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Production Planning and Opportunistic Preventive Maintenance for Unreliable One-Machine Two-Products Manufacturing Systems

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Abstract: This paper develops an effective joint production, setup and maintenance control policies in an unreliable one-machine two-products manufacturing system. The main objective is to reach a higher synchronization level of the preventive maintenance (PM) interventions in the planning of production activities. The proposed joint control policy integrates the concept of the opportunistic maintenance by taking advantage of the machine stoppage during setup operations in order to conduct preventive actions. This aims to increase the machine availability and to reduce the risk of shortages.

Performance evaluation of the proposed control policy is carried out using a combined continuous/discrete event simulation model. It is subsequently analyzed by statistical techniques of optimization such as design of experiments, analysis of variance and response surface methodology. An illustrative numerical example followed by an in-depth comparison study for a wide range of the system configurations are performed in order to demonstrate the usefulness and the robustness of the results.

Keywords: Optimal control, Production control, Setup, Preventive maintenance, Opportunistic maintenance, Manufacturing systems, Simulation, Optimization.

1. INTRODUCTION

Most previous works on the problem of the optimal flow control for failure prone manufacturing systems have focused on the concept of hedging point policy (HPP), introduced by Akella and Kumar (1986) for an single-machine one-product manufacturing system (M_1P_1). In such a policy, an optimal inventory level is maintained to hedge against future capacity shortage brought by machine failures. The HPP was then extended to other manufacturing contexts. Gharbi et al. (2011) developed the Multiple HPP (MHPP) for multiple state systems. For systems producing two part types (M_1P_2), Bai and Elhafsi (1997) developed a suitable production and setup control policy called the Hedging Corridor Policy (HCP). In the same context, Gharbi et al. (2006) develop the Modified Hedging Corridor Policy (MHCP) in order to effectively determine a better sequence of setups. Using quantitative and qualitative criteria, an in-depth comparison study between the HCP and the MHCP which has been improved in order to further reduce the shortage costs was conducted in (Assid et al., 2014). They showed that HCP can become better than MHCP in terms of cost depending on the service level adopted. In addition, it requires a lower storage space since it generates less shortage.

Based on the inventory control problem, many others have been interested in integrating preventive maintenance (PM) in the production planning for its important contribution of the maintaining of production tools in service. For unreliable M_1P_1, mathematical models have been developed in order to combine PM strategies with production control policies as in (Rezg et al., 2008) and (Chelbi and Ait-Kadi, 2004) which are based respectively on the Block Replacement Policy (BRP) and the Age Replacement policy (ARP). However, the optimality of the structure of such control policies has not been established. Gharbi and Kenné (2000) proposed a near-optimal age-dependent control policy in the case of an increasing failure rate. Berthaut et al. (2010) addressed the same optimal control problem but instead of ARP, PM interventions are controlled with BRP. Note that the BRP is more practical to implement and to manage in an industrial context than the ARP since it does not require continuous tracking of the equipment utilization time. The proposed control policy could skip PM actions when the inventory level is bellow a given threshold. The idea of skipping PM aims to avoid consecutive failures and PM, which lead to a waste of components and higher shortage costs.

As far as we know, no other work has addressed the joint control problem which simultaneously considers the production and the PM planning in the case of non-flexible M_1P_2. In this work, we consider a joint control policy which combines the HCP and the BRP, both are characterised by simple management and ease of implementation. The purpose is to control simultaneously the production the PM intervention activities as well as the sequence of setups of the

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M_1P_2. The opportunistic maintenance (OM) is also integrated with the aim of making dynamic decisions based on the overall performance control of our system. The concept of OM is well known in the industry and its practice is in an increasing use (Derigent and al., 2009). According to Bouillaut (2007), it takes into account the interactions between the different system components in order to benefit from an equipment stoppage (or more) by performing preventive actions on other equipments of the system if deemed necessary. This concept is used in (Levrat and al., 2008) which is based on the availability criterion to select, among the different planned production downtimes, the execution time of maintenance interventions. This idea of taking advantages of production downtimes is considered in our paper. Indeed, PM interventions decisions will be taken during setup operations, when the production changes from one product type to another. These operations require the stoppage of the concerned machine for a non-negligible time. The aim is two-fold: to propose a joint control policy structure which simultaneously combines production, setup and PM activities for an M_1P_2 and to demonstrate the economic gains generated when the concept of the OM is integrated in the production planning. An experimental approach combining simulation, experimental design, analysis of variance and response surface methodology is used to optimize the control parameters which minimize the total cost incurred. The latter is composed of inventory, backlog, setup, corrective maintenance (CM) and PM costs.

The rest of this paper is organized as follows. In Section 2, the joint production/setup/maintenance control problem of the studied manufacturing system is discussed. Section 3 summarizes the system data and the experimental resolution approach used in order to determine the optimal control parameters. The numerical example and the results of the optimization are presented in Section 4. Using the cost criterion, a comparative study between the considered control policies is conducted in Section 5 while varying different system parameters. This article is concluded in Section 6.

2. DESCRIPTION OF THE JOINT CONTROL POLICY

The purpose of this section is to describe the joint control policy considered in this paper. It combines the Hedging Corridor Policy (HCP) and the Block Replacement Policy (BRP) and integrates the concept of the OM.

2.1 Notation

The following notations are used throughout the paper. For every i,j = {1,2}, i≠j:

P_i	: Type of product i
$x_i(t)$	: Inventory level (or backlog) of P_i at time t
d_i	: Constant demand rate of the product P_i
u_i	: Production rate of the product P_i
U_i^{max}	: Maximum production rate of the product P_i
Z_i^{inv}	: Storage space capacity of the product P_i
T_{PM}	: Time interval between two PM interventions
T^s_{ij}	: Setup time required to switch from P_i to P_j
c_i^+	: P_i inventory cost
c_i^-	: P_i backlog cost
c^s_{ij}	: Setup cost to switch from P_i to P_j
c_{pm}	: Preventive maintenance (PM) cost
c_{cm}	: Corrective maintenance (PM) cost
C^*_P	: Optimal total cost incurred when the control policy "P" is used

2.2 Hedging Corridor Policy (HCP)

It is characterized by a single threshold Z_i^{inv} (i = {1,2}) for each part type. The HCP corridor guides the surplus trajectory of the product types to target positive stock thresholds (Z_1^{inv} for P_1 and Z_2^{inv} for P_2) built up. Thus, the machine operates at maximum capacity throughout the availability period and the setups are performed when the stock level of a part type reaches its threshold. The stocks built help to continue meeting the customer demand even when the system state becomes unavailable (repair actions, setup operations or when the machine produces the other part type). The HCP structure is defined by the following equations:

$$u_1(.) = \begin{cases} U_1^{\max} \cdot I(S_{21}=1) & \text{if } x_1 < Z_1^{inv} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$u_2(.) = \begin{cases} U_2^{\max} \cdot I(S_{12}=1) & \text{if } x_2 < Z_2^{inv} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$S_{21} = \begin{cases} 1 & \text{if} \left(x_2 = Z_2^{inv}\right) \text{ and } \left(x_1 < Z_1^{inv}\right) \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$S_{12} = \begin{cases} 1 & \text{if} \left(x_1 = Z_1^{inv}\right) \text{ and } \left(x_2 < Z_2^{inv}\right) \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

With,

$$I(S_{ij}=1) = \begin{cases} 1 & \text{if } S_{ij}=1 \\ 0 & \text{otherwise} \end{cases}$$

2.3 Block Replacement Policy (BRP)

It is characterized by preventive interventions which are performed periodically at predetermined time intervals $k.T_{PM}$ (k=1,2,...). In addition, when a failure occurs before the next scheduled PM, the machine is repaired during a non-negligible delay.