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An EOQ model with partial backordering with regard to random yield: two strategies to improve mean and variance of the yield

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ABSTRACT

This paper presents an economic order quantity (EOQ) inventory model with partial backordering, where a buyer purchases its required products from a supplier. Each received batch from the supplier includes a random proportion of defective items. In other words, supplier's production process works to a random yield. A recursive solution method to find the optimal values for main decision variables is examined through a series of numerical examples. Moreover, it is considered that the yield can be improved at a given cost. To this extent, two ways to achieve the yield improvement have been considered: the first way is investment in order to improve the mean of the yield to an ideal value, and the second way is investment to reduce the yield variability to an acceptable value. The impacts of the proposed strategies are investigated through some numerical analysis and managerial insights are proposed.
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1. Introduction

Presence of defective products in manufacturing processes is inevitable. There is no production process which can guarantee that all its products would be perfect and free from defect. Hence, there is a yield for any production process. Basic and classical inventory control models usually ignore this fact. They assume all output products are perfect and with equal quality; however, due to the limitation of quality control procedures, among other factors, items of imperfect quality are often present. So it has given researchers the opportunity to relax this assumption and apply a yield to investigate and study its impact on several variables of inventory models such as order quantity, and cycle time (see, for example, Yano & Lee, 1995). Many studies in this area consider supplier's yield to be a continuous random variable, which does not alter the lot size (see Paknejad, Nasri, & Affisco, 2005; Paknejad, Nasri, & Affisco, 2015).

By considering the yield, inventory control models are prone to changes, and results may be different from previous models. EOQ is one of the most widely used models in researches. Applying shortage in this model also enhances its appeal for researchers. The shortage can be either backordering mode or lost-sale mode, and or generally be a combination of both, called partial backordering (PBO). Applying the issue of the yield in EOQ model with partial backordering causes different results from that problem without considering yield. For instance, IKCO, one of the largest car manufacturers in Middle East, works with several automobile part suppliers, which provide different components of an automobile. Each of these suppliers' production process follows a different yield. Needless to say, without considering the yields, IKCO cannot perform in an efficient and responsible way. Furthermore, in case of IKCO, this corporation does investments to improve the suppliers' yield. After cost analysis, IKCO figures out whether it is affordable to carry out these investments. If IKCO finds it cost-effective, then these investments result in cost reduction and also smaller order sizes. Besides this, those suppliers become long-term suppliers for IKCO.

In this paper, first, we introduce an EOQ inventory model from the buyer's point of view considering shortage in partial backordering form, where each lot delivered by the supplier to the buyer includes a random proportion of defective items. This involves that a random rate of products are defective. We introduce the problem in two cases and propose a recursive algorithm to find optimal value of decision variables. Then, in the next step, we investigate two strategic avenues to improve the yield. By 'making improvement' in the yield, we mean enhancing the mean of the yield or reducing the yield variability.

In this section, we provide the literature review on the most related works. Literature of each aspect of the study will be introduced, and then we integrate them toward discovering the research gap.

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Harris (1915) introduced an inventory model to discover what quantity to make at once called economic order quantity model. If each of its assumptions gets relaxed, it makes difference in the model. One of these relaxations can be the relaxation of no shortage assumption. The shortage may be in backordering or lost-sales mode, or even including both of them. In this paper we address the EOQ inventory model with partial backordering. Montgomery, Bazaraa, and Keswani (1973) were the first to develop a model and solution procedure for the basic EOQ with partial backordering (EOQ + PBO) at a constant rate. San Jose, Sicilia, and Garcہa-Laguna (2005), and Pentico and Drake (2009), independently introduced two EOQ models with partial backordering with two different approaches. In the first model by San Jose et al. (2005), decision variables are the length of the inventory cycle where the net stock is positive and length of the inventory cycle over which the net stock is less than or equal to zero. However, in the second one by Pentico and Drake (2009), decision variables are cycle time and fill rate- percentage of demand filled from stock. Needless to say, considering assumptions such as yield of production process, as it was discussed, helps the inventory models become more realistic.

Shih (1980) assumed that stockouts are exclusively caused by defective items, where the yield is between zero and one and does not vary with lot size. In that work, the optimal order size depends only on the holding cost and the shortage cost per unit of time, contributing to a larger lot size than traditional models. Salameh and Jaber (2000) extended an EOQ model for a case in which a random proportion of units in a batch are defective. They supposed that units are subject to 100% inspection. Poor-quality items are kept in stockroom and sold as a single batch at a reduced price in the end of the inspection process. Moreover, shortage is not allowed and this is assured by a constraint in the model. Papachristos and Konstantaras (2006) ratiocinated that the constraint in Salameh and Jaber (2000) does not completely assure the premise that shortage will not occur. Also they drew the conclusion that models based on imperfect quality need a direct consideration of shortage in any model formulations. Porteus (1986) introduced a modified Economic Manufacturing Quantity (EMQ) model, which indicates a significant relationship between quality and lot size. In this work, demand is assumed to be deterministic and the optimal order size is concluded to be smaller than that of basic EMQ model. Moinzadeh and Lee (1987) studied the effect of defective items on reorder point and order quantity of a continuous-review model (r, Q) with constant lead time, where the demand follows a poison distribution function. Goyal, Gunasekaran, Martikainen, and Yli-Olli (1993) surveyed the early literature on integrating lot size and quality control policies. Muckstadt and Roundy (1987) introduced optimal or near optimal procedures to solve problems with consideration of demand and production yield for complex manufacturing systems. In addition to that, Gerchak and Henig (1994) investigated these problems with three types of yield randomness: binomial, stochastically proportional and interrupted geometric. Rosenblatt and Lee (1986) studied the impacts of an imperfect production process on the optimal production cycle time. The system is assumed to deteriorate during the production process and produces a proportion of defective items. The optimal production cycle was derived, and was illustrated to be shorter than that of the classical EMQ model. The analysis was extended to the case where the defective rate is a function of set-up cost, for which set-up cost level and the production cycle time are jointly optimized. Cheng (1991) presented an EPQ model with imperfect production process and quality-dependent unit production cost. Yano and Lee (1995) reviewed the literature on quantitatively oriented approach for determining lot sizes when production or procurement yields are random. They provided a review of the existing literature concentrated on description of the types of problems that had been solved and had important structural results. Chiu and Gong (2004) proposed an EPQ model with considering random defective rate of products. They assumed that the imperfect items are not repairable and scraped after production the process ends. Also in another research Chiu (2003) considered the impacts of reworking defective items on the EPQ model with allowed backordering. He considered a random defective rate and assumed that when the regular manufacturing process ends, reworking the defective items starts. The random yield rate is assumed to have a known probability density function. Ouyang, Wu, and Ho (2007) investigated an integrated vendor–buyer inventory model. They considered just-in-time (JIT) policy and tried to propose a model with considering quality improvement and lead time reduction. Inderfurth and Kiesmüller (2015) investigated a (r,Q) inventory model with considering stochastic demand and random yield. They considered two different models for the uncertain supply, named stochastically proportional and binomial, also they considered the lead time to be positive and constant. They proposed two new approaches to achieve optimal and near optimal reorder point. In the first one, they used Markov chain approach, and with neglecting lead time they derived exact optimal value. In the second approach, they provided a steady-state analysis to derive closed-form expressions for the optimal reorder point.

It seems that focus in the field of yield rate is more on the situation where yield is a continuous random variable. Nasri, Paknejad, and Affisco (2009) investigated the relationship between the order quantity and quality of production processes that have not yet achieved the state of statistical control, such as those that are in the initial stages of implementing a quality program. The authors assumed that each lot contains a random proportion of defective items. Upon arrival, the buyer inspects the entire lot. It is assumed that the buyer's inspection process is perfect, and all rejected items are returned to the vendor without any cost to the buyer. Also they assume that the vendor pays the inspection costs. The authors adjusted the EOQ with planned shortage model to the random rate of perfect parts in each arrived lot. Moreover, they provided closed-form expressions for two special cases where the proportion of defective items follows exponential or uniform distributions. Khan, Jaber, Guiffrida, and Zolfaghari (2011) extended an imperfect quality model where the buyer at a discounted price salvages imperfect items, while Jaber, Zanoni and Zavanella (2014) presented two models that extend the Salameh and Jaber (2000) model considering that imperfect items can be sent to a repair shop who charges a cost plus a markup margin or can be replaced by good ones from a local supplier at a higher cost. Glock, Grosse, and Ries (2014) provided a literature reviews on the field of lot sizing. One of the major outcomes of this research is a classification scheme for lot sizing models. This scheme includes two dimensions: the first is the technical structure dimension, which deals with the nature of the product and prevailing supply and demand conditions. The second dimension is content-related which itself consists of two categories, the first category is lot sizing models whose target is the determination of optimal production, order and shipment quantities. The second category is developed lot sizing models that consider additional aspects like incentives such as quantity discounts or trade credits, scheduling, and productivity which includes issues such as worker learning, items with limited shelf lives, and the production of defective units. Sarkar et al. (2015a), Sarkar et al. (2015b) investigated a continuous review inventory model with order quantity, reorder point, backordered price discount, process quality, and lead time as decision variables. They used an investment function to improve the process quality. They extended two models based on the probability distribution of demand lead time. In the first model the demand lead time follows a normal distribution and in the second model it does not follow any specific distribution but the mean and standard deviation are

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