Int. J. Production Economics 119 (2009) 101–111

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Production and preventive maintenance control in a stochastic manufacturing system

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ARTICLE INFO

Article history:
Received 11 November 2004
Accepted 19 January 2009
Available online 7 February 2009

Keywords:
Production control
Preventive maintenance
Stationary distribution
Threshold policy
Average cost

ABSTRACT

This paper considers the problem of production and preventive maintenance control in a stochastic manufacturing system. The system is subject to multiple uncertainties such as random customer demands, machine failure and repair, and stochastic processing times. A threshold-type policy is proposed to control the production rate and the preventive maintenance operation simultaneously. The explicit form of the stationary distribution of the system state is derived analytically and used to produce the formula for various steady-state performance measures. The optimal threshold values can then be obtained by optimising the relevant formula. Numerical examples demonstrate that the proposed threshold policy is indeed optimal or extremely close to the optimal policy in a range of scenarios.

1. Introduction

The failure-prone manufacturing systems have attracted much attention recently. An important problem is how to control the system so that the exogenous demand process can be satisfied with the minimum cost subject to a variety of uncertainties, e.g. random demands, stochastic processing times, machine failures and repairs. By properly controlling the production rate at machine's operational mode, a positive inventory level can be maintained to hedge against the effect of uncertainties. On the other hand, by executing preventive maintenance the reliability of the machine can be improved and therefore the disruptions caused by the machine failures are reduced. There are two types of preventive maintenance operations: a tool change, which necessitates a machine stoppage; and a control, which does not necessitate a machine stoppage (Cavory et al., 2001). This paper focuses on the second type of maintenance. In order to achieve the best performance, an integrated control policy for both production and maintenance is preferable.

In practice, many performance measures may be of interest, e.g. the long-run average cost (which consists of the inventory cost, the backlog cost and the maintenance cost), stock-out probabilities (*SP*) (representing the customer service level), average backlog level (*BL*) (representing the degree of backlogs), average inventory level (*IL*), and machine utilisation.

Literature in failure-prone manufacturing systems (or deteriorating production systems) can be classified into two groups (Buzacott and Shathikumar, 1993). The first is based on "fluid flow models", where the production is modelled as a continuous production process. The second is "discrete part manufacturing systems", where parts are produced in discrete mode.

The first group with the maintenance decisions included can be referred to Boukas and Haurie (1990), Boukas (1998), Gharbi and Kenne (2000), Boukas and Liu (2001), Kenne and Nkeungoue (2008) and the references there. In Boukas and Haurie (1990), the probability of machine failure is an increasing function of its age, while in Boukas and Liu (2001) the machine has multiple operational states and the machine failure rates are state-dependent. With the assumptions of a constant demand rate and a discounted linear cost function, they established the optimal production and maintenance

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doi:10.1016/j.ijpe.2009.01.009

policies using stochastic dynamic programming. Gharbi and Kenne (2000) considered a multiple-identical-machine system and investigated the modified hedging point policy for maintenance and production using simulation-based approach. Kenne and Nkeungoue (2008) considered the control of corrective and preventive maintenance rates in a manufacturing system in which the failure rate of a machine depends on its age.

The second group often takes into account the randomness in both production process and demand process. Sharafali (1984) studied the effects of a machine failure on the performance measure in which the production is controlled by an (s, S) policy. Srinivasan and Lee (1996) extended the above work by adding preventive maintenance option to the (s, S) policy. It is assumed that when the inventory level reaches S, the preventive maintenance is undertaken and the machine becomes as good as new. They obtained the optimal parameters s and S in order to minimise the total average cost. In their model, preventive maintenance and production are executed separately and the preventive maintenance is impliedly determined by the production policy.

Van der Duyn Schouten and Vanneste (1995) considered a single machine production system with an exogenously given finite capacity buffer. The production policy is fixed and determined by the buffer level and capacity. They proposed a suboptimal preventive maintenance policy which is based on the age of the machine and the buffer level. Das and Sarkar (1999) studied a production inventory system where the unit production time, repair time and maintenance time have general probability distributions. They presented a preventive maintenance policy based on the inventory level and the number of items produced since the last repair or maintenance operation. The production is governed by the (s, S) policy where the parameters s and S are exogenously given. Iravani and Duenyas (2002) considered a single machine system with multiple operational states and investigated how the structure of the integrated production and maintenance policy changes as the system enters different operating states. They introduced a double-threshold policy to characterise the decisions of production and maintenance and developed algorithms to implement the policy. The above three papers assumed that the unmet demands are not backordered (or partially) and therefore the system state space is finite. Yao et al. (2005) investigated the structural properties of the optimal joint preventive maintenance and production policy for an unreliable production-inventory system with constant demands and time-dependent failures.

This paper considers a discrete part manufacturing system. The system produces a single product type with stochastic processing times to satisfy an exogenous demand process. Unmet demands are backordered. The machine may break down and is repaired afterwards. At machine's operational states, both production rate and preventive maintenance rate are simultaneously controllable. The preventive maintenance does not require a machine stoppage. Such preventive maintenance includes lubrication, cleaning and adjustment. On one hand, preventive maintenance can improve the machine's reliability to some extent; on the other hand, it will slightly disrupt the production and therefore reduce the production capacity. The objective is to find good production and maintenance policies to optimise a steady-state performance measure such as the long-run average cost.

The assumption that unmet demands are backordered makes the state space infinite. Three random processes (i.e. production process, demand arrival process and failure/repair process) together with the production and preventive maintenance policy determine the behaviour of the system. It is usually the stationary distribution of the system state that we need to compute the performance measures. We apply a threshold-type policy to control the production and preventive maintenance. This is based on the facts that threshold policies are simple, easy to operate and indeed optimal in many cases without preventive maintenance (e.g. Sethi and Zhang, 1994; Song and Sun, 1999; Feng and Xiao, 2002). In the context of production and maintenance control, Boukas and Haurie (1990) showed the existence of hedging surfaces, in which the preventive maintenance actions are triggered by switching curves. Boukas (1998) studied the effectiveness of a hedging point policy in a production and corrective maintenance control problem. Yao et al. (2005) demonstrated that the optimal production and maintenance policies have the control-limit structure and the optimal actions on the entire state space are divided into regions. The hedging point policy can be regarded as a special type of threshold policies and the switching-curve or switching-region policy is an extension of threshold policies. Moreover, the (s, S) type of policies (e.g. Srinivasan and Lee, 1996; Das and Sarkar, 1999) are typical examples of threshold policies. Therefore, threshold policies deserve more studies in production and maintenance control problems. In fact, we will show later on through numerical examples that the threshold policies we proposed are actually optimal in many cases (cf. Section 5). Our main task is to derive the explicit form of the stationary distribution under the proposed threshold policy, evaluate various steady-state performance measures, find the optimal threshold values in order to implement the policy, and demonstrate its effectiveness.

The rest of the paper is organised as follows. The problem is formulated into an event-driven Markov decision process in Section 2. In Section 3, a threshold policy is presented and the stationary distribution under the threshold control is derived using the characteristic equation approach. In Section 4, various performance measures are evaluated and the computation of optimal threshold values are addressed. Numerical examples are given in Section 5 and conclusions are made in Section 6.

2. Problem formulation

Consider a manufacturing system producing one part-type with two modes: operational mode and failure mode. We first introduce the following basic notation:

d — the demand rate. The customer demand follows a homogeneous Poisson flow with rate d.

λ — the production rate, which is a controllable variable that takes a value in $[0, r_1]$. It is assumed that the production time is