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# Maintenance scheduling and production control of multiple-machine manufacturing systems

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## Abstract

This paper deals with the production and preventive maintenance control problem for a multiple-machine manufacturing system. The objective of such a problem is to find the production and preventive maintenance rates for the machines so as to minimize the total cost of inventory/backlog, repair and preventive maintenance. A two-level hierarchical control model is presented, and the structure of the control policy for both identical and non-identical manufacturing systems is described using parameters, referred to here as *input factors*. By combining analytical formalism with simulation-based statistical tools such as experimental design and response surface methodology, an approximation of the optimal control policies and values of input factors are determined. The results obtained extend those available in existing literature to cover non-identical machine manufacturing systems. A numerical example and a sensitivity analysis are presented in order to illustrate the robustness of the proposed approach. The extension of the proposed production and preventive maintenance policies to cover large systems (multiple machines, multiple products) is discussed.

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*Keywords:* Preventive maintenance; Hierarchical control; Flexible manufacturing systems; Simulation; Experimental design; Response surface methodology (RSM)

## 1. Introduction

The problem of controlling manufacturing systems with unreliable machines was formulated as a stochastic control problem by Older and Suri (1980). Failure and repair processes were supposed to be

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described using homogeneous Markov processes. The related optimal control model falls under the category of problems studied previously by Rishel (1975). Similar investigations have resulted in the analytical solution of the one-machine one-product manufacturing system control problem obtained by Akella and Kumar (1986). In the case of non-homogeneous Markov processes involving states and control-dependent transition rates, the control problem becomes more complex. In this sphere, Boukas and Haurie (1990) considered the fact that the failure probabilities of a machine depend on its age, and they added the possibility of performing preventive maintenance to the existing models. The related age-dependent set of dynamic programming equations were solved numerically for a given manufacturing system. However, with the numerical scheme presented by Boukas and Haurie (1990), it remains difficult to obtain a general structure for the optimal control of a large class of manufacturing systems. A potential way of coping with such a difficulty is to develop heuristical methods based on the reduction of the size of the considered control problem. Hence, different approaches have been proposed in the existing literature with a view to deriving simple near-optimal control policies for manufacturing systems.

The concept of *hedging point policy*, introduced by Kimemia and Gershwin (1983), is one of the simple ways available for finding suboptimal control policies in the production planning and maintenance scheduling of manufacturing systems. For further details on this concept, we refer the reader to the age-dependent hedging point concept presented by Boukas, Kenne, and Zhu (1995) and Kenne and Gharbi (1999). Because of the computation of threshold levels, the derivation of suboptimal policies based on this concept seems to be difficult for a large class of manufacturing systems. Another approach is to develop hierarchical control methods based on the particular structure of the system. This can be done by using the singular perturbation approach. Such an approach mainly involves reducing the size of the control problem according to the discrepancy between the time scales of events involved. By replacing fast processes with their respective mean values, one can construct a deterministic limiting problem, which is computationally more tractable. Details on this approach can be found in Kokotovic, Khalil, and O'Reilly (1986), Lehoczky, Sethi, Soner, and Taksar (1991), Sethi and Zhang (1994), and Soner (1993). In this paper, we will first define the structure of the optimal control policies, both for identical and for non-identical machine manufacturing systems. Based on such structures, we will then extend the production and maintenance rates control model presented in Kenne and Boukas (2003) in order to determine the control policy in a more general case including non-identical machine manufacturing systems. The resulting structure is described through a set of parameters we call *input factors*. We resort to a combination of analytical and simulation-based experimental approaches to find an approximation of the optimal control policies for production and preventive maintenance by determining the values of input factors.

In the proposed approach, the parameterized near-optimal control policy is used as an input for the simulation model. For each entry consisting of a combination of parameters, the cost incurred is obtained. It is from this relationship that the best control factor values are determined and a relationship between input factors and such a cost is given. The application of such an approach is motivated by the works of Gharbi and Kenne (2000) and Kenne and Gharbi (1999). We refer the reader to these works for a literature review on the applications of simulation and statistical methods such as experimental design and RSM in the sphere of manufacturing systems control.

The remainder of the paper is organized as follows. In Section 2, the optimal control problem is described both for identical and non-identical machine systems. The proposed control approach is described in Section 3. The logic of the simulation model is described in Section 4. In Section 5,

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