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Joint optimization of lot sizing and condition-based maintenance for multi-component production systems

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ABSTRACT

This paper presents a joint optimization model of production lot sizing and condition-based maintenance for a multi-component production system which produces the products to meet the demand in a finite time horizon. The components in the system deteriorate gradually with usage and age. To evaluate the conditions of components, inspections are carried out after each production run. The condition-based maintenance decision-making rules are based not only on the predictive reliability but also on the structural importance of each component. Moreover, the economic dependency among components is also considered when performing corrective maintenance actions. The preventive maintenance cost, the corrective maintenance cost, the setup cost, the inspection cost, the inventory holding cost and the shortage cost are considered in this paper. The aim is to minimize the total cost by jointly optimizing two decision variables: the production lot size and the preventive maintenance threshold. The optimal joint policy is obtained by coupling simulation model and genetic algorithm. Finally, the use and advantages of our model are illustrated through a case study of a cluster tool.

1. Introduction

In the earliest production-inventory models, a common assumption made is that machine breakdown never occurs during a production run. However, due to the accumulation of damage through life (e.g., corrosion, material fatigue, wearing out and fracturing), most production systems deteriorate physically with usage or age. Eventually, the machine breakdown occurs from this deterioration which has a great influence on the production process. To improve the system reliability and ensure the continuity of production process, an appropriate preventive maintenance (PM) policy should be selected. From the point of view of maintenance in management level, maintenance management is to provide the long-term business strategy that ensures capacity of the production, quality of the product, and the best life cycle cost. In addition, it focuses on continuously improving the performance of machinery (Ansari, 2014). Ansari, Fathi, and Seidenberg (2016) proposed a comprehensive literature review on problem-solving approaches in maintenance cost management form two perspectives: synoptic/incremental and heuristics/meta-heuristics.

In operation level, production-maintenance models have been extensively studied by many researchers. Groenvelt, Pintelon, and Seidmann (1992) considered the economic production quantity (EPQ) model with machine breakdown. The corrective maintenance is carried out immediately after a machine breakdown occurs. Two production control policies, i.e., the no-resumption (NR) policy and the abort/resume (AR) policy were proposed to deal with the machine breakdown, respectively. Abboud (2001) assumed that the times-to-failure and the repair times are geometrically distributed. The author developed a production-inventory model by Markov chain and proposed an efficient algorithm to solve the model. El-Ferik (2008) studied an EPQ model for an unreliable machine. The age-based PM is imperfect and thus the machine will be replaced by an identical new one after the *N*th maintenance. They obtained the optimal PM interval and replacement policy such that the long-run average cost rate is minimized. Chan and Prakash (2012) proposed distance-based fuzzy multi-criteria to select the most appropriate maintenance policy for manufacturing systems. Cheng, Zhou, and Li (2016) studied an integrated control policy of production rate and maintenance for machining systems. Other production-maintenance joint models can be seen in Wee and Widyadana (2012), Kamyar, Mostafa, Arash, and Gholamreza (2012), Pal, Sana, and Chaudhuri (2013), Liao (2013).

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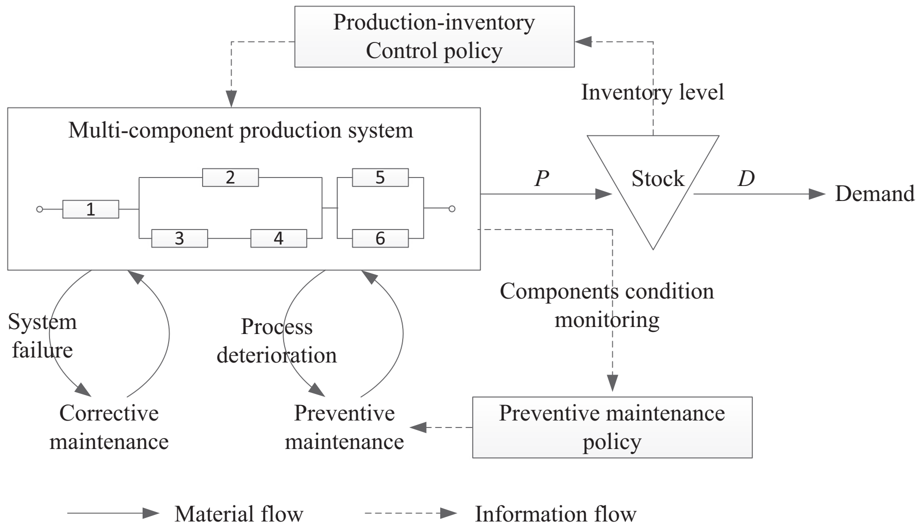

Fig. 1. Multi-component production system under study.

Thanks to the development of sensor and information technologies, we can monitor the deterioration level of systems to facilitate the prediction of failures. Therefore, the condition-based maintenance (CBM) has been widely used in maintenance engineering due to its effectiveness and efficiency. However, only few studies have been done to jointly consider the EPQ model and CBM policy. Jafari and Makis (2015) considered the joint optimization of EPQ and CBM for a production facility. The deterioration process is determined by the age and covariate values which is modelled as a Markov process. The problem is formulated and solved in the semi-Markov decision process framework. Recently, Jafari and Makis (2016) studied the optimal lot-sizing and maintenance policy for a partially observable production system by using multivariate Bayesian control approach. Peng and Houtum (2016) developed a model to optimize the production lot-sizing by taking the CBM activities into account. The long-run average cost rate of a degrading manufacturing system is obtained by using renewal theory.

Note that most of the above literatures regard the production facility as a mono-component system. In fact, nowadays, the structures of production facilities become more and more complex with a large number of different components. For instance, cluster tools used for wafer processing are typical multi-component complex systems which consist of several different processing chambers and robot cells. Generally speaking, for multi-component systems, there exist inter-dependencies among the components such as stochastic, economic and structural dependencies (Nicolai and Dekker (2008)). The stochastic dependency indicates that the condition of components influence the state or deterioration process of other components. The economic dependency indicates that combining maintenance activities can save costs compared with performing maintenance on components separately. The structural dependency indicates that components in the system structurally form a unified part. Due to these dependencies, the maintenance models become much more complicated and the maintenance policies for mono-component systems cannot be adapted to multi-component systems directly. In the last decade, many researchers have studied the maintenance strategies for multi-component systems by incorporating the dependencies among components. Many of them consider the economic dependency by using opportunistic maintenance policy (Huynh, A., & C., 2013; Shi & Zeng, 2015) or grouping maintenance policy (Bouvard, Artus, Bérenguer, & Cocquempot, 2010; Do, Vu, Barros, & Bérenguer, 2012). Some of studies investigate the stochastic dependency (see Barros, Berenguer, & Grall, 2003; Bian & Gebraeel, 2014). Relatively fewer studies have been done to consider the structure dependency, especially for CBM strategies. When considering the structural dependency, to select a component to be preventively maintained not only depends on its condition or reliability but also depends on the location of this component in the system (or the 'importance' of the component). To face this issue, Birnbaum (1969) introduced the structural importance (or Birnbaum importance). Later on, the structural importance has been extended and some other importance measures are introduced (Wu & Coolen, 2013; Borgonovo, Aliee, Glaß, & Teich, 2016). Recently, component importance measures have been incorporated in maintenance decision-makings for complex systems (Nguyen, Do, & Grall, 2014; Vu, Do, & Barros, 2016; Wu, Chen, Wu, & Wang, 2016).

However, the above CBM models for multi-component complex systems were not considered in the context of real production organization. In fact, the production process has a great influence on maintenance decision-making, and vice versa. Performing PM actions can improve the condition and the reliability of components, but it also takes time and hence reduces the availability of the whole production system. To face this dilemma, the PM-threshold needs to be optimized to avoid insufficient maintenance or excess maintenance. In addition, to reduce the interruption of production process, PM activities are performed when a production run (or a production lot) is finished. Since the time between two successive lots is limited, we should take full advantage of this limited downtime to inspect components and perform maintenance actions. To this end, we need to select components properly to be maintained. Therefore, the maintenance decision-making process is closely connected with the production factors such as the lot size, the production and demand rate, the shortage cost rate and the planed time horizon. However, from the author's literature search, no research has been done to jointly consider the production lot-sizing and CBM policy for multi-component production systems.

The aim of this paper is to propose an integrated model of the production lot-sizing and CBM policy for multi-component production systems. The production system produces the products to meet the constant demand in a finite time horizon, as