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Preventive maintenance scheduling for serial multi-station manufacturing systems with interaction between station reliability and product quality

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ABSTRACT

Station reliability and product quality usually interact with each other stochastically in the multi-station manufacturing systems, which brings much trouble for the preventive maintenance (PM) scheduling of the system. In this paper, a station reliability evaluation method is developed firstly based on the introduced bidirectional interaction mechanism between station reliability and product quality, in which the focus is on the derivation of the failure rate of the stations. Then, a dynamic opportunistic PM (OM) policy is presented for the series multi-station systems with such quality integrated station reliability. The OM model is built up based on an extended cost saving method, and the optimal PM scheme of the system is obtained by maximizing the short-term cost savings which not only come from the stations conducting PM but also come from the downstream stations of those PM stations. Finally, a numerical example is given to illustrate how this PM scheduling approach works, and a numerical comparison on different OM policies is also given to show the effectiveness of the proposed OM policy under such interaction between station reliability and product quality.

1. Introduction

Preventive maintenance (PM) is an important approach to ensure the operation of the manufacturing systems. In reality, most manufacturing systems are composed of multiple stations whose operating conditions interact with each other. This interaction makes the PM scheduling of these systems become very complex. However, with the increasing demand from industry, more and more research efforts are being paid on the PM modeling for these multi-station manufacturing systems with interactions between stations (Nicolai & Dekker, 2008).

Commonly, from the perspective of maintenance, there are three types of interactions between stations: economic dependence, structural dependence and stochastic dependence. Economic dependence usually indicates that the preparatory or set-up work (i.e. the preparation cost associated with erecting a scaffolding) can be shared when several stations are preventively maintained simultaneously (Do Van, Barros, Bérenguer, Bouvardd, & Brissaude, 2013; Zhou, Zhang, Lin, & Ma, 2013; Zhang & Zeng, 2015; Dao, Zuo, & Pandy, 2014). Structural dependence often happens when the manufacturing system is in series or series-parallel. In such an instance, the PM of a station may cause the stop of the whole system or the series subsystem. Thus, grouping PM activities for other system or subsystem stations can decrease the number of system PM stops and then save the set-up cost for the system (i.e. the downtime cost due to production loss) (Zhou, Xi, & Lee, 2009; Wong, Chan, & Chung, 2014; Zhou, Lu & Xi, 2012; Xia, Xi, Zhou, & Lee, 2012). Stochastic dependence usually means that the deterioration of a station may affect the deterioration of other stations in the system. That implies under stochastic dependence, the shape of the lifetime distribution of a station depends not only on the deterioration state of this station itself but also on the deterioration states of other stations in the system (Sheu, Liu, Zhang, & Chien, 2008; Shi & Zeng, 2016; Khorshidi, Gunawan, & Ibrahim, 2016; Zhang, Zhang, & Du, 2018).

Because stochastic dependence brings uncertainty on the deterioration of system stations, it makes the PM modeling of the system much more complex. For this sake, compared with economic dependence and structural dependence, the efforts on the PM modeling for the systems with stochastic dependence are relatively scarce. In the area of stochastic dependence, Murthy and Nguyen (1985) firstly introduce two types of failure interactions between different components in a system. Type 1 is the failure of one component can lead to the failure of the other component. For example, the fracture of the belt in a car may lead to the breakage of the engine. Type 2 is the failure of one component can affect the failure rate of the other component. For example, in a k-out-of-n system with shared workload, the failure of one component increases the workload of other components and subsequently speeds up the deterioration of these components (Zhang et al., 2018). Based on this definition on failure interaction, Golmakani and Moakedi (2012) propose a PM model to find the optimal periodic inspection

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Nomenclature

PM preventive maintenance
OM opportunistic PM
PQD product quality deviation
QVs quality variables
NVs noise variables
$X_j(t)$ deterioration of the QV related component in station j
$Z = [Z_1, Z_2, ..., Z_L]'$ vector of noise variables
$E(Z)$, $Cov(Z)$ expected value and covariance matrix of Z
$D_j(t)$ PQD from station j
C_j, A_j, B_j, Ψ_j coefficients for PQD function
$E(D_j(t))$, $Var(D_j(t))$ expected value and variance of $D_j(t)$
$Q_j(t)$ product quality from station j
$\lambda_j(t)$ hard failure rate of station j
$\lambda_{ij}(\tau)$ hard failure rate of station j within PM cycle i
$\mu_j(t)$ soft failure rate of station j
ξ_j coefficient on the deterioration rate of the QVs of station j without upstream quality impact
Ω_j coefficient vector describing the effect of upstream quality on the QVs of station j
c^{pd}, c^{ud} downtime cost for a PM and for a minimal repair respectively
c_j^p, c_j^c maintenance cost for a PM and for a minimal repair for station j respectively
c_j^q cost for the appearance of an out of tolerance product
T_{ij} the ith PM interval for station j
t_{ij} start time of the ith PM cycle for station j
τ_{ij} operation duration for station j since the $(i-1)$th PM of this station
$t_1^*, t_2^*, t_3^*, \cdots, t_s^*$ happening moments of the upstream stations of station j within the ith PM cycle of station j
$t_1, t_2, \cdots, t_n$ predetermined PM moments for station $1, 2, \cdots, n$
CS_k cost savings for PM alternative k
$CS_k Part1$ cost savings for PM alternative k coming from the OM stations
$CS_k Part2$ cost savings for PM alternative k coming from the downstream stations of the OM stations
SMC_{jl} maintenance cost saving for station j
SDC_{jl} downtime cost saving for station j
SQC_{jl} quality cost saving for station j
PC_{jl} penalty cost for the OM of station j
TC total maintenance cost throughout the PM scheduling horizon of the system

interval for a two-component repairable system, Zhang, Wu, Li and Lee (2015) study an Opportunistic PM (OM) policy for a multi-component system, and Lai and Yan (2016) present a discrete replacement policy for a two-unit system. These research results are good references for the PM modeling of the multi-station systems. However, the focus of the above efforts is on the components in a reparable system and these components are usually physically connected or workload shared. This makes it possible that the failure rate of a component is directly affected by the deterioration of another component. Obviously, this circumstance may not be applicable for a series multi-station manufacturing system.

In fact, the stochastic dependence between stations in a series multi-station system is usually indirectly and it often happens through the product. The deterioration of the upstream station can cause the deviation of the product quality from this station. This deviation will be transferred to the downstream station along with the product and then affects the deterioration process of that station. For example, the wear of the drilling tool may lead to a smaller diameter of the hole. This increases the workload of the downstream reaming station and subsequently speeds up the wearing of the reaming tool. From this aspect, the product plays important roles in connecting the manufacturing stations, and it is the medium which brings stochastic dependence between stations. For this sake, it is necessary to consider the product quality simultaneously when processing the PM scheduling for the multi-station systems with such stochastic dependence.

In recent years, a lot of research results have been published on the PM scheduling for manufacturing systems by integrating product quality (Fakher, Nourelfath, & Gendreau, 2015; Rivera-Gomez, Gharbi, & Kenné, 2013; Nafissa, Hayet, & Okba, 2013; Yin, Zhang, Zhu, Deng, & He, 2015). However, most of the efforts just simply combine the maintenance and the product quality in the cost function, and they do not interpret how the deterioration of the station and the deviation of the product quality interact with each other. In this research area, Chen and Jin (2005) gives a quality-reliability chain model for multi-station manufacturing systems. In this model, the failure rate of a station is affected by the deterioration of the incoming product quality, and the deterioration of the upstream station causes the deterioration of the downstream product quality. Based on this interaction model, Sun and Xi (2011) proposes an optimal PM policy for a degrading manufacturing system, where the impact of the tool-degraded state on the product quality is deeply discussed. Lu and Zhou (2016) develops a maintenance-quality jointed PM model for a single-unit deterioration system, with considering how the quality related components in the system impacts on the product quality. Chen and Jin (2005), Sun and Xi (2011), Lu and Zhou (2016) are the few research results focusing on the interaction between station reliability and product quality, and these works greatly promote the development of the maintenance-quality jointed modeling technique. However, the PM models proposed by Sun and Xi (2011), Lu and Zhou (2016) are for the single-unit manufacturing systems, and they only consider the impact of the station deterioration on the product quality. As proposed by Chen and Jin (2005), for a multi-station manufacturing system, the upstream product quality can also affect the deterioration of the downstream station. It would be much more challenging to present an effective PM scheduling approach for the multi-station systems with bidirectional interaction between station reliability and product quality.

In this paper, a dynamic OM policy is proposed for the series multi-station systems with such bidirectional interaction between station

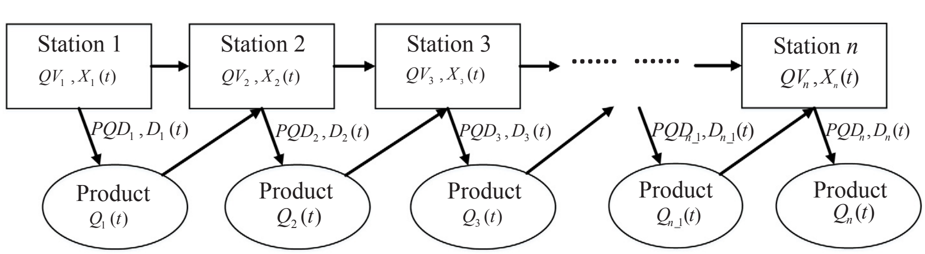

Fig. 1. Interactions between station reliability and product quality in a serial n-station system.