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Stohastic optimal production control problem with corrective maintenance

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Abstract

We consider a production control problem in a manufacturing system with failure-prone machines and a constant demand rate. The objective is to minimise a discounted inventory holding and backlog cost over an infinite planning horizon. The availability of the machines is improved through a corrective maintenance strategy. The decision variables are the production and the machine repair rates, which influence the inventory levels and the system capacity, respectively. It is shown that, for constant demand rates and exponential failure and repair times distributions of the machines, the hedging point policy is optimal. Such a policy is modified herein and parameterised by factors representing the thresholds of involved products and switching inventory levels for corrective maintenance. With the obtained policy, simulation experiments are combined to experimental design and response surface methodology to estimate the optimal production and corrective maintenance policies, respectively. The usefulness of the proposed approach is illustrated through a numerical example.

Keywords: Stochastic optimisation; Corrective maintenance; Simulation; Experimental design; Response surface methodology

1. Introduction

This paper deals with the control problem of a stochastic manufacturing system consisting of different machines producing different part types. The stochastic nature of the system is due to the machines that are subject to random breakdowns and repairs. The capacity of the system is improved by controlling the machine repair rates. The machine capacities are assumed herein to be described by a finite state Markov chain. The decision variables are input rates to the machines and their repair rates, which influence the surplus. The surplus means the difference between the cumulative demand and the cumulative

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production of finished goods or commodities produced. Many authors contributed in the sphere of the production-planning problem of flexible manufacturing systems (FMS) and proposed different formalisms. However, the problem becomes much more complicated with large FMS involving multiple machines, multiple parts and random demands.

Based on the pioneering work of Older and Suri (1980) and Rishel (1975) presented a model for FMS with unreliable machines whose failures and repairs are described by certain homogeneous Markov process. The main difficulty with this approach is the lack of efficient methods for solving the optimisation problem characterised by stochastic Hamilton–Jacobi–Bellman (HJB) equations. Akella and Kumar (1986) solved analytically a one-machine one-part type problem and Sharifnia (1988) studied the steady state probability distribution of a multiple-machine one-part type problem. Investigation in the same direction gave rise to the extension presented in Boukas and Haurie (1990) where the authors considered a machine age dependent matrix generator for the Markov process which describes the machine states. They added to the previous models (as in Akella and Kumar (1986)) the possibility to do preventive maintenance. The related machine age dependent dynamic programming equations were solved numerically for the two-identical-machine one-product system. However, with this numerical scheme, it remains difficult to obtain the optimal control of large scale FMS. One of the most important methods of dealing with this problem is that of hierarchical decomposition. The literature provides several different ways by which to reduce the complexity of some particular structure of FMS (see Kenne (1997) and Sethi and Zhang (1994)). However, the control problems in large manufacturing systems are not studied in the works mentioned in the literature. In addition, the complexity of the optimal control problem increases with the fact that the Markov chain is non-homogeneous (i.e. transition rates are control policy dependent as in this paper).

The non-homogeneous Markov processes, such as in Boukas and Haurie (1990) and Kenne (1997) are considered in order to increase the capacity of the FMS. The approaches presented in those papers assume that failure rates and control policies are machine age dependent. Hence, machines become more available with preventive maintenance. With machine age dependent control policies, the dimension of the problem is large given that the machines ages and preventive maintenance states are additional state variables and Markov chain states, respectively. Instead of proceeding with the preventive maintenance as in aforementioned papers, the availability of the production system is increased through the use of corrective maintenance as in Boukas (1998) and Kenne, Boukas and Gharbi (2004). In this paper, we propose to combine such a model to a simulation based optimisation approach. The proposed approach is focused on the combination of analytical formalism and simulation based statistical tools such as experimental design and Response Surface Methodology (RSM). Several details on the concepts of experimental design and/or RSM, used hereinafter, can be found in Gharbi and Kenne (2000) and in Kenne and Gharbi (1999).

In the proposed approach, a parameterised near-optimal control policy is used as operating point of the simulation model and for each entry consisting of a combination of parameters, the cost incurred is obtained. The significant effects of control variables are determined by the experimental design and the relationship between the cost and input factors is obtained through a response surface model. By solving this model, an approximation of the optimal control policy is obtained. Based on the results given by numerical methods, a structure of the control policy (production and corrective maintenance strategies) is defined and parameterised herein by parameters called control parameters. The obtained near-optimal control policy is then used as control policy of considered multiple-machine, multiple-product FMS without solving the related optimality conditions.