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A study on negative binomial inspection for imperfect production systems ☆

Yeu-Shiang Huang [a,*], Yan-Jun Lin [a], Jyh-Wen Ho [b]

[a] Department of Industrial and Information Management, National Cheng Kung University, Taiwan
[b] Department of Industrial Management and Enterprise Information, Aletheia University, Taiwan

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ABSTRACT

Production systems continuously deteriorate with age and usage due to corrosion, fatigue, and cumulative wear in production processes, resulting in an increasing possibility of producing defective products. To prevent selling defective products, inspection is usually carried out to ensure that the performance of a sold product satisfies the customer requirements. Nevertheless, some defective products may still be sold in practice. In such a case, warranties are essential in marketing products and can improve the unfavorable image by applying higher product quality and better customer service. The purpose of this paper is to provide manufacturers with an effective inspection strategy in which the task of quality management is performed under the considerations of related costs for production, sampling, inventory, and warranty. A Weibull power law process is used to describe the imperfection of the production system, and a negative binomial sampling is adopted to learn the operational states of the production process. A free replacement warranty policy is assumed in this paper, and the reworking of defective products before shipment is also discussed. A numerical application is employed to demonstrate the usefulness of the proposed approach, and sensitivity analyses are performed to study the various effects of some influential factors.

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1. Introduction

The performance of facilities has been substantially improved due to the significant enhancement in technology. Nevertheless, it is possible that some highly reliable production systems may still produce inferior products which cannot be detected by ordinal control charts using quantitative measures. Inspection before the distribution of products to the market turns out to be a common way of ensuring that the quality of a sold product can satisfy customer requirements. However, in practice, a full inspection is unfeasible due to high inspection cost and long inspection time. Thus, a random sampling inspection is usually adopted to save both inspection time and cost which has to preset an upper limit of the number of defective items for inspection, and the entire lot is sent out as long as the number of defective items found in the randomly selected sample does not reach the upper limit. This may result in an undesirable situation in which a considerable number of defective products have been sold to customers, and unsatisfied customers might take certain actions that would have unfavorable impacts on the future sales of the product. Since selling defective products is unavoidable with a random sampling inspection, warranties thus play a crucial role after a product has been sold.

The deterioration of production systems is unavoidable because of component corrosion, material fatigue, and cumulative wear in production processes. Several researchers explored the deterioration with the deliberation of the inventory. For instance, Sett, Sarkar, and Goswami (2012) proposed an inventory model by assuming the product deterioration varies with time in order to minimize the system cost. Sarkar (2013) employed different types of deterioration function to develop an inventory model for investigating the optimal lot size. Sarkar (2012c) explored the order model for an imperfect production system, whose deterioration rate depends on time, to maximize the product profit. Furthermore, the deteriorating production system is actually an imperfect production system that has a threshold to separate the system into in-control and out-of-control states. Recent years have seen increased attention to develop more realistic models for dealing with such imperfect production systems (Chung & Hou, 2003; Salameh & Jaber, 2000; Sarkar, 2012a, 2012b; Wang & Sheu, 2000, 2003; Yeh, Ho, & Tseng, 2000), but research on imperfect production systems has generally assumed that the elapsed time of the production system has an exponential distribution, with the aim of simplifying the model construction.

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* Corresponding author. Address: Department of Industrial and Information Management, National Cheng Kung University, 1 University Rd., Tainan 701, Taiwan. Tel.: +886 6 2757575x53723; fax: +886 6 2362162.

E-mail address: yshuang@mail.ncku.edu.tw (Y.-S. Huang).

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For a reliable highly automatic production system whose rate of producing defective items is usually fairly small, performing a product inspection without considering the system operation status will lead to an unnecessary increase of inspection cost. It turns out that the defective items might need to be reworked and the product profit would be diminished. Some of the related issues can be seen in the literature. For instance, Cárdenas-Barrón, Sarkar, and Treviño-Garza (2013) proposed a model regarding the defective items being reworked with an aim to investigate the optimal replenishment lot size. Sarkar, Saren, and Wee (2013) developed a quantitative model to deliberate the profit maximization under the limited production rate with the consideration of the defective items. Additionally, on account of the deterioration, the performance of a production system decreases as the production time increases, warranties are of special importance in raising product sales and increasing customer satisfaction. However, the trade-off between higher warranty cost and greater sales revenue is always a crucial decision for manufacturers. Murthy and Djamaludina (2002) stated that warranties play different roles from the perspectives of manufacturers and customers, respectively. For customers, warranties are a safeguard with which customers are able to regain the functionality of a broken product without bearing any expense. It is thus of special interest for the manufacturer to determine an appropriate warranty policy in which the warranty cost and product sales can be optimally managed to maximize the expected profit. However, due to variations of the production process, defective items inevitably increase the warranty cost. The discussion of issues with various warranty policies is widely studied in literature (Jung & Park, 2003; Mi, 1999; Nancy & Lutz, 1998). Since warranty terms usually last more than 1 year in practice, time discounting is essential in evaluating the expected warranty cost.

Based on the aforementioned discussion, warranties can increase customer confidence of the product, enhancing its competitiveness. Manufacturers must focus more on quality management to ensure product quality and to prevent excessive warranty cost. To prevent defective or nonconforming products from being sold to customers, which would increase the warranty cost and damage the company reputation, an appropriate sampling inspection scheme is necessary. Inspection ensures better product reliability, and monitors whether the status of the production system is in the in-control state, since the defect rate increases when the production system deteriorates and gradually switches into the out-of-control state (Wang & Sheu, 2000). Inspection can assist the manufacturer in evaluating the current status of the production system and cut down the warranty cost but it incurs a sampling and testing cost. The primary concern of an inspection strategy is the trade-off between the high inspection cost from a full inspection and the high warranty cost from a random inspection. Dradjad (1996) stated that traditional product inspection is performed after a production cycle has completed, which implies that the nonconforming items have been produced before the inspection. However, recently, due to technology improvements in automation and small-size production, a full inspection is feasible and affordable for the manufacturer. In addition, since both the production system and the product deteriorate, a reasonable inspection program is beneficial for the manufacturer. Various sampling plans have been proposed to assist management in determining an optimal inspection program (Hsu & Kuo, 1995; Mohandas, Dipak, & Rao, 1992).

In summary, an effective inspection plan has to consider related costs from three aspects: the production system, the product inspection, and the post-sale warranty. Huang, Lo, and Ho (2008) proposed an inspection scheme in which the optimal sampling number is determined by considering the trading off among the costs of production, inspection, and warranty. However, since the evaluation of inventory cost is not based on time, and the product demand along with the system and product inspection times as well as the reworking of defective items are not considered, their model seems insufficient for a practical implementation. Consequently, in this study, the model developed in Huang et al. (2008) is extended. The proposed inspection strategy provides management with an effective and efficient inspection mechanism to deal with possible imperfections in production systems with the aim of minimizing the expected total cost by determining the optimal inspection number and reworking time.

The rest of this paper is organized as follows: Section 2 introduces the problem of product inspection for imperfect production systems. Section 3 shows the development of the proposed inspection scheme for imperfect production systems. Section 4 demonstrates the usefulness of the proposed inspection scheme using a practical numerical case. Sensitivity analyses are also carried out to investigate the factors which affect the optimal sampling scheme. Finally, Section 5 contains the concluding remarks.

2. Product inspection for imperfect production systems

The deterioration of an imperfect production system usually results in two system statuses during the production process: the in-control state and the out-of-control state. The system starts in the in-control state in which the production process is stable with a low defect rate and is capable of producing reliable products. As time goes by, the system may switch to the out-of-control state in which the production process is undependable and the defect rate gets worse. Such a state might be due to either the improper management during the manufacture or primarily the deterioration of the machine function. It turns out that an appropriate program for system repair and product inspection would be beneficial to prevent costly reworking and to uphold the product image, especially for the application to improve the imperfect production system under the mass manufacture. For example, Wang and Tsai (2012) proposed a heuristic inspection policy to determine the optimal production lot size according to the quality degree and unit nonconforming cost of the input material. Tirkel and Rabinowitz (2012) devised the inspection policy in a decision support tool to prevent the production yield from declining. Inman, Blumenfeld, Huang, and Li (2013) integrated the quality inspection process with the production system in order to diminish the influence of improper system on the quality. Rezaei and Salimi (2012) conducted product inspection with considering the relationship between buyer and supplier to determine the economic order quantity of the buyer. Chung (2013) developed an inspection plan with extra consideration of the warranty and inventory policies for effectively reducing the quality cost. Furthermore, in this study, a negative binomial inspection is proposed to improve the manufacturing efficiency under the imperfect production system.

2.1. Negative binomial inspection

Suppose that an imperfect production system whose elapsed time from the in-control state to the out-of-control state can be modeled by a Weibull distribution with a scale factor α and a shape factor β. It is assumed that, for every production cycle T, the system starts in the in-control state and keeps functioning until the end of the production cycle. At the end of each production cycle, the production system has to be set up again and inspected to examine the system status and to prepare it for the next run of production. If the out-of-control state is identified by the system inspection, a repair action is undertaken to restore the system to the in-control state and a product inspection is then carried out to ensure the quality of the products to be sold. As for the preventive maintenance (PM), Wong, Chan, and Chung (2013) proposed a scheduling way to perform the PM in terms of inspection and reliability regarding

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