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Economic order quantity models for imperfect items with buy and repair options

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ABSTRACT

One of the celebrated extensions of the economic order/production quantity (EOQ/EPQ) model is one that assumes a received shipment contains a fraction of imperfect (non-conforming) quality items, where these items, detected by 100% screening, are sold as a single batch at a discounted price. This paper revisits this model (Salameh and Jaber, 2000, Int. J. Prod. Econ. 64 (1), 59–64) and extends it by assuming that a shipment is coming from a distant supplier and, therefore, it is not feasible to replace the imperfect items with an additional order to the same supplier. To address this restriction, two models are presented. The first assumes that imperfect items are sent to a repair shop who charges a cost plus a markup margin, while the second model assumes that imperfect items are replaced by good ones from a local supplier at a higher cost. The inventory environment assumed in this paper is relevant in todays globalised supply chains, thus practical implications of the problem faced are discussed. Numerical results are also presented and discussed. The results show that there exists a threshold value of the unit purchase cost of an emergency-ordered item and a fraction of defectives to which it is decided to either buy or repair.

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1. Introduction

It is the 100th birthday of the economic order quantity (EOQ) model (Harris, 1913) this year, 2013. Surprisingly, the EOQ continues to be the central model in inventory, supply chain and logistics management. The popularity of the model did not go without critique, sometimes harshly, on the grounds that its assumptions are never met. For example, Woolsey (1988) wrote: “If you continue to love and use the EOQ without knowing what it is costing you, I can only suggest that you deserve each other.” This led several researchers to fine-tune the EOQ model so as to give it a flavor of reality. Just to recall one of the most recent and fascinating variations of the EOQ model that worth noting here is the non-classical approach to modeling inventory problems by applying the first and second laws of thermodynamics, where the commodity flow (demand rate) is modelled similar to heat flow in thermodynamic systems so as to calculate the disorder (entropy) cost generated when controlling the flow of commodity from the system to the market (see Jaber et al., 2004; Jaber, 2009). One of the limitations of the EOQ model that has received a considerable attention in the literature is that all items in a produced or received batch conform to quality characteristics. The earliest works along this line of research are those of Porteus (1986) and Rosenblatt and Lee (1986) who independently investigated the problem, and similarly concluded that ordering/producing in smaller lots reduce the percentage of defects per lot. This was because the assumption that the percentage of defectives is lot size dependent. Another interesting extension of the EOQ model is the work of Salameh and Jaber (2000) who dealt with the same issue, but from a different angle. This work has been considerably cited in the literature and continues to be a center of interest for researchers in inventory and logistics management (see, e.g., Khan et al., 2011). This work will be the starting point of the models developed in this paper.

Salameh and Jaber (2000) developed a version of the EOQ model where a shipment contains a random percentage of defective items. They assumed that upon receiving a lot, it is screened at a rate faster than the demand rate to ensure no shortages. By the end of the screening period, those items are classified as imperfect. Salameh and Jaber (2000) implied that an imperfect item is not necessarily defective, but rather of a quality suitable for a second grade product. They also assumed that the imperfect quality items detected are withdrawn from inventory by the end of the screening period and are salvaged in a secondary market at a discounted price. They suggested ordering larger lots than what the EOQ model suggests. This work has been corrected (e.g. Cárdenas-Barrón, 2000, Maddah and Jaber, 2008), critiqued (Papachristos and Konstantaras, 2006), simplified (Goyal and

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Nomenclature

y	order quantity size quantity (units)
t_I	time to screen a lot of size y (years)
t_R	time to transport, repair and return imperfect items to the buyer (years)
D	demand rate (unit/year)
ρ	fraction of defective items
$f(\rho)$	probability density function of ρ
T	cycle time (years)
X	inspection rate (units/year)
S	repair setup cost ($)
A	transportation fixed cost ($)
c_1	material and labour cost to repair an item ($/unit)
c_T	unit transportation cost ($/unit)
h'	holding cost at the repair facility ($/unit/year)
h	holding cost of a good quality item ($/unit/year)
c_R	unit repair cost charged to the buyer ($/unit)
t_R	total transport time of defective units from the buyer to the repair shop and back to the buyer (year)
c_I	unit inspection cost ($/unit)
R	repair rate (units/year)
h_R	holding cost of a repaired item ($/unit/year)
h_E	holding cost of an emergency ordered item ($/unit/year)
m	markup percentage by the repair shop (%)
c_E	unit purchasing cost of an emergency order ($/unit)
K	buyer's order cost ($)
c_U	unit cost ($/unit)
c_I	unit inspection cost ($/unit)
P	unit price ($/unit)
$E[.]$	expected value of a random variable

Cárdenas-Barrón, 2002) and extended (e.g. Jaber et al., 2008, Maddah et al., 2010). A good review of the studies that dealt with the work of Salameh and Jaber (2000) can be found in Khan et al. (2011). Following this review, several papers appeared in the literature that extend or modify the work of Salameh and Jaber (2000), for example, Khan et al. (2012), Moussawi-Haidar et al. (2012), Rezaei and Salimi (2012), Yassine et al. (2012), Jaber et al. (2013), Nasr et al. (2013), Hsu and Hsu (2013), Vörös (2013), and Khan et al. (2014).

A common assumption among those works that are surveyed in Khan et al. (2011) and those appeared after is that imperfect items are withdrawn from inventory as a single batch, either by the end of the screening period or by the end of the cycle, and sold at a discounted price. There may be situations where an item, of considerable value, is either substituted from a local supplier by a good quality item, at a higher price, or an imperfect quality item can be sent out for repair at a third-party facility. These situations were not considered in the context of the inventory problem described by Salameh and Jaber (2000). So, this paper extends the model of Salameh and Jaber (2000) by assuming that imperfect quality items are sold at a discounted price and an equivalent number of good items is bought from a local supplier, or imperfect quality items are shipped to a third part facility for repair to as-good-as-new state, after which they are returned to inventory.

In modern supply chains the acquisition of raw material and components is often performed on a global scale. Guaranteeing that procured material and components conform to quality characteristics, even if this aspect is contractual, can be a complex challenge. In advanced supply chains with a consolidated partnership between its players the incoming inspection of procured material and components has become a routine procedure because quality assurance has been moved to process capability analysis, thus a large portion of the incoming supply is acquired by a "free pass" agreement. However, in a global market, procured material and components can be acquired from distant suppliers with no established relationship or buying history, and thus the incoming inspection should be performed so as to guarantee the right fulfillment of production lines with components that meet the quality requirements. An incoming shipment may contain a fraction of non-conforming items. Since an emergency shipment from the distant supplier to substitute for the defective items may not be feasible, a firm operating in such an environment has two options to guarantee the procured quantity: (1) repair the items or (2) buy new items from a local supplier, but at a higher price.

Moreover, it should be underlined that the statistics on the percentage of defective items of incoming materials procured from a distant supplier can be evaluated on the basis of the item category and on the expertise of the company (i.e. the expected defective items can be roughly evaluated on the basis of the country of origin, e.g. Far East, East Europe, etc., and of the specific category, e.g. die cast aluminum component, cast iron part, printed circuit board, etc.). Additionally, the disadvantage of global sourcing relating to the quality issue may also be linked to product safety (this implication is discussed in Berman and Swani, 2010).

Given the above-mentioned motivation, the models proposed in this paper aim at supporting managers in taking the right decision when a received lot from a distant supplier has a certain percentage of defective items. Thus, in order to guarantee the satisfaction of the quantity and quality of a received order, a decision of either to repair the imperfect items or to substitute them by buying good quality ones from a local supplier is needed.

The remainder of this paper is organised as follows. The next section is for mathematical modelling for the two scenarios of dealing with imperfect quality items, which is followed by a numerical examples' section. The paper concludes in Section 4.

2. Mathematical models

This section extends the work of Salameh and Jaber (2000) in two directions. The first model assumes that the imperfect quality items withdrawn from inventory are repaired, while the second model assumes that the imperfect quality items are substituted by purchasing good items.

2.1. Model I: Repair

A lot of size y is received every T units of time and is depleted at a rate D. The lot is subjected to a 100% inspection at a rate $X>D$, where ρy units (ρ is a percentage) of imperfect quality are withdrawn from inventory at the end of the screening period, t_I, and sent to a repair shop. Repaired items are returned after t_R units of time, which includes transportation and repair times where $t_I+t_R\le T$ and $T=y/D$. Note that this paper does not consider the case when $t_I+t_R>T$ as in our opinion it will logically be expensive favouring the buy option described in Case 2 as one has to account for backordering costs. We will leave this case as a mathematical exercise for interested readers. Further, this paper assumes that the repair process at the shop is always in control, which is not necessarily true. There are cases where the repair process may go out of control and restored through performing preventive maintenance (e.g. Jaber (2006); Liao and Sheu (2011); Liao, 2012).

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