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Control of Production and Corrective Maintenance Rates in a Multiple-Machine, Multiple-Product Manufacturing System

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Abstract—This paper presents the analysis of the optimal production control and corrective maintenance planning problem for a failure prone manufacturing system consisting of several identical machines. Machines are subject to breakdowns and repairs and can produce several parts of products. At any given time, each machine can only produce one type of product. The introduction of the corrective maintenance will increase the availability of the production system which guarantees the improvement of the system's productivity if the production planning is well done. The decision variables are the production and the machine repair rates which influence the inventory levels and the system capacity, respectively. The objective of the work is to minimize the cost of surplus and repair activities. A computational algorithm, based on numerical methods, is given for solving the optimal control problem. Finally, a numerical example is presented to illustrate the usefulness of the proposed approach and extensions to more complex manufacturing systems are discussed.

Keywords—Production control, Corrective maintenance, Numerical methods, Flexible manufacturing systems.

1. INTRODUCTION

A flexible manufacturing system (FMS) consists of several computer controlled machines with facilities for automatic changing of workpieces and tools, interconnected by automated handling and storage facilities [1]. Such a system is designed to manufacture a variety of items and to provide alternative processing routes for individual products. Most previous work on the problem

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of the optimal flow control of such systems has been focused on systems whose underlying states processes are Markov processes [2]. These systems were modeled with jump Markov disturbances based on the Rishel formalism [3]. For systems with homogeneous Markov state processes, the hedging point policy is the optimal control policy [4]. In such a policy, a positive production surplus of part-types is maintained during time of excess capacity availability to hedge against future capacity shortage brought by machine failures. The concept of hedging point is extended to manufacturing systems with unreliable machines and random demands in [5,6].

Based on the concept of hedging point, several approaches have been proposed to determine optimal or near-optimal controls [7,8]. Motivated by Sharifnia's results, Caramanis and Sharifnia [9] used a decomposition method to design a near optimal manufacturing flow controller. They then decomposed a multiple-part-type problem to many analytical tractable one-part-type problems. However, the problem becomes much more difficult when the state processes of the systems are nonhomogeneous Markov processes. Boukas and Haurie [10] considered a system which has two machines with age-dependent failure rates and where preventive maintenance is a decision variable. Other authors contributed in the sphere of nonhomogeneous Markov processes in terms of the dependence of the machine failure rates on production rates [11–13].

Nonhomogeneous Markov processes, such as in [10], are considered in order to increase the capacity of the FMS. This is obvious because machines become more available with preventive maintenance. With such an approach, the control policy is machine age dependent and the dimension of the problem is large. The ages of machines and states of preventive maintenance are additional state variables and Markov states, respectively. Instead of proceeding with the preventive maintenance, the use of corrective maintenance will increase the availability of the production system with a model which is not age dependent [14]. In this paper, we propose to improve the capacity of the FMS by controlling the machines repair rates. The proposed approach is based on a small number of state variables and the related optimality conditions are then more tractable compared to approaches focused on preventive maintenance.

An important question that arises is to know if the contribution of the approach proposed herein in terms of total cost reduction is significant compared to a fixed repair rate situation. The theory presented in this paper answers this question in the affirmative under reasonable assumptions (demand rates of various products are constants, the machines are completely flexible, etc.). This theory is based on the fact that the structure of the control policy (production and machine repair rates) can be obtained by using the fact that the value function is the unique solution to the associated Hamilton-Jacobi-Bellaman (HJB) equations. We first used a numerical approach to determine an approximate value function, instead of the true value function, to construct the control policy. We then showed that, under certain appropriate conditions, the control policy constructed is asymptotically optimal as the difference between the true value function goes to zero. Finally, we presented a numerical example that illustrates the usefulness of the proposed approach. Extensions to more complex manufacturing systems are also discussed herein.

The paper is organized as follows. In the next section, we state the model of the problem under consideration. In Section 3, we present the HJB equations and prove that the control policy obtained is insensitive to a small perturbation of the value function in Section 4. We show in Section 5 that a numerical scheme can provide an approximation of the value function. Then in Section 6, we present a numerical example and discuss the extensions of the proposed approach to more complex manufacturing systems. The paper is finally concluded in Section 7.

2. PROBLEM STATEMENT

We consider an FMS with m identical machines subject to breakdowns and repairs. The FMS can produce n different part types. Machines are subject to random failures and repairs and the state of each machine can be classified as operational, denoted by $\mathbf{1}$ or under repair, denoted by $\mathbf{0}$. When a machine is operational, it can produce any type of part and when it is under repair