Int. J. Production Economics 171 (2016) 134–150

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Production control problem integrating overhaul and subcontracting strategies for a quality deteriorating manufacturing system

Héctor Rivera-Gómez [a], Ali Gharbi [b,*], Jean-Pierre Kenné [c], Oscar Montaño-Arango [a], Eva Selene Hernandez-Gress [a]

[a] Academic Area of Engineering, Autonomous University of Hidalgo, Pachuca-Tulancingo Road km. 4.5, City of Knowledge, Mineral de la Reforma, Hgo 42184, Mexico

[b] Automated Production Engineering Department, École de Technologie Supérieure, Production System Design and Control Laboratory, Université du Québec, 1100 Notre Dame Street West, Montreal, QC, Canada H3C 1K3

[c] Mechanical Engineering Department, École de Technologie Supérieure, Laboratory of Integrated Production Tehcnologies, Université du Québec, 1100 Notre Dame Street West, Montreal, QC, Canada H3C 1K3

ARTICLE INFO

Article history:
Received 26 July 2014
Accepted 13 October 2015
Available online 30 October 2015

Keywords:
Quality
Manufacturing system
Production
Subcontracting
Deteriorating systems

ABSTRACT

We study an unreliable deteriorating manufacturing system that produces conforming and non-conforming parts to satisfy a constant demand product rate. The manufacturing system is comprised of a failure-prone machine. Due to the combined effect of random availability variations and deterioration, the system is not able to fulfill long-term product demand. In particular, when finished goods inventory is positive, clients demand are fulfilled on-time and without delay. When backlog exists, subcontracting options are available at a higher cost to supplement the limited production capacity of the manufacturing system. The effect of deterioration is observed mainly in the quality of the parts produced, since the rate of defectives increases as the machines deteriorate. Overhaul activities can be conducted to mitigate the effect of deterioration. We propose a joint feedback control policy based on a stochastic dynamic programming formulation which aims simultaneously to determine the production and overhaul rates, and the rate at which subcontractors are requested. The proposed joint control policy minimizes the total cost, including the inventory, backlog, repair, overhaul, defectives, production and subcontracting costs, over an infinite planning horizon. To determine the optimal control parameters, we adopt a numerical scheme to solve the optimality equations and a numerical example is presented as an illustration of the approach. The structure of the joint control policy is validated through an extensive sensitivity analysis.

1. Introduction

In modern organizations, quality and production planning are critical for market survival. Typically, a number of disruptions such as deterioration, delays, defectives, failures, etc., limit the organization's ability to satisfy product demand without delays, leading to increased lead times and customer dissatisfaction. Therefore, manufacturing systems must be designed efficiently to respond quickly to such disruptions, mainly among manufacturers with limited capacity. One attractive option is to increase capacity to reduce the lead time through the use of subcontractors. The cost associated with subcontractors can be justified by the ensuing reduced lost sales and required inventory. Furthermore, maintenance strategies are available to improve the system performance. Unfortunately, more research is needed to have a better understanding of the connection between production and quality, as well as to include the effect of maintenance and subcontracting issues in analyzing such relationships. In this study, we therefore aim to propose an integrated model that defines the structure of an optimal joint policy for the interaction of production, quality, maintenance and subcontracting activities in the context of deterioration.

Closed-form solutions were available for the production control problem with the work of Akella and Kumar (1986), who addressed the case of a single-machine, one-part type considering a discounted cost; as well they determined the structure of the so-called Hedging Point Policy. Since quality is a major factor in competitiveness in current markets, recent extensions of this research area include connections to quality issues. For instance, Inman et al. (2003) highlighted the importance of the interaction between production and quality issues, and reviewed the limited

* Corresponding author.
E-mail addresses: hriver06@hotmail.com (H. Rivera-Gómez), ali.gharbi@etsmtl.ca (A. Gharbi), jean-pierre.kenne@etsmtl.ca (J.-P. Kenné), oscarma11@hotmail.com (O. Montaño-Arango), evaselenehg@hotmail.com (E.S. Hernandez-Gress).

http://dx.doi.org/10.1016/j.ijpe.2015.10.008
0925-5273/

literature on the intersection of quality and production system design. Colledani et al. (2014) revised problems, methods and tools to support the strong interaction among production logistics, quality and maintenance functions; also they highlighted the main challenges and opportunities for zero-defect oriented manufacturing industries. Mathematical models integrating production and quality issues were presented in Kim and Gershwin, 2005, 2008 where they determined several performance metrics for small and larger systems. Other analytical models were introduced in the work of Colledani et al. (2014), who proposed an integrated quality and production logistics model, which significantly reduced the output fraction of defectives. With this model improved performance is achieved towards existing solutions, which deal only with quality aspects. Further, some authors have incorporated quality issues in the production policy. For instance, Radhoui et al. (2010) developed a model for lots that are subject to quality control and determined the maintenance strategy and the optimal buffer size. Analytical expressions for the production control policy and the related total cost are presented in Mhada et al. (2011), for a failure-prone machine whose final product includes some defective parts. Defective production is also covered in the work of Bouslah et al. (2013) in which an acceptance sampling plan is used to control the quality of the lots produced. They jointly optimize the batch size, the hedging level and the sample size. Additionally, Dhouib et al. (2012) presented an integrated strategy for the production inventory control and preventive maintenance for a manufacturing system with imperfect production, using an age-based preventive maintenance policy to reduce the shift rate to the out-of-control state. We should note that the above works have a restrictive assumption, regarding the rate of defectives which is assumed to be constant for the entire time horizon. Obviously, this might not be true in practice, since it is very common for manufacturing systems to experience the accumulated effect of deterioration, which has serious impacts on several parameters of the system. The deteriorating systems field may therefore provide an appealing approach for our research.

As a matter of interest deterioration has been a major topic in the manufacturing systems field. For example, Martinelli and Piedimonte (2008) described an optimal backlog/inventory problem for a production system whose deterioration depends on its production rate. A combination of the replacement planning problem with production control and preventive maintenance was presented in Dehayem Nodem et al. (2011), where they focused on a manufacturing system that experienced a double deterioration caused by the age of the machine and by imperfect maintenance. A key observation to be made here is that the aforementioned papers analyze the effect of deterioration on increasing failure rates or decreasing production rates, while disregarding its effect on quality. The influence of deterioration on part quality was covered for the case of degrading machines in Colledani and Tolio (2012), who tackled the production rate of conforming parts of deteriorating machines controlled by preventive maintenance and control charts. Additionally, a more detailed discussion about quality deterioration can be found in Rivera-Gómez et al. (2013), who determined production and major maintenance strategies for a manufacturing system with increasing defectives caused by the influence of deterioration. In spite of these primary attempts to relate deterioration with part quality, we believe that more research is required in order to fully understand its effect on the control policy, mainly because, in real production, manufacturers encounter a wide variety of phenomena. Additionally, it is important to use effective measures to palliate limited capacity, and to that end, one option is the use of subcontracting to ensure on-time fulfillment of product demand.

Utilizing subcontractors can be a possible option for production systems with limited capacity. Tan and Gershwin, 2004 derived a feedback control policy that determines the production rate and the rate at which subcontractors are required to deliver products for a random demand scenario. Another subcontracting model was presented in Hajej et al. (2014), who obtained an optimal production plan and preventive maintenance program, where products returned by customers are sent to a subcontractor for recycling and remanufacturing. An adjustable capacity for an unreliable manufacturing system was treated in the work of Gharbi et al. (2011), in which a reserve machine is called upon as support to satisfy the product demand if the inventory level falls below a specific threshold. Recently, Dror et al. (2009), proposed a methodology to determine safety-stock level and storage capacity for a multiple manufacturing facilities multiple product with subcontracting options. An extension of this model was done by Assid et al. (2015) who tested different subcontracting policies. One important remark that can be made here concerns the fact that none of the works mentioned above considered subcontracting actions in the context of progressive limited capacity. Indeed, in these works, subcontracting is not studied in the context of machine wear causing a continuous deterioration of the part quality.

Following the above discussion, we can observe that the purpose of this study is to develop a stochastic optimal control model allowing us to extend previous contributions, such as (Rivera-Gómez et al., 2013; Gharbi et al., 2011; Dror et al., 2009), in three important directions. First, we cover the impact of quality issues on the production control policy, in a bid to further analyze the relationship between production and quality. Second, we analyze the impact of the progressive wear of the manufacturing system, which leads to a Semi-Markov model where the property of memoryless holds for the transition failure rate. However, we keep memory of the age of the machine to model quality deterioration. Third, with subcontractors, we provide the manufacturer with external product sources. When the demand exceeds the capacity of the manufacturing system, subcontractors may be useful for reducing backlog, improving customer service and reducing the number of lost sales. Also, overhaul activities can be conducted to mitigate the effect of deterioration. One of our goals is to minimize the total incurred cost over an infinite planning horizon comprising the inventory, backlog, repair, overhaul, defectives, production and subcontracting costs. To the best of our knowledge, this set of characteristics has not been covered jointly in the literature. We use Hamilton–Jacobi–Bellman equations to determine the structure of the control policy and the results obtained are further examined in a sensitivity analysis.

The rest of the paper is organized as follows. The industrial context of the paper is presented in Section 2. The model description and its assumptions are given in Section 3. The control problem formulation is presented in Section 4. The joint control policy is detailed in Section 5. Additionally, the evaluation of the control policy is described in Section 6 through a sensitivity analysis comprising the effect of cost and system parameters variation. Section 7 discusses about some managerial implications for the obtained results. Section 8 concludes the paper.

2. Industrial context

The model presented in this paper is suitable for many industries characterized by deterioration in which machines are unreliable and their production rates can be controlled. Examples of such systems include machining tools (i.e. machining centers, grinders, milling, etc) typically comprised by a large number of components which stochastically deteriorate over time, as remarked in Dehayem Nodem et al. (2011). The phenomenon of deterioration is common in the automobile, aircraft, machine tools