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Adaptive Age Replacement Using On-Line Monitoring

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Abstract

Age replacement is one of the most used maintenance policies based on preventive action in order to prevent the failure of a system. Age replacement means that a system is replaced at failure or at a specified replacement age, whichever occurs first. In current age replacement policies, the replacement age is identified without consideration of the effects from operating conditions. However, the lifetime of a system may be affected by various operating conditions, such as the surrounding environment and the operators. In such cases, the replacement age of the system should differ for different situations. Thanks to the improvement of information communication technology, various information about the systems operating conditions can be obtained via the on-line monitoring. This research proposed an adaptive age replacement policy for systems under variable operating conditions using a cumulative exposure model. Based on the on-line information, we proposed a new time-scale instead of the age with consideration of operating conditions. Next, the new time-scale is used to determine the optimal replacement interval which will minimize the average maintenance cost per unit time (also known as cost rate). Some numerical examples are carried out in order to illustrate the proposed adaptive age replacement policy. The optimal age replacement policy considering the operating conditions reduces the total maintenance costs and enhances the effective maintenance plan for systems operating under various conditions.

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Keywords: Cost rate; cumulative exposure model; dynamic covariates; operating condition; time-scale; use rate

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1. Introduction

1.1 Background

The breakdowns of systems sometimes can have a great impact on society. Due to technical reasons, it is sometimes difficult to improve the reliability of systems at the design stage. Maintenance is usually carried out to ensure the reliability of a system. Generally, there are two types of maintenance: preventive maintenance and corrective maintenance depending on whether the system is maintained before or after it breaks down. Corrective maintenance usually is costly, so it is necessary to carry out preventive maintenance. However, it is not effective to preventively maintain the system too frequently. From this point, many policies integrating prevent and corrective maintenance have been proposed such as age replacement policy, and condition monitoring maintenance. This research focuses on age replacement, which is one of the most used maintenance policies to prevent breakdowns.

Originally, the age of a system was considered to be a random variable. Barlow and Hunter (1960) proposed and studied the basic age replacement policies, call Policy I and Policy II. In Policy I, a preventive maintenance performs after T hours of counting operation without failure. If the system fails before T, an emergency replacement performs at the time of failure, and the preventive maintenance at the time is rescheduled. For this policy, the system is assumed to be as good as new after a replacement is performed. In Policy II, preventive maintenance is carried out after the system has been operating a total of T hours regardless of the number of intervening failure. It is assumed that after each failure only minimal repair is made and that the system's failure rate is not disturbed after performing minimal repair. Barlow and Hunter (1960) found the optimum maintenance periods T^* in the sense of limiting system availabilities. Based on Policies I and II, Makabe and Monirmura proposed a Policy III, which is more efficient and simpler than Policy II for their practical uses. In policy III, replacement is performed at k-th failure of the system, but for first $(k-1)$ times of failures, perform minimal repairs only. The properties of the optimal age replacement policy are investigated in the sense of limiting efficiency (Makabe and Monirmura (1962a, 1963b) and the maintenance cost rate (Makabe and Monirmura (1963b, 1963c).

1.2 Literature review

In the past decades, the basic age replacement policies were developed by many researchers. Tahara and Nishida (1975) introduced the maintenance policy, "replace the unit when the first failure after t_0 hours of operation or when the total operating time reaches T_0 ($0 \leqslant t_0 \leqslant T_0$) whichever occurs first." In their model, failures during (0, t_0) are removed by minimal repair. Note that if $t_0 = 0$, it becomes the basic age replacement policy. Segawa, Ohnishi and Ibaraki (1992) investigated the optimal age replacement problem with minimal repairs under the average cost criterion, and showed that among all allowable policies, an optimal policy is a T-policy. That is, failures before age T are minimally repaired, but the system is replaced when a failure after age T occurs. Nakagawa (1984) extended the age replacement policy to replacing a system at time T or at number N of failures, whichever occurs first, and undergoes minimal repair at failure between replacements. The decision variables for this policy are T and N. In this policy, if $N = 1$, this policy reduces to the age replacement policy. Herein this policy is called $T-N$ policy. Wang and Pham (1996) made another extension of age replacement policy, called "mixed age preventive maintenance policy." In this policy, after N-th imperfect repair, there are two types of failures. A type I failure might be total breakdowns, while another type II failure can be interpreted as a slight and easily fixed problem. When a failure occurs, it is a type I failure with probability $p(t)$ and a type II failure with probability $1-p(t)$. After the first N imperfect repairs, the unit will be