Omega 61 (2016) 110–126

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Integrated production, sampling quality control and maintenance of deteriorating production systems with *AOQL* constraint☆

B. Bouslah [a,b], A. Gharbi [b,*], R. Pellerin [a]

[a] Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal, Case postale 6079, Succursale Centre-ville Montréal, Québec, Canada H3C 3A7

[b] Automated Production Engineering Department, École de Technologie Supérieure, Production System Design and Control Laboratory, University of Québec, 1100Notre-Dame West, Montréal, Québec, Canada H3C 1K3

ARTICLE INFO

Article history:
Received 23 December 2014
Accepted 29 July 2015
Available online 11 August 2015

Keywords:
Dynamic process deterioration
Production/inventory control
Lot sizing
Acceptance sampling plan
Preventive maintenance
Simulation-based optimization

ABSTRACT

This paper considers the problem of integrated production, preventive maintenance and quality control for a stochastic production system subject to both reliability and quality deteriorations. A make-to-stock production strategy is used to provide protection to the serviceable stock against uncertainties. The quality control is performed using a single acceptance sampling plan by attributes. The preventive maintenance strategy consists in carrying out an imperfect maintenance as a part of the setup activity at the beginning of each lot production, while a major maintenance (overhaul) is undertaken once the proportion of defectives in a rejected lot reaches or exceeds a given threshold. The main objective of this study is to jointly optimize the production lot size, the inventory threshold, the sampling plan parameters and the overhaul threshold by minimizing the total incurred cost. To meet customer requirements, the optimization problem is subject to a specified constraint on the average outgoing quality limit (AOQL). A stochastic mathematical model is developed and solved using a simulation-based optimization approach. Numerical examples and thorough sensitivity analyses are provided to illustrate the efficiency of the proposed integrated model. Compared with the 100% inspection policy which is widely used in the literature on integrated production, maintenance and quality control, the results obtained show that an economic design of acceptance sampling in such an integrated context can lead to important cost savings of more than 20%.

1. Introduction

Over in the past few decades, a lot of effort has been devoted to integrating production planning, quality control and maintenance scheduling and to investigating the hidden interactions between these three aspects. In a recent literature review on this topic, Hadidi et al. [26] drew a distinction between the concepts of interrelation and integration between the three fundamental functions: interrelated models are those in which the decision variables of only one function is considered, taking into account the remaining functions as constraints, while integrated models are those in which two or the three functions are modeled and optimized simultaneously. Based on Hadidi et al. definition's, we find that most of the integrated models in the literature consider only two functions at a time. For example, many models integrating only production and preventive maintenance (PM) have been proposed since the second half of the 1990s, without considering the quality aspect (see the literature review by [12]). Recent advances in integrated production and PM include the joint determination of the Economic Production Quantity (EPQ) and PM policy (e.g., [58,38]), joint production and opportunistic PM scheduling (e.g., [66,65]) and simultaneous control of production and PM rates (e.g., [9,4]). On the other hand, research on integrating only the production and quality control policies dates back to the 1970s and 1980s (see the literature review by [24]). More recently, Inman et al. [32] surveyed the advances on the interface between quality and production system design in the past two decades. Research during this period has been concerned with the mutual effects of production and quality settings, such as the impact of production complexity and technology, operations speed, setup planning and tolerance design on the deterioration of process quality (e.g., [56,46,40,34]) and, conversely, the impact of quality inspection planning on production flow (e.g., [36]), etc. In addition, there is a growing interest in the integration of production control design with Statistical Quality Control (SQC)

☆This manuscript was processed by Associate Editor Tkindt.

* Corresponding author. Tel.: +1 5143968969; fax: +1 5143968595.
E-mail addresses: bassem.bouslah@polymtl.ca (B. Bouslah), ali.gharbi@etsmtl.ca (A. Gharbi), robert.pellerin@polymtl.ca (R. Pellerin).

http://dx.doi.org/10.1016/j.omega.2015.07.012
0305-0483/

techniques such as control charts (e.g., [15]), process capability (e.g., [28]), and sampling plans [10,11]. Nevertheless, Inman et al. [32] have reported that there are still a large number of sub-areas in quality control (including reliability and maintenance scheduling) that have not been fully integrated with production, and they recommended further investigation of the traditional quality control system design in the production context.

Indeed, only a limited number of papers in the literature deal with the simultaneous integration of the three functions. We can classify these papers into two categories, based on the quality control policy used. The first category includes studies integrating production and PM design with a 100% inspection policy of all items produced. For example, Liao et al. [39] and Wee and Widyadana [64] integrated PM programs with the EPQ model for an imperfect production process where all defective items produced must be reworked. Radhoui et al. [51,52] suggested an integrated PM and production control policy for an unreliable imperfect process producing a random proportion of non-conforming items. They assumed that each lot produced is subject to an automated quality control of negligible duration and cost. The second category of integrated models corresponds to studies using the SQC tools rather than 100% inspection. For example, Ben-Daya and Makhdoum [8] and Ben-Daya [6] presented various integrated models for the joint determination of the EPQ, the economic control chart design and the optimal PM level. Nevertheless, some other important aspects of the SQC, such as the acceptance sampling plans have not yet been integrated simultaneously with production and PM planning. Acceptance sampling plans have been widely used in industry for a long time to control the outgoing quality especially in situations where 100% inspection of all items produced is technically or economically impractical [60]. In addition, they have significant impacts on production and inventory, as shown by Bouslah et al. [10]. Unlike 100% inspection and control charts, the interactions between acceptance sampling plans and PM policies have not yet been investigated in the literature.

In the literature on integrated models, many attempts have been made by researchers to adequately pattern the product quality and equipment reliability deteriorations. For example, Rosenblatt and Lee [55] studied three dynamic patterns of process deterioration (linear, exponential and multi-state) on the EPQ. Moreover, many industrial and academic studies have shown the significant impact of production rate on performance deterioration intensity, as in Felix Offodile and Ugwu [18], Khouja and Mehrez [35] and Sana [57]. However, for simplicity, most of the existing integrated models neglect the dynamic aspect of process deterioration and the impact of production settings on the deterioration intensity. Generally, the researchers assume that the proportion of defective items produced during ‘out-of-control’ periods is constant or follows a prior known distribution.

Furthermore, almost all of the integrated models do not simultaneously consider the quality and reliability deterioration phenomena [13]. When both phenomena are observed, the PM plays a double role: increasing the reliability of the production equipment and restoring the product quality to the desired level [7,54]. Because of the direct impact of deterioration on the production system availability and on the output quality, it is more appropriate to base the PM decision on the actual deterioration state rather than on equipment age [25]. An inference on the deterioration state could be based on the equipment condition or on the product quality characteristic [16]. Condition-based maintenance has attracted a great deal of attention over the past two decades, in conjunction with the technological advances in condition monitoring techniques such as vibration, corrosion, thermography and acoustics analysis [53,17]. On the other hand, in situations where quality is directly affected by the degradation of the production system, the quality information feedback, which does not require a costly and high technology for data acquisition and analysis, such as in condition monitoring techniques, could represent an alternative solution to recognize the system degradation. Maintenance based on quality information feedback is becoming increasingly attractive as a field of research, especially in the context of maintenance and quality control integration. Tapiero [61] was among the first to formulate a feedback stochastic control maintenance problem based on the products quality, assuming that quality is a known function of the machine's degradation state. Hsu and Kuo [30] studied the performance of an inspection and maintenance policy that begins 100% inspection of a production lot after producing a given number of items and then initiates a preventive/corrective maintenance activity when the fraction of defective parts reaches a given threshold. Similarly, Radhoui et al. [51,52] also used the 100% inspection policy to determine the proportion of non-conforming items of each lot produced and then compare this proportion to some given thresholds to make decisions on PM and overhaul actions. Recently, Panagiotidou and Tagaras [48], Pan et al. [47] and Zhang et al. [68] suggested integrating condition-based maintenance and statistical process control strategies where the maintenance decisions are made based on the quality information feedback from the control chart. Nevertheless, the interactions between the acceptance sampling plans and maintenance strategies have never received the same attention in the literature. To the best of our knowledge, there is no published study that investigates the usefulness and relevance of information provided by sampling plans such as the observed percentage of accepted/rejected lots, the current inspection mode (sampling or 100% inspection), etc., for process condition monitoring and maintenance decision-making.

To overcome the limitations of existing integrated models, in this paper, we intend to develop a new model integrating production lot sizing, production rate control, inventory control, single acceptance sampling plan and PM strategy. Our focus on the acceptance sampling plan techniques in the context of integrated operations management is motivated by three considerations. Firstly, acceptance sampling plans have specific statistical properties [60] that should be deeply analyzed in order to extract relevant information for process condition monitoring and to make the appropriate maintenance decisions accordingly. Secondly, compared with the 100% inspection policy which is extensively used in the integrated models in the literature, sampling plans are usually more economical, and they significantly reduce the unnecessary inspection essentially during periods when the process is in the ‘in-control’ state [42]. Thirdly, it is expected that an economic design of acceptance sampling plans in such a context, instead of using traditional sampling inspection standards such as ANSI/ASQC Z1.4 and ISO 2859, could lead to significant economic savings [45]. In fact, those standards are purely based on quality considerations, and completely neglect the economic aspect and the interactions with production, inventory and maintenance in the design of sampling plans.

In this study, we present a stochastic dynamic model considering non-negligible delays and costs of setup, quality control and maintenance operations. Both the product quality and machine reliability deteriorations depend on the production equipment usage. We consider that the production setup includes an imperfect PM activity. An overhaul is also required to perfectly restore the performance of the production process. Our objective is to jointly design and optimize the production, quality control and maintenance policies. The optimal integrated solution should minimize the total incurred cost while meeting a predefined restriction on the average outgoing quality limit (AOQL). We use a simulation-based optimization approach to solve this complex and stochastic problem. Moreover, we present a thorough