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Optimal lot sizing for an unreliable production system based on net present value approach

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Abstract

The paper considers the net present value (NPV) approach to determine the economic manufacturing quantities for an unreliable production system over an infinite planning horizon. The NPV of the expected total cost is obtained under general failure time and general repair time distributions and its asymptotic characteristics are examined by perturbation of the instantaneous discount rate. The criteria for the existence and uniqueness of the optimal production time (lot size) are derived under exponential failure and constant/zero repair time. The performance of the NPV model is compared with the traditional long-run average cost model in terms of the NPV of the expected total cost based on the optimal decisions of the two models. From numerical experiments, it is observed that the decision based on the average cost can be 10% worse than the decision based on the NPV depending upon the machine failure rate.
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Keywords: EMQ; Machine breakdown and repair; Optimal lot sizing; Net present value

1. Introduction

The economic manufacturing quantity (EMQ) problem for an unreliable production facility (joint production and maintenance control problem) has been one of the most interesting topics of production planning research in the last decade. When a machine failure occurs in the production phase (which is a natural phenomenon in the manufacturing environment), the production lot is interrupted and aborted. As a result, the basic EMQ model loses its usefulness. Hence, from a practical perspective, there arises a need to design and study EMQ models recognizing the random failure of machine(s) and maintenance. A research on EMQ model with unreliable production was initiated by Bielecki and Kumar (1988). They showed that there exists a range of parameter values describing an unreliable manufacturing system, for which the zero inventory policy is exactly optimal even when the production capacity is uncertain. Posner and Berg (1989) obtained the steady-state distribution of the inventory level and some important system characteristics related to machine utilization and customer service level in an unreliable production environment. Groenevelt et al. (1992a) analyzed the effects of machine breakdowns and corrective maintenance on economic lot-sizing decisions. Assuming exponentially distributed inter-failure time and instantaneous repair time, they showed that the optimal lot size is always larger than that given by the classical EMQ

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model without machine failure. The same authors (1992b) also investigated the issue of safety stocks required to meet a managerially prescribed service level in a similar environment. The stochastic EMQ models of Groenevelt et al. (1992a, b) were extended in the literature by many researchers (Kim and Hong, 1997; Chung, 1997; Kim et al., 1997; Dohi et al., 1997). Tse and Makis (1994) studied an EMQ model with preventive replacement and major/minor repair. When a major failure occurs, the failed unit is replaced by a new one and the interrupted lot is aborted. In case of a minor failure, the failed unit is corrected with minimal repair and the production is resumed afterwards. Makis (1988) and Dohi et al. (1998) further showed that the optimal preventive replacement policy is an age replacement-like policy if the failed machine is minimally repaired and that the optimal lot size is generally a function of the operating age of the machine. Posner and Berg (1989) and Berg et al. (1994) analyzed unreliable production–inventory systems where a single machine is utilized or multiple identical machines are devoted to produce a single part type. Abboud (1997) presented an approximate model that describes the production batching problem with Poisson machine breakdowns and general repair times. The joint effect of process deterioration and machine breakdown on the optimal lot size and the optimal number of inspections in a production cycle were studied by Makis and Fung (1998). Cheung and Hausman (1997) and Dohi et al. (2001) investigated the joint implementation of preventive maintenance and safety stocks in an unreliable production environment.

The optimal lot-sizing policies of the EMQ models stated above are derived by minimizing the long-run average cost in the steady state, i.e., the time average of the undiscounted total cost, assuming that the system will continue to operate over an infinite planning horizon. The average cost approach does not reflect the time value of money. In economy, money is endowed with time and its value ought to reduce as time passes if a greater economic change or revolution does not take place. Since the cost of capital tied up in inventory is included as a part of the inventory carrying cost, in theory, a more accurate approach would be to determine the optimal lot-sizing policy by minimizing the net present value (NPV) of the expected total cost over all future time. Hadley (1964) was the first who applied the NPV criterion to the problem of finding optimal ordering quantities. Since then several researchers (Trippi and Lewin, 1974; Gurnani, 1983; Rachamadugu, 1988; Chao, 1992; Dohi et al., 1992; Moon and Yun, 1993; Klein Haneveld and Teunter, 1998; Jaber and Bonney, 2001; Laan, 2003) have studied various economic order quantity (EOQ)/EMQ models using the NPV.

Our objective in the present article is to study an EMQ model for an unreliable production system with the NPV approach. For better understanding and comparison with the corresponding average cost model, we reconsider the EMQ problem of Dohi et al. (1997) under the framework of the NPV. The rest of the paper is organized as follows. In the next section, notation and description of the model are given. The NPV of the expected total cost for an infinite time span is obtained under general failure time and general repair time distributions and its asymptotic characteristics are examined by perturbation of the instantaneous discount rate. In Section 3, we formulate the model under general failure time and constant repair time and derive the criterion for the existence and uniqueness of the optimal production time (lot size). Section 4 treats the specific formulation and analysis of the model under exponential failure and constant/zero repair time. The numerical experiments are carried out in Section 5 to investigate the optimal EMQ policy and to compare the performance of the NPV and average cost models on the basis of their optimal decisions. The paper concludes with some remarks given in Section 6.

2. The model with general failure and general repair time distributions

2.1. Notation

The following notations are used throughout the paper:

X i.i.d. random variable denoting time to machine failure

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