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Production lot sizing with process deterioration and machine breakdown under inspection schedule☆

Tulika Chakraborty, B.C. Giri*, K.S. Chaudhuri

Department of Mathematics, Jadavpur University, Kolkata 700 032, India

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Abstract

The paper develops integrated production, inventory and maintenance models for a deteriorating production system in which the production facility may not only shift from an ‘in-control’ state to an ‘out-of-control’ state but also may break down at any random point in time during a production run. In case of machine breakdown, production of the interrupted lot is aborted and a new production lot is started when the on-hand inventory is depleted after corrective repair. The process is inspected during each production run to examine the state of the production process. If it is found in the ‘in-control’ state then either (a) no action is taken except at the time of last inspection where preventive maintenance is done (inspection policy-I) or (b) preventive maintenance is performed (inspection policy-II). If, however, the process is found to be in the ‘out-of-control’ state at any inspection then restoration is done. The proposed models are formulated under general shift, breakdown and repair time distributions. As it is, in general, difficult to find the optimal production policy under inspection policy-I, a suboptimal production policy is derived. Numerical examples are taken to determine numerically the optimal/suboptimal production policies of the proposed models, to examine the sensitivity of important model parameters and to compare the performance of inspection and no inspection policies.

Keywords: Inventory; Production; Machine breakdown; Inspection; Maintenance

1. Introduction

During the last few decades, numerous research efforts have been undertaken to extend the classical economic production quantity (EPQ) model to fit closely in real-world situations. One of the important expansions involves model development for production systems which are imperfect or deteriorating in nature. The effect of process deterioration on production systems guided the previous research efforts in two main directions. In one direction, it is assumed that the process deterioration may result in shifting the process from an ‘in-control’ state to an ‘out-of-control’ state and as a consequence it begins to produce a certain percentage of defective items. The process remains in that state until the end of the production run or until the ‘out-of-control’ state is discovered by inspection. Several research efforts have been devoted to investigate the effects of process deterioration on the optimal lot sizing decisions. Porteus [1] was one of the first to consider the situation where the production process may shift from an ‘in-control’ state to an ‘out-of-control’ state with a given probability each time it produces an item. He concluded that it is economically beneficial to produce smaller lot

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* Corresponding author. Tel.: +91 9830654335.
E-mail address: bibhas_pnu@yahoo.com (B.C. Giri).

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sizes than the economic manufacturing quantity (EMQ). In a similar type of work, Rosenblatt and Lee [2] found, by assuming exponential shift distribution, that the optimal manufacturing quantity for an imperfect production system is smaller than that for a system with no defects. Hence, they arrived at the conclusion that the optimal production run length is shorter than that of the classical EMQ model. The optimal production quantity and inspection schedules were simultaneously determined by Lee and Rosenblatt [3] who showed that when maintenance by inspections is adopted, the optimal inspection intervals are equally spaced in case of an exponential shift distribution. A comparative study of continuous and periodic inspection policies for a deteriorating production system is carried out by Rosenblatt and Lee [4]. Lee and Park [5] reformulated the model of Lee and Rosenblatt [3] by considering two kinds of costs: 'reworking cost' and 'warranty cost', in which the reworking cost of an unsold defective item is much smaller than the warranty cost after sale. Lin et al. [6] generalized the Lee and Rosenblatt [3,7] model for an increasing failure rate (IFR) case. Tseng [8] introduced a perfect preventive maintenance policy instead of an inspection policy to improve the system's reliability. The effects of inspection errors were incorporated by Liou et al. [9] and Makis [10]. Hariga and Ben-Daya [11] derived the distribution free bounds for the optimal cost by considering an arbitrary probability distribution for the time to shift from an 'in-control' state to an 'out-of-control' state in Rosenblatt and Lee's [2] model. A further extension of Lee and Rosenblatt's [3] work was carried out by Kim et al. [12] who derived the exact production run length and inspection schedule. Lee and Rosenblatt [3] obtained these results by approximating the average cost function using McClaurin's series. Wang and Sheu [13] generalized the model of Porteus [1] introducing a product inspection policy. Lin et al. [14] reformulated the model of Lee and Park [5] by introducing the raw material cost in the total operating cost for a single product imperfect manufacturing system. Kim and Hong [15] assumed that defective items are detected after the production run and then rework cost for the defective items is calculated ignoring the quality related cost for producing these defective items. Wang [16] extended Kim and Hong's [15] work considering a product inspection policy only at the end of the production run, instead of full inspections during a production run. He showed that the outcome of Rosenblatt and Lee's [2] model where the optimal economic production time (EPT) is shorter than the classical EPT is not always true when the cost of correcting an out-of-control system is higher than the defective item cost under an inspection policy. Several integrated production, quality and maintenance models for imperfect production systems were also studied by Rahim et al. [17–21].

The other direction of research for deteriorating production systems has focused on the impact of machine breakdown [22] and repair on the lot sizing decisions. Groenevelt et al. [23] were the first who studied the effects of machine breakdown and corrective maintenance on the economic lot sizing decisions. Assuming an exponential failure time distribution and an instantaneous repair of the machine, they showed that the optimal lot size is always larger than that of the classical EMQ model and it always increases with the failure rate. Groenevelt et al. [24] further extended the Groenevelt et al.'s [23] model with a constant failure rate and a randomly distributed repair time. In this model, they assumed that a certain fraction of the items produced will be diverted to the safety stock in order to satisfy the demand when the machine is being repaired. Since then several researchers have extended the above seminal works to fit into various realistic situations. The concept of preventive replacement together with two types of machine failure—major and minor—was introduced by Tse and Makis [25]. In the case of major failure, the failed unit is replaced by a new one and the interrupted lot is aborted. Again, when minor failures occur, the failed unit is corrected with minimal repair and production is resumed immediately. Berg et al. [26] studied an EMQ problem with Poisson demand, exponential failure and repair time distributions in which multiple identical machines are required to produce a single part type. Srinivasan et al. [27] studied an unreliable EMQ model where demand is assumed to be Poisson, processing time is to follow an arbitrary probability distribution and the failure distribution of the machine is IFR. For an EMQ model with stochastic machine breakdown and repair, Dohi et al. [28] derived an optimal policy which can be characterized as an age replacement-like policy. They assumed that preventive maintenance is carried out immediately, even if the machine breakdown does not occur. Kim et al. [29] extended the Groenevelt et al.'s [23] model by assuming constant repair time, and observed that the optimal lot size does not always increase as the machine failure rate or the time to repair increases, which was the claim of the Groenevelt et al.'s [23] model. Kim and Hong [29] developed an extended EMQ model for a failure-prone machine with general life time distribution. Chung [30] derived the bounds for the optimal lot size in Groenevelt et al.'s [23] model. Liu et al. [31] formulated a two critical number policy (m, M) to random machine breakdown to control