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Optimizing integrated manufacturing and products inspection policy for deteriorating manufacturing system with imperfect inspection

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A B S T R A C T

In this paper, we study an inventory-production system with process deterioration and imperfect inspection. Both in-control and out-of-control states are investigated and a mathematical model for deteriorating process representing the expected total cost is derived to obtain the optimal solutions. The aim of this research is to determine the optimal production period length and inspection policy, such that the expected total cost is minimized. In order to solve the proposed model, some useful properties are obtained and the convexity of objective function is proved. Numerical examples and sensitivity analysis are provided to illustrate the applicability of the proposed model and solution method.

1. Introduction and literature review

The classical economic production quantity (EPQ) model assumes that a production system always remains in the in-control state and all of the produced items are conforming. This assumption may not hold in general and in many practical situations a production system continuously deteriorates due to usage or age such as corrosion, fatigue, and cumulative wear [1]. Recently this issue is widely investigated and many researchers have studied the impact of process deterioration, machine breakdown, and inspection schedule on the production policy.

Kim et al. [2] studied an economic production quantity model to determine the optimal production length and inspection schedules simultaneously in a deteriorating production system. They assumed that production system state, because of random deterioration changes from in-control to the out-of-control state. It means that proportion of the produced items is defective [2]. Abound [3] developed an integrated inventory-production model with machine breakdown using Markov chain. He assumed that both failure and repair times are random variables and during the repair, demand is backordered but the backordering level does not exceed a prescribed amount. Chung and Hou [4] developed a mathematical model for an integrated inventory-production system to determine an optimal production length for a deteriorating production system when shortage is permitted and is fully backlogged. Also in this research elapsed time until the production process shift, is arbitrarily distributed. Wang [5] studied a production system with random deterioration in which more defective items in the out of control state are produced. In this research, inspections are performed only at the end of the production run. Ben-Daya et al. [6] extended two single-buyer single-vendor integrated inventory-inspection models with and without replacement of nonconforming items while inspection policies include no inspection, sampling inspection, and 100% inspection. Chen and Lo [7] investigated an imperfect manufacturing process with allowable shortages for products sold with free minimal repair warranty. Giri and Dohi [8] studied the impact of scheduling of inspections for imperfect production system where the process shift time from an ‘in-control’ state to an ‘out-of-control’ state is assumed to follow an arbitrary probability distribution with an increasing failure rate. They assumed that during each production run, the process is monitored through inspections to assess its state. Kenne et al. [9] developed a mathematical model for joint optimization of inventory and preventive maintenance policies in a production system with random machine breakdowns. Chiu et al. [10] developed an integrated inventory-production model in which scraped production, rework process, and stochastic machine breakdown exist. They have

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assumed that a portion of the defective items is considered to be scraped; while the rest is assumed to be re-workable. Hu and Zong [1] developed an inventory-production model with deteriorating production process in which random deterioration in out-of-control state occurs. In order to reduce the defective items, they proposed a new inspection policy for a deteriorating production system such that inspections are performed in the middle of each production cycle. You et al. [11] examined a profit maximizing economic production quantity model incorporating both imperfect production and two-way imperfect inspections. The first type is inspection error of falsely screening out a proportion of conforming items and disposing them like non-conforming ones and the second type is inspection error of falsely not screening out a proportion of non-conforming items. Chakraborty et al. [12] developed an integrated inventory-production-maintenance model for a deteriorating production process in which not only the production facility may shift from an 'in-control' state to an 'out-of-control' state but also may randomly break down during a production process. Sana [13] developed an economic production quantity model in an imperfect production system with variable production rate such that the production system is the 'in-control' state at the beginning of process and produced items are conforming. However, process shifts from the 'in-control' state to the 'out-of-control' state after certain time due to the higher production rate and production run-time. Karamatsoukis and Kyriakidis [14] extended a mathematical model for a manufacturing system in which an input generating installation transfers a raw material to a subsequent production unit. Chiu et al. [15] studied a production system producing defective items randomly such that a portion of them is considered to be scraped and remaining items are re-workable. Moreover, in the proposed system random breakdown may occur and when it occurs, the abort/resume (AR) policy is adopted. Ma et al. [16] studied the effects of imperfect production system and decisions making about how and when screening process for defective items generated during a production process can be implemented. Khan et al. [17] developed an economic order quantity model for items with imperfect quality and learning in inspection in which partial backordering is assumed. Chiu et al. [18] developed a mathematical model to optimize an integrated inventory-production system in which defective items are randomly produced due to random equipment failure. Lin et al. [19] studied the impacts of inspection errors, imperfect maintenance, and minimal repairs in an imperfect production system using mathematical model for integrated production-maintenance-quality problem. Nodem et al. [20] developed a method to determine the optimal production, rework, and preventive maintenance policies for a manufacturing system in which random machine failures are assumed. Yoo et al. [21] developed an integrated inventory-production model for imperfect production and inspection processes with various inspection options including one-time and continuous improvement investment. Rezaei and Salimi [22] studied the relationship between vendor and buyer in a production system in which inspection exists. Chiu et al. [23] developed an integrated inventory-manufacturing mathematical model in which optimal replenishment run time for a production system with stochastic machine breakdown and failure in rework process are derived.

Although there are some researches related to the topic of this paper, some of which are not described here, but none of them are focused on the real assumptions considered here. In this paper we will study an inventory-production system with process deterioration and imperfect inspection. Moreover both in-control and out-of-control states will be mentioned and we suppose that time elapsed to process shifts follows an arbitrary probability distribution. The most related research (Kim et al. [1]) in this area studied this manufacturing system under single rate for producing defective items in out-of-control state while we assume that the defective rates in in-control and out-of-control states are produced at different rates. Another novelty is that defective items can be found at two stages including detection from inspection process and defective items which sold out to market and detected by customers. Never this issue is studied by previous researchers. Defective items sold out to market, impose discredit cost for company and repairable portion of these defectives items are reworked on secondary machine along with defective items detected during inspection. Imperfect inspection is planned to confront with cost incurred by sold out defective products. What described above are differences between this paper and what exist in literature.

According to the above description, we want to develop a mathematical model for deteriorating process representing the expected total cost to obtain the optimal solution. The aim of this research is to determine the production period length and inspection policy such that the expected total cost is minimized.

In Sections 2 and 3 the problem definition and mathematical modeling are respectively presented. Then in Section 4, numerical examples and sensitivity analysis are performed and finally in conclusion section, paper is summarized.

2. Problem definition

Consider a single product production system in which the production system at any time can be either in the in-control state or out-of-control state. If the system is in the in-control state then θ_1 percent of the produced items will be defective and if the process is in the out-of-control state, the percentage of defective produced items increases to $\theta_2(\theta_2 > \theta_1)$. During the production run time, process may shift from in-control state to out-of-control state. The elapsed time of the process in the in-control state is denoted as a random variable X which follows a general distribution function $f_{(x)}$ with cumulative distribution function $F_{(x)}$. Since in many processes, it is impossible or expensive to interrupt the production to inspect the production system, therefore in this paper we assume that when setup is done at the beginning of each cycle, production system will be inspected too. The percentage of non-inspected products (u) is defined such that $u = 1$ and $u = 0$ refer to two common strategies of no-inspection and full-inspection, respectively. Our objective is to determine the integrated optimal production run time and non-inspected fraction of products in each cycle to reduce the expected total cost.

Moreover, we assume that product inspection is not error free and error type II could occur during inspection. This means that in the inspection process, the non-conforming items may be accepted as perfect items and all re-workable non-conforming items will be sent to be reworked on another machine. Non-conforming items which are detected by inspection are called as type I non-conforming item. Obviously some non-conforming items may enter to the market incorrectly. These items may be produced either during inspection-free part of the process or produced during that part of the process where inspection is performed; but due to inspection error they are categorized as perfect items. These items, that are detected after they reach to the market, are called non-conforming items type II. Part of type I of defective items is reworked and the rest will be scraped. Type II defective items incur discredit cost and that portion which could be re-worked, should be send back to factory. In our study, we make the following assumptions.

1. Production and demand rates are constant and shortage is not allowed.
2. System deterioration can be classified as either in-control state or out-of-control state.