Int. J. Production Economics 121 (2009) 255–265

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Economic production quantity model with imperfect-quality items, two-way imperfect inspection and sales return

Seung Ho Yoo [a], DaeSoo Kim [b,*], Myung-Sub Park [b]

[a] Seoul Women's University, Gongneung 2-dong, Nowon-gu, Seoul 139-774, Republic of Korea
[b] Korea University, Business School, Anam-dong, Seongbuk-gu, Seoul 136-701, Republic of Korea

A R T I C L E I N F O

Article history:
Received 18 May 2007
Accepted 6 May 2009
Available online 28 May 2009

Keywords:
Inventory
Imperfect quality
Inspection error
Defect return
Rework and salvage

A B S T R A C T

In practices, not only production but inspection processes are often not perfect, thereby generating defects and inspection errors. Previous imperfect-quality inventory studies, however, have mostly focused on developing cost-minimizing models that do not consider imperfect inspection processes and related defect sales return issues despite their practical significance. Thus, this study proposes a profit-maximizing economic production quantity model that incorporates both imperfect production quality and two-way imperfect inspection, i.e., Type I inspection error of falsely screening out a proportion of non-defects and disposing of them like defects and Type II inspection error of falsely not screening out a proportion of defects, thereby passing them on to customers, resulting in defect sales returns. We also consider rework and salvage in disposing of screened and returned items. Then we solve the model optimally and present numerical sensitivity analyses to provide important managerial insights into practices.

1. Introduction

In a typical manufacturer–customer supply chain, the manufacturer's production process quality is often not perfect and hence produces imperfect-quality defective items. Since the pioneering work by Rosenblatt and Lee (1986) and Porteus (1986), many researchers have developed various imperfect-quality inventory models for this important problem involving an imperfect production process.

In detail, previous imperfect-quality inventory models can be divided into two streams in terms of an inspection method of defects related to different imperfect production processes (see also Yano and Lee, 1995 for a review). One stream of research has examined a production system which deteriorates in every cycle as run cycles progress after an initial state involving no error, and thus produces defects. In this deteriorating process situation, most of the researchers have examined an inspection method of defective items based on regular intervals (Rosenblatt and Lee, 1986; Porteus 1986; Lee and Rosenblatt, 1987, 1989; Lee and Park, 1991; Liou et al., 1994; Vickson, 1998; Kim et al., 2001; Chen et al., 2008; Jaber et al., 2009), while others have explored an inspection based on an interval with a constant integrated hazard (Rahim, 1994; Rahim and Ben-Daya, 2001), an entire lot inspection at the end of a process (Guu and Zhang, 2003), and an inspection of the last k units (Yeh and Chen, 2006). On the other hand, the other line of research has investigated an imperfect production process with no deterioration over time. In this non-deteriorating case, the inspection was mostly done by an entire lot screening (Cheng, 1989, 1991a, b; Anily, 1995; Lee et al., 1996; Salameh and Jaber, 2000; Hayek and Salameh, 2001; Chiu, 2003; Tripathy et al., 2003; Chiu et al., 2006; Leung, 2007; Jaber et al., 2008), except for Zhang and

* Corresponding author. Tel.: +82 2 3290 2817; fax: +82 2 928 4905.
E-mail address: kimd@korea.ac.kr (D. Kim).

0925-5273/$ - see front matter
doi:10.1016/j.ijpe.2009.05.008

Gerchak (1990) involving an inspection of a fraction of a lot.

A closer look at the literature above reveals us some crucial points that serve as underpinning of building a more comprehensive inventory model. First, regardless of inspection methods, most of the previous studies have focused on developing cost-minimization models that reflect only internal effects of defects which increase operating costs, by not considering inspection errors (except for Liou et al., 1994; Rahim, 1994; Rahim and Ben-Daya, 2001; Yeh and Chen, 2006) or delivery of defects to customers (except for Lee and Park, 1991; Liou et al., 1994; Yeh and Chen, 2006). Whereas these studies may be reasonable for certain circumstances, we also frequently discover in practices an inspection process that is not perfect or error-free, let alone a production process, thereby resulting in a Type II inspection error of falsely not screening out some proportion of defects and thus passing them on to customers, causing subsequent customers' sales returns of defects back to the manufacturer. For example, according to a survey of 45 apparel and 65 consumer electronics manufacturers by RLEC (Reverse Logistics Executive Council) (1999), the average return rates amount to 19.44% and 8.46%, of which 49.45% and 35.71% are due to defects, respectively, not to mention even more serious return problems from the recent spurred growth of e-commerce and e-business in various industries. Second, besides the Type II inspection error, an imperfect inspection process also results in a Type I inspection error of falsely screening out some proportion of non-defects and thus disposing of them like defects, thereby losing an opportunity to make more profit by not being able to sell those screened non-defects to customers (Liou et al., 1994). Thus, it is practically significant to examine an imperfect inspection process involving both Type I and Type II inspection errors which affect a firm's profitability through the delivery of defects to customers, their subsequent defect sales returns, loss of some non-defect sales opportunities, and additional production and disposition work of salvage and rework. Third, with respect to model components, many previous studies have not considered the costs related to defect sales returns and goodwill loss, although some (Zhang and Gerchak, 1990; Lee and Park, 1991; Liou et al., 1994; Vickson, 1998; Guu and Zhang, 2003; Yeh and Chen, 2006) incorporated penalty or warranty costs. In practices, however, defect returns involve not only return costs related to communication and reverse logistics of defects but also penalty cost due to goodwill loss from customers' quality dissatisfaction. And fourth, most of the previous studies have treated inventory holding costs indifferently between non-defects and defects (Rosenblatt and Lee, 1986; Porteus, 1986; Lee and Rosenblatt, 1987, 1989; Lee and Park, 1991; Liou et al., 1994; Kim et al., 2001). However, given that a major inventory holding cost component is a firm's cost of capital (Chopra and Meindl, 2004; Jaber et al., 2009), it may be more reasonable to distinguish holding costs by including additional operating costs for handling different types of items (i.e., defective and non-defective, serviceable, screened and returned, and produced and reworked items).

Therefore, based on the previous literature analysis and practices, this study aims to extend the existing body of knowledge on the imperfect-quality inventory problem by developing a more practical and comprehensive profit-maximizing inventory (lot-sizing) model which relaxes the previous common assumption of perfect inspection with no sales return. Our model can be considered an extension of imperfect-quality economic production quantity (EPQ) models with perfect lot screening (i.e., no inspection errors) and continuous rework process after production period (Hayek and Salameh, 2001; Chiu, 2003; Chiu et al., 2006), and the imperfect-quality economic order quantity (EOQ) model with error-free lot screening and salvage process (Salameh and Jaber, 2000), which were widely referred by many researchers recently (Huang, 2004; Papachristos and Konstantaras, 2006; Tsou, 2007; Wee et al., 2007; Jaber et al., 2008). More specifically, our model deals with not only an imperfect production process based on the EPQ model, not EOQ, but also an imperfect inspection process based on a typical entire lot screening, involving Type I and Type II inspection errors. Thus, due to the Type II inspection error, a proportion of defective items produced are falsely not screened out internally during the inspection process and passed on to customers, thereby causing defect sales returns and reverse logistics from customers back to the manufacturer. Further, due to the Type I inspection error, a proportion of non-defective (good-quality) items produced are falsely screened out like defective items. Then, those screened and returned items are handled through rework and salvage processes.

In solving the model, we prove the concavity of the profit function for global optimality, and obtain an optimal solution. Then we present numerical sensitivity analyses to provide key managerial insights into practices. The significance of this study may lie in exploring a previously untapped richer problem structure involving imperfect production and Type I and Type II inspection errors along with two disposition methods and a proper lot sizing model, i.e., EPQ rather than EOQ. The rest of the paper is organized as problem and model formulation, numerical example, and sensitivity analyses, followed by concluding remarks.

2. Problem and model formulation

2.1. Problem description and assumptions

We examine a typical manufacturer–customer supply chain where the quality of the manufacturer's production process and inspection process is not perfect. Figs. 1 and 2 describe its forward and reverse material flow and inventory behaviors (see notations summarized in Appendix A henceforth). The manufacturer produces and simultaneously inspects a lot y at a rate of M during its production run and inspection time of T_M. Since the production process is not perfect, the lot y contains defective items of py along with non-defective items of $(1-p)y$, where a defect proportion of p $(0<p<1)$ follows a known probability density function (*pdf*) of $f(p)$.