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Joint production and major maintenance planning policy of a manufacturing system with deteriorating quality

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ABSTRACT

We investigate the simultaneous production planning and quality control problem for an unreliable single machine manufacturing system responding to a single product type demand. The machine is subject to deteriorations, and their effect is observed mainly on the rate of defectives, which increases continuously over time. Due to the uncertainty caused by failures, the machine may not meet long-term demand, and an overhaul can be conducted in order to counter the effect of the deterioration. The main objective of this study is to simultaneously determine the optimal production plan and overhaul schedule for the analyzed manufacturing system, in order to minimize the total cost, comprising the inventory, backlog, repair and overhaul cost, over an infinite planning horizon. A stochastic dynamic programming model is proposed, in which a numerical scheme is adopted to solve the optimality condition equations. It is observed that the optimal control policy is described by a machine deterioration-dependent hedging point policy (MDDHPP). To accurately approximate the related control parameters, a simulation optimization approach based on design of experiments, simulation modeling and response surface methodology is applied. The results obtained provide a better understanding about the influence of the deterioration of quality in the production and overhaul policies. A numerical example and an extensive sensitivity analysis are conducted, and show the robust behavior and usefulness of the policy obtained.

1. Introduction

Production planning has been studied by several authors, with the common objective of improving productivity. However, a major limitation encountered in most of the literature in this domain lies in the assumption that all the parts produced are conforming items; an assumption which is obviously not realistic in industrial contexts. Fortunately, the inter-relation between productivity and quality has been received growing attention of researchers. We start by examining the need to integrate quality aspects in production policies, since all companies must satisfy high levels of productivity and high standards of quality. Additionally, if we take into account that manufacturing systems progressively degrade over time means that, this factor may have an impact on its operating conditions. Therefore, through this research, we contribute to a better understanding of the inter-relation between production planning and quality, in the case where the manufacturing system is subject to deterioration, which has a negative influence on the quality of parts produced.

In the literature, various authors have covered the production planning problem for unreliable manufacturing systems; for example, in the production systems studied by Kimemia and Gershwin (1983) and Akella and Kumar (1986), the control policy that they obtained was found to have a structure called hedging point policy. The importance of such a policy lies in being an efficient way of determining production policies for manufacturing systems. Following these two studies, several extensions to this research area were realized, considering a wide range of aspects such as; transportation delay from the machine to the inventory as in Mourani et al. (2008), multiple-types production satisfying a low and a high demand as in Chan et al. (2008), remanufacturing operations considering a reserve logistic network as in Kenné et al. (2012), etc. Nevertheless, the majority of such extensions on production planning have not covered the influence of quality issues on the control policy. While the importance of quality cannot be ignored, it should be noted that it reflects the need for further analysis of the inter-relation between production and

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quality aspects. Some papers have highlighted the importance of this inter-relation, such as that by Inman et al. (2003), which presented a comprehensive list of research issues involving the relationship between quality and production system design. However, consideration of quality issues only started growing with the series of works of Kim and Gershwin (2005, 2008), who introduced mathematical models to evaluate the performance of small and large production systems with quality and operational failures. Colledani and Tolio (2006, 2009, 2011) similarly addressed the evaluation of the performance of production systems, where the behavior of machines were monitored by control charts. Although these papers study the influence of quality aspects, their focus is on performance measures, whereas our research approach is different. We focus mainly on the structure of the control policy, and we aim to investigate the impact of quality aspects on the production control rule.

A recent area of research has emerged addressing quality issues on the production policy; Radhoui et al. (2009), for instance, used the rate of defectives as a decision variable to determine when to perform preventive maintenance and define the buffer size. The simultaneous determination of maintenance activities and production planning is covered by Njike et al. (2009), who applied several operational states that monitor the system′s condition. They used the quantity of defective products as feedback to optimally control the system. Further, Mhada et al. (2011) analyzed the production control problem for an unreliable manufacturing system producing a random fraction of defective items, and succeeded in stating analytical expressions for the production threshold and the optimal cost. Additionally Dhouib et al. (2012) incorporates to the production planning problem, an age-dependent preventive maintenance policy that reduces the shift rate to the out of control state, where their productive systems produces non-conforming items. Despite the pertinence of these works, we conjecture that the joint production and quality control problem can be studied from a different perspective. For instance, this includes bearing in mind that in real industrial contexts, the production system is subject to deteriorations (because of an infinite set of factors), meaning therefore that the effect of the deterioration may certainly have an impact on the quality of the parts produced. This effect will allow us to extend the concept of deterioration, and relate this factor to the quality yield of the production system. We find some support for our conjecture in the area of deteriorating systems.

Many papers have been published in the area of deteriorating systems, with the typical method used to model deterioration based on the concept of imperfect maintenance. A good discussion on the subject of imperfect maintenance can be found in Pham and Wang (1996). In addition, Wang and Pham (1999) present an interesting method, and propose that after an imperfect repair, the operating time of the system decreases as the number of repairs increases. The idea to treat certain deterioration in the operating conditions was extended by Lam (2007), who proposed that the operating times after a repair decrease, while the consecutive repair times after failure increase. We find another approach for modeling deteriorating systems in the work of Dehayem et al. (2011), who described a model in which the operating time of the production system follows a decreasing function given by the age of the machine, while the repair time consists of an increasing function with the number of failures. As can be seen from the previous models, it is assumed that deterioration has an effect on the availability of the production system, and that it is used as indicator of the level of deterioration either the age of the machine or the number of failures. Nevertheless, these models do not link the degrading process to the parts quality. This observation in turn raises the question of whether it is possible to relate the deterioration phenomenon with the quality yield of the production system. Typically, an efficient alternative for determining the optimal control policies of stochastic manufacturing systems has been the use of simulation optimization approaches.

Simulation modeling has proved to be an effective means to analyze manufacturing systems, as observed in the work of Lavoie et al. (2010), who compared different pull control mechanisms for homogenous transfer lines. Simulation has also been applied to compare different maintenance strategies, such as in Boschian et al. (2009), where they analyzed the case of two machines working in parallel, applying different maintenance strategies. Other applications of the simulation optimization approach, such as the presented by Berthaut et al. (2010), deal with the determination of production and periodic preventive maintenance rates. Recently, this hybrid methodology was extended by Gharbi et al. (2011), who analyzed the case of the production control problem of a manufacturing cell comprising a central and a reserve machine. Moreover Hajji et al. (2011) used a simulation based approach to determine the production control parameter and product′s specification limits that have a direct influence in the rate of non-conforming items. A closer look at these models reveals that this simulation optimization approach is not yet in use in cases where the degrading process of the production system has a continuous deterioration on the parts quality.

Therefore, given this context, we intend to develop a new model for the simultaneous production and quality control policy of a mono-product manufacturing system, composed of a single unreliable machine that is subject to progressive quality deterioration and uncertainties. This is motivated by the need to study the inter-relation between quality issues and the production policy, where phenomena such as deterioration are present. Furthermore, the notion of relating the deterioration of the machine with the parts quality is based on the concept of worse repairs (a maintenance action which increases the rate of defectives). The uncertainties are due to machine failures in a dynamic continuous time stochastic context. We develop a stochastic dynamic programming model with two decision variables, the production rate and the quality decision related to the overhaul strategy, which counters the effect of the deterioration. This specific problem has not been yet addressed in the literature. The resultant control policy called machine deterioration dependent hedging point policy (MDDHPP), adjusts the control parameters according to the level of deterioration of the machine. The contribution of this article is further illustrated by the robust behavior of the MDDHPP facing several variations of the system parameters in a sensitivity analysis, and providing a better knowledge of the production system behavior. We propose a simulation optimization approach combined with the control theory to achieve a close approximation of the optimal control policy parameters.

The remainder of the paper is structured as follows. After an overview of the literature in Section 1, the notations and the system description are presented in Section 2. The control problem statement is detailed in Section 3. Numerical methods are applied to characterize the structure of the obtained control policy in Section 4. The proposed simulation optimization approach is presented in Section 5, along with a detailing of the simulation model and its validation. In Section 6, a numerical example is reported to illustrate the system′s behavior. A sensitivity analysis of the control policy is presented in Section 7, with regards to different cost parameters and trajectories of the rate of defectives. Finally, concluding remarks that illustrate new insights into this topic are given in Section 8.

2. Notation and system description

This section presents the notation and the system description of the manufacturing system under consideration.