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Optimal safety stocks and preventive maintenance periods in unreliable manufacturing systems

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Abstract

We consider a manufacturing system with preventive maintenance that produces a single part type. An inventory is maintained according to a machine-age-dependant hedging point policy. We conjecture that, for such a system, the failure frequencies can be reduced through preventive maintenance resulting in possible increase in system performance. Traditional preventive maintenance policies, such as age replacement, periodic replacement, are usually studied without finished goods inventories. In the cases where the finished goods inventories are considered, restrictive assumptions are used, such as not allowing breakdown during the stock build up period and during backlog situations due to the complexity of the mathematical model. In order to solve this problem, we develop a more realistic mathematical model of the system, and derive expressions of the overall incurred cost used as the basis for optimal determination of the jointly production and preventive maintenance policies (i.e. production rates and preventive maintenance frequency, depending on inventory levels of the produced parts). Such a cost consists of inventory, backlog, corrective and preventive maintenance costs. The work reported here has a significant practical application (no restriction on failures occurrence and backlog situations) in the context of production planning of manufacturing systems. Numerical examples are included to illustrate the importance and the effectiveness of the proposed methodology.

Keywords: Preventive maintenance; Inventory; Production; Reliability; Manufacturing systems

1. Introduction

A failure prone part production inventory system is considered in this paper. The system produces a single product type to satisfy an exogenous demand process. To hedge against the uncertainties in the both production and the demand processes, provision for finished inventory buffer between the system and the demands is kept. Demands that arrive when the inventory buffer is empty are back ordered and are, therefore not lost as in available models (Das and Sarkar (1999), Rezg et al. (2004) and references therein). It has been largely shown in the literature that implementing preventive maintenance strategies for several randomly failing production units can be an effective way to extend

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their lives and reduce operating costs (Barlow and Proschan (1965), Savsar (1997), Chelbi and Ait-Kadi (2004) and references therein). The reader is referred to Savsar (2006) for details on other maintenance policies and their effects on the productivity and availability of a manufacturing system. A overview of relevant literature reveals that significant contributions, in the performances optimisation of manufacturing systems, have been proposed based on: (i) preventive maintenance, (ii) production control, and (iii) jointly production and maintenance optimisation models. Those models are considered individually or simultaneously and are restricted to simplified assumptions that sometimes provide less realistic preventive maintenance or production policies.

In the last few decades, maintenance planning has been an active area of research focused on the reliability theory as presented recently by Chelbi and Ait-Kadi (2004). Hence, a replacement policy which ensures maximum utilisation of the useful life of a component before its preventive replacement is an obvious option for large and costly components. Age replacement policy (ARP) is one such option over block replacement policy (BRP) or group replacement policy (GRP). For details on such policies, the reader is referred to Barlow and Proschan (1965), Ajodhya and Damodar (2004) and references therein. One of the basic and simple replacement policies is the age replacement policy, where the unit is replaced upon a failure or a prefix age, whichever occurs first (see Hong and Jionghua (2003), Ajodhya and Damodar (2004)). Given that ARP is based on age-dependant preventive maintenance periods instead of fixed periods, as in BRP, it remains more realistic and hence attracts many researchers. We refer the reader to extended versions of the age replacement policies and their implantation presented in Ajodhya and Damodar (2004). The related policies are no realistic in the context of manufacturing systems given that frequent machine breakdowns inevitably create bottlenecks for the process. Hence, preventive maintenance (to reduce likelihood of machine breakdowns) combined to the control of finished goods inventory is a potential way of reducing the overall incurred cost.

The aforementioned models are classified herein as static models given that the obtained policies are based on the mean values of the involved stochastic processes. In addition, the dynamics of the finished goods inventory is not considered in those models for a large class of manufacturing systems. Conversely, manufacturing systems with unreliable machines have been modelled using the so-called stochastic optimal control theory in which failures and repairs processes were supposed to be described by homogeneous Markovian processes. The related optimal control model fails in the category of problems presented in the pioneering work of Rishel (1975). Investigation in the same direction provided the analytical solution of the one-machine, one-product manufacturing system obtained by Akella and Kumar (1986). Preventive maintenance planning problems are combined to the production control to increase the availability of the production system and hence to reduce the overall incurred cost (see Boukas and Haurie (1990)).

A preventive maintenance model for a production inventory system is developed in Das and Sarkar (1999) using information on the systems conditions (such as finished product demand, inventory position, costs of repair and maintenance, etc.) and a continuous probability distribution characterizing the machine failure process. An analytical model of BRP and safety stock strategy is formulated by Ki-Ling and Warren (1997), using also restrictive assumptions such as: the time to accomplish build-up and depletion of safety stock is small relative to the mean time to failures (MTTF). The model presented in Salameh and Ghattas (2001) combines ARP and safety stock to show that one need to built an inventory just before the preventive maintenance. It is assumed in Salameh and Ghattas (2001) that extra capacity is maintained to buffer against uncertainties of the production processes and that there is no possible breakdown of the machine before the preventive maintenance date. Without the assumption made by Salameh and Ghattas (2001) on the machine dynamics, the stochastic optimal control theory is used in Boukas et al. (1995), Gharbi and Kenné (2000, 2005), Kenné and Gharbi (1999) and in Kenne and Boukas (2003) to define an machine-age-dependant production and preventive maintenance policies. Such policies are based on non-homogeneous Markov models, and hence are restricted to exponential distributions describing operational and down times of the involved machines.

The purpose of this paper is to investigate the joint implementation of preventive maintenance and safety stocks in a more realistic manufacturing environment using a stochastic model not restricted to Markovian processes as mentioned previously.