screening on part of the buyer.

Keeping these various issues in mind, the existing literature is extended in this paper by considering an integrated single-vendor single-buyer production-inventory model with stochastic demand, a non-negligible finite screening period and investment to improve the production process quality. For better understanding, a comparison of the proposed model with some of the related works in the literature is given in Table 1.

3. Model development

3.1. Notations and assumptions

To develop the proposed model, the following notations are used:

D expected demand rate (units/time) non-defective items
P production rate ($P=1/p$)
A buyer's ordering cost per order
B vendor's setup cost

Table 1
A comparison of the present model with some related works in the literature.

Paper	Demand	Production	Screening	Investment
Huang (2004)	Constant	Imperfect	Yes	No
Ben-Daya and Hariga (2004)	Stochastic	Perfect	No	No
Ouyang et al. (2007)	Stochastic	Imperfect	No	Yes
Lin (2013)	Stochastic	Imperfect	Yes	No
Shu and Zhou (2014)	Constant	Imperfect	No	Yes
Present model	Stochastic	Imperfect	Yes	Yes

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