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Combining a maintenance center M/M/c/m queue into the economic production quantity model with stochastic machine breakdowns and repair

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ABSTRACT

This article considers a production system in which "m" identical machines produce nonidentical products at production rates. Products made by each machine are on the other hand consumed at a specific demand rate. Machines may be affected by unwanted breakdowns. Machines break down according to a Poisson distribution with equal rates and the failed machines are sent to maintenance center for repair which is consisted of "c" servers or servicemen. However, Number of machines is greater than number of servicemen ($m > c$). Hence, if the number of failed machines is greater than that of servicemen, the machines have to be put in a queue. Machines are put in one queue with the order of queue being FCFS. The queue has a typical M/M/c/m system. If machines are broken down during production, shortage will occur. This problem has been considered to obtain a single production cycle for the machines and an optimum number of the servers such that costs are minimized. For this purpose, distribution of waiting time for machines in repair center is calculated and a cost function is formed. Steepest descent and direct search methods are applied in this work to obtain optimal production cycle and maintenance servers, respectively. The proposed methods are studied using a comprehensive example.

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1. Introduction

One of the most famous models being used in production–inventory area of industry which contributes to find the size of economic production lot is Economic Production Quantity (EPQ) model. This is a simple mathematical model to confront inventory management issues in production–inventory systems, where production economic quantity is determined in such a way that total production–inventory costs are minimized. By means of this model, economic production quantity is achieved in instances, where one product is produced by one machine and definitive demand is met within limited time horizon. EPQ model is generally proposed under simplified assumptions which are rather far from the reality.

One assumption of these models is that machine breakdown does not occur during production period. Since production systems are always exposed to breakdowns, considering such an assumption would be unreasonable. In the following, some previous articles are referred to which have focused on EPQ models with machine breakdown. Generally, articles considering EPQ model with machine breakdown can be divided into two groups: first, models with constant or trivial maintenance times, and second, models with stochastic maintenance times. In the following paragraphs, models with constant or trivial and those having stochastic maintenance times are reviewed.

Groenvelt, Pintelon, and Seidmann (1992a) investigated determination of economic lot by taking into account stochastic machine breakdown and relevant modifying repairs. They considered two production control policies to confront machine breakdown. Under the first policy, it is supposed that production does not continue after occurrence of a breakdown. Instead, once the available inventory is finished, a new production cycle starts. Under the second policy, if the available inventory is less than a threshold level following occurrence of a breakdown, production will be started immediately. However, repair time is trivial in both policies. Production unit is repaired after breakdown or after termination of specific time periods. Production unit is repaired if a breakdown occurs, otherwise maintenance operations will be implemented on the production unit just at the end of some specific periods. System returns to its initial operational state after each repair. Groenvelt, Pintelon, and Seidmann (1992b) later on investigated a case in which lot size and inventory policies are adopted simultaneously. In this case, repair times are considerable with general probability distribution while the interval between breakdowns is of exponential distribution. Posner and Berge (1989) investigated a model, where demand has compound Poisson distribution. The time between machine breakdown and the repair times are both exponential. Hopp, Nati, and Jones (1989) suggested an inventory control policy for a production system of

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two machines having middle buffer. In this case, only the first machine was subjected to stochastic breakdown with the repair times being exponential.

Tse and Makis (1994) studied a model with preventive replacement and partial or total breakdown of machines. Kuhn (1997) investigated the effect of possible breakdowns on Dynamic Lot Size Model. Kim and Hong (1997) adopted model of Groenvelt et al. (1992a) thus the time between two successive breakdowns obeyed a general distribution trend. Repair time is supposed to be trivial. Moinzadeh and Aggarwal (1997) studied a production–inventory system which is affected by breakdown, where repair time is supposed to be constant. Time interval between two successive breakdowns is exponential and shortages are quite lost in their work. Based on Poisson results and building new processes, Abboud (1997) presented a simple approximation for EPQ problem with machine breakdowns and generally distributed repair times. In another article, Abboud (2001) modeled the production–inventory system as a Markov chain and developed an efficient algorithm to compute the potentials used to formulate cost function. In this article the rate of failure and repair were defined in terms of discrete time units while distributions of time to failure and time to repair were assumed to be geometric.

Lee and Rung (2000) studied a two-stage production system in which only the first machine is exposed to breakdown with repair times being generally distributed. Liu and Cao (1999) investigated a production–inventory model under the assumption that demand follows a compound Poisson distribution and machine encounters stochastic breakdowns. Chung (1997) obtained limits for economic lot size whenever a machine breaks down. He obtained upper and lower limits for optimum lot size values under the two policies suggested by Groenvelt et al. (1992a) in EPQ model. Kim and Hong (1999) obtained optimum production period length in deteriorating production processes. They assumed that production process moves from a controlled state to an out of control one due to stochastic deterioration and having an arbitrary probability distribution. Consequently, optimum length of production period is obtained under three different assumptions of deteriorating processes, namely: constant, linearly and exponentially incremental.

Chung (2003) made some approximations for economic lot sizes with machine breakdown. He showed that Average Cost Function during long run is a single modal exponential and not concave or convex contrary to the time unit for breakdown. In this article, he achieved a better upper and lower limit for economic lot values in EPQ model with stochastic breakdown. Chiu, Wang, and Chiu (2007) investigated the problem of optimum production period for EPQ model with losses, reworking of defective products, possible breakdown of machine and constant repair times. Lin and Gong (2006) represented an approximate solution to obtain a nearly optimum answer for production period of EPQ model with stochastic machine breakdown, deteriorating products and fixed repair time.

Widyadana and Wee (2009) investigated the issue of optimum production period in EPQ model with machine's stochastic breakdown, deteriorating products and stochastic repair times. Giri and Dohi(2005) proposed an exact formulation for stochastic EPQ model in which times between machine breakdowns, preventive and corrective maintenances and repair times follow general probability distributions altogether. Liao and Sheu (2011) applied periodical preventive maintenances to EPQ model in which production process breaks down stochastically. In this system, which is deteriorated by increased rate of risk, partial repair and reworking in the time of breakdown (i.e. system is out of control) are applied. In this article, two preventive maintenances, including perfect preventive maintenance and imperfect preventive maintenance, are taken into consideration and the repair time is found to be negligible.

Recently, Chen, Chiu, and Ting (2010) studied optimum replenishment policy in EPQ model with stochastic reworking and breakdown in the time of delayed order replenishment. Moreover, Cheng, Chang, and Chiu (2010) examined inventory replenishment optimum policy with delayed order, reworking and machine breakdown which occurs in storage time. Chiu, Chen, Cheng, and Wu (2010) employed a mathematical modeling to determine the optimal run time of a finite production rate model with scrap, rework and stochastic machine breakdown as well as constant repair time under abort/resume policy. Chiu (2010) also investigated EPQ model and determined the optimal production run time under stochastic machine breakdowns, constant repair times, abort/resume control policy and failure-in-rework. Ting et al. (2011) investigated effects of generating defective items and breakdown of production equipment on EPQ model in which repair times are constant. They utilized a mathematical modeling and applied renewal reward theorem to cope with variable cycle length of the system. Chiu, Lin, and Chang (2011) adapted an inventory control policy to manufacture run time problem under random machine breakdown, constant repair time and generation of defective items.

In all the reviewed articles, the problem of obtaining economic lot size or optimum production period length in EPQ model within single or two machine state has been investigated. In this article, it has been tried to obtain a single optimum production period length in EPQ model in multi-machine state, where machines break down stochastically. The repair time is stochastic and obtained based on probability distribution of machines' waiting time at maintenance center. Number of servers in the maintenance center is another parameter which is tried to be minimized next to production period length. To the best of our knowledge, this is the first paper to consider economic production quantity model with stochastic machine breakdowns under the condition, where the broken down machines may stand in maintenance queue. Assuming maintenance times as expected waiting times of machines in the maintenance center, will represent the actual world in a significantly better way.

Two main purposes are sought in this article. First, based on prevailing rules on EPQ model and queuing theory, a cost function is formed to obtain a single optimum amount for the production period length and the number of servers in repair/maintenance

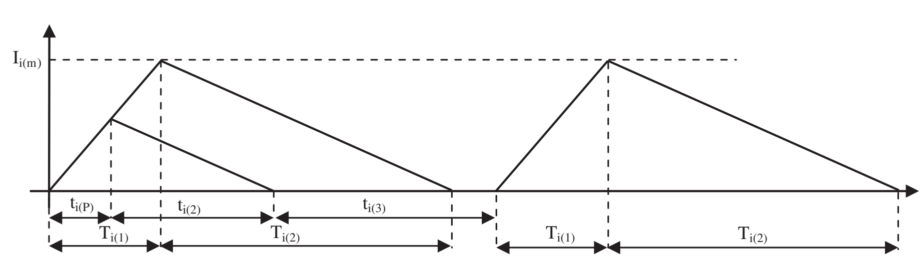

Fig. 1. Representation of inventory policy.

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