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A TBE control chart-based maintenance policy for a service facility

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ABSTRACT

In service industry, malfunctioning or failure of service facilities commonly occur due to environment-related factors. Such malfunctioning or failure is usually handled by resetting the system to avoid interruption of service. However, maintenance is needed if there is system degradation which may cause failure to occur more frequently. As system degradation is not self-announced, whether a simple resetting action or maintenance is needed to address a failure is critical. In this paper, a condition-based maintenance (CBM) model for service facility is established. The maintenance model determines whether maintenance is needed by monitoring the time between failure occurrences with a TBE (Time Between Events) control chart. The service queueing system is formulated as a Markov chain, with which the steady-state costs of the system can be obtained and minimized. Numerical experiments show that the proposed maintenance model yields significant cost saving compared to the model without using TBE control chart. The effects of system parameters on both the optimal policy and cost saving are discussed.

1. Introduction

As services account for an increasing share of economic activities, the service industry is becoming more technology based. Advanced service facilities are changing the way customers interact with service providers (Meuter, Ostrom, Roundtree, & Bitner, 2000). Service quality is increasingly dependent on the performance of the service facilities.

In service industry, the facilities are generally running continuously. It is common that a service facility may malfunction or fail from time to time. For example, service facilities, like cash register machines in supermarkets, ticket vending machines in theaters, auto teller machines in banks and security inspection machines in airports, may halt or breakdown due to environment-related factors. These factors may include changing of operational environment (e.g., high temperature), overloading of cargo or data, wrong procedure of service operators and inappropriate use of service users, etc. Commonly, the malfunctioning or failure of the service facility is usually fixed by resetting the system to reduce the impact on the customer service.

However, a failure may be actually caused by facility-related factors (e.g., ageing of components). In this case, the facility has been degraded internally and failure may occur frequently if it is only fixed by resetting the system rather than a repair (maintenance). Unfortunately, the real cause of a failure is usually not self-announce. The decision on when to perform a repair (maintenance) is critical. Both frequent failure and frequent maintenance are not desirable as they both have implications on cost and service levels. A cost-effective maintenance policy is important for the service providers to compete in the market (Öhman, Finne, & Holmström, 2015).

Maintenance policy and management in manufacturing industry has received a great amount of research in the literature (Ding & Kamaruddin, 2015). Most manufacturing companies adopt preventive maintenance (PM), which is usually performed periodically (Kang & Subramaniam, 2018). Nevertheless, preventive maintenance may not be mostly cost effective because optimal maintenance interval is hard to identify (Wang, Chu, & Wu, 2007). In order to improve the cost-effectiveness of maintenance, condition-based maintenance (CBM) has been proposed and adopted (Yang, Ma, & Zhao, 2017). Most existing CBM approaches rely on control charts, like $\overline{X}$ charts, to monitor the product quality statistics. Through examining the rate of defects or the proportion of defective items in a process, the control charts may signal an abnormal condition for maintenance to be conducted.

Existing CBM models in manufacturing industry are not applicable in service industry because there is usually no product in service industry. Nonetheless, similar to manufacturing industry, the condition of the facility may be reflected in the frequency of the failure occurrence. When the system is degraded, failure occurs more frequently than the normal situation. This allows the potential application of condition-based maintenance model to be applied for service facilities.

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In this paper, we establish a condition-based maintenance model for service facility. The model determines when reactive maintenance is needed upon failure by monitoring the time between failures with a time-between-event (TBE) control chart. Preventive maintenance is also considered in the established model. The control limit of the TBE control chart that triggers the reactive maintenance and the frequency of preventive maintenance are jointly determined to minimize the system cost, which covers the costs associated with operation and maintenance and the costs associated with reduced service level.

The remainder of the paper is organized as follows. Section 2 discusses relevant literature. Section 3 describes the problem and the established maintenance model in details. Because the service system is a queueing system with random arrivals of customers, in Section 4 the service queueing system is formulated as a Markov chain, with which the steady-state costs of the system can be obtained. In Section 5, the optimal maintenance model is developed to minimize the steady-state system cost. Section 6 conducts a numerical study to evaluate the effectiveness and robustness of the established model. In addition, the impacts of the parameters variation on the optimal maintenance policy are analyzed. Finally, the paper concludes in Section 7.

2. Literature review

There has been a great amount of research in the literature focusing on the maintenance policies in manufacturing industries (Ding & Kamaruddin, 2015). The existing models normally apply both reactive maintenance (RM) and preventive maintenance (PM). Reactive maintenance usually means a repair, and is the oldest type of maintenance policy (Mechefske & Wang, 2003). The maintenance will only be carried out after a failure occurs. In most literature, reactive maintenance means to replace/renew the problematic components of the facility. On the contrary, preventive maintenance is a type of maintenance that is performed before a machine fails and helps improve system reliability. Preventive maintenance is usually performed periodically (Kang & Subramaniam, 2018).

In order to improve the cost-effectiveness of maintenance activities, condition-based maintenance (CBM) has drawn extensive attentions in recent years (Yang et al., 2017). The CBM is a maintenance policy that recommends maintenance actions based on the information collected through condition monitoring process (Ahmad & Kamaruddin, 2012). Yang et al. (2017) pointed out that CBM is a key measure in preventing unexpected failures caused by interval-based deterioration and external environmental shocks. Originally, the system condition is practically monitored (e.g., sensor data). More recently, the statistical process control (SPC) techniques (mainly control charts), originally used for process monitoring, are used in condition-based maintenance policies (Makis, 2015). For instance, Yeung, Cassady, and Schneider (2007) used $\overline{X}$ control charts to determine when to conduct a reactive maintenance, in combination with preventive maintenance. Pan, Jin, Wang, and Cang (2012) adopted a control chart to monitor the process and optimize the maintenance policy. Zhang, Deng, Zhu, and Yin (2015) proposed a delayed maintenance policy which allows a delay time for the detection and maintenance after the control chart triggers an alarm. Salmasnia, Kaveie, and Namdar (2018) developed an integrated model of economic production quantity, maintenance, and SPC that monitors several quality characteristics by the VP-T^2 Hotelling control chart. In their model, the control chart is used to adjust the maintenance policy dynamically.

The existing control chart-based maintenance models rely on monitoring the product quality characteristics in a manufacturing process, which is usually not available in most service environments. In service industry, the malfunction or failure of facilities commonly happens, which has significant implications on service level. In order to reduce the impacts on service level, the malfunction or failure is simply handled by resetting the system. Nonetheless, the frequency of failure may increase if system has degraded due to internal problems (e.g., aging of components). The timing of a reactive maintenance could be decided by monitoring the frequency of the failure.

Liu, Xie, Goh, and Ranjan (2004) found that in manufacturing environments where the event occurrence rate is low, to monitor the time-between-events is important and more convenient rather than to monitor rate of occurrence of defects or the proportion of defective items in a process. Lucas (1985) and Vardeman and Ray (1985) first proposed the TBE control charts to monitor the time between events, e.g. defects or equipment failure (Khoo & Xie, 2009). Zhang, Xie, and Goh (2005) established an economic approach for the design of TBE control charts. They compared the performance of statistical design, economic design and economic-statistical design of TBE control chart. Zhang, Shamsuzzaman, Xie, and Goh (2011) developed an economic model of TBE control chart. In their model, the process shift is considered to be random and modeled by a Rayleigh distribution. Khoo and Xie (2009) developed a TBE control chart for monitoring a system with preventive maintenance. However, the control chart is used only for monitoring the system process and helps make a decision on whether the system has deteriorated to a state where regular maintenance is no longer effective. The TBE control chart is not used for triggering the maintenance actions. To the best of our knowledge, there has been no research on using the TBE control chart in maintenance policy.

This study differs from the existing literature in two aspects: (1) The proposed model utilizes TBE control chart which avoids the reliance on product quality statistics, so that condition-based maintenance can be realized in service industry. (2) Service related costs including customer delay cost and cost of lost sales are considered explicitly in the model to reflect the reality of service industry.

3. Model description

The notations used in this study are given in the following. The problem and the model are established with the definition of the following notations.

λ	Arrival rate of customers;
μ	Service rate of the service facility;
p_m	Frequency of preventive maintenance;
t_{TBE}	Time between two consecutive failures;
LCL	Lower control limit of TBE control chart;
β	Rate at which the facility transits from healthy state to unhealthy state;
$\gamma_I(\gamma_{II})$	Rate of occurrence of Type-I (Type-II) failure;
$\theta_{r0}(\theta_{r5})$	Rate of the reset procedure when the facility is under healthy (unhealthy) condition;
$\theta_{m0}(\theta_{m5})$	Rate of maintenance when the facility is under healthy (unhealthy) condition;
$E[L]$	Expected queue length;
C_0	Operation cost per unit time in state 0;
C_1	Operation cost per unit time in state 5;
C_{reset}	Cost of the reset procedure per unit time;
C_{RM}	Cost of reactive maintenance per unit time;
C_{PM}	Cost of preventive maintenance per unit time;
C_d	Delay cost per customer per unit time;
C_{lost}	Loss of sale cost per customer not served by the system;
λ_{lost}	Expected number of lost customers per unit time due to fully use of buffer;
N	Capacity of system buffer.

The following describes the problem formulation and assumptions. A single service facility is considered, which can be modeled by a M/M/1 queueing system with finite buffer size, N. That is, the customers arrive according to Poisson process with rate λ and the service times are independent and identically distributed exponential random variables with rate μ. A finite buffer (or waiting room) for the service system is