Condition-based Maintenance Problem of a Consecutive-\(k\)-out-of-\(n\): F System with Load-Sharing Dependent Components

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1. Introduction

A maintenance problem of a linear consecutive-\(k\)-out-of-\(n\): F system with load-sharing dependent components is considered. This system consists of \(n\) components which are arranged linearly and fails if \(k\) consecutive components fail [1]. This system is commonly found in the integrated circuits, relay stations in telecommunication system, oil pipeline system, vacuum system in accelerators, and spacecraft relay stations [2]. Many studies have been done for this system. However, the studies focused on how to calculate the exact system reliability or the efficient lower bound of the system reliability. System design problems have also been considered in previous studies. However, there are a very few studies considering the maintenance problem for this system.

Bollinger and Salvia built a recursive equation to calculate the reliability of a consecutive-\(k\)-out-of-\(n\): F system [3]. Lambiris and Papastavridis proposed a model for the system reliabilities of linear and circular consecutive-\(k\)-out-of-\(n\): F systems [4]. Pekoz and Ross simplified the model in Lambiris and Papastavridis [5]. Canfield and McCormick proposed an asymptotic reliability model [6]. Yun, Kim, and Yamamoto proposed a modified formula to calculate the system reliability of a circular consecutive-\(k\)-out-of-\(n\): F system and a method to find the optimal system design for the circular consecutive-\(k\)-out-of-\(n\): F system with \((k-1)\)-step Markov dependence [7]. Flynn and Chung proposed a maintenance policy related to the critical component policies (CCP) for consecutive-\(k\)-out-of-\(n\): F systems [8]. The failed components are replaced only if the components are in the critical component set. They used a branch and bound algorithm to find the optimal CCP. Zuo and Wu studied an age replacement policy for \(k\)-out-of-\(n\): F system and consecutive-\(k\)-out-of-\(n\): F system [9]. Yun, Kim, and Yamamoto considered system design problems and age replacement policy for linear and circular consecutive-\(k\)-out-of-\(n\): F systems with load sharing dependence [10]. Yun and Endharta developed a condition-based maintenance policy for linear consecutive-\(k\)-out-of-\(n\): F systems and linear connected-(\(r\), \(s\))-out-of-(\(m\), \(n\)): F systems and used simulation to get the optimal decision variable [11].

In this paper, we study a maintenance problem for a linear consecutive-\(k\)-out-of-\(n\): F system. A condition-based maintenance policy which has been developed in Yun and Endharta [11] is used. If there is at least one minimal cut set with one working component, a preventive maintenance will be done after a certain time interval. If the system fails before reaching the preventive maintenance time, the system will be maintained correctly at failure time. We consider two scenarios. First, we replace all components at maintenance time and second, we replace only failed components at maintenance time. We derive the mathematical model analytically to find the expected cost rate value for both scenarios. The optimal preventive maintenance time interval \((T_{CM})\) is obtained by minimizing the expected cost rate. The policy is compared to the existing maintenance policies, such as corrective maintenance and age PM policies.

The assumptions used in the paper are as follows:

- Components and system have two states: working and failed.
- Time when there is one minimal cut set with one working component can be known, but the failed components are unknown.
- Replacement times are negligible.
- Component failure times are independent, identical and following an exponential distribution with parameter \(\lambda\).

2. Condition-based maintenance

The preventive maintenance (PM) occurs after a time interval \(T_{CM}\) after a certain condition. The condition is that there is at least one minimal cut set consisting of only one working component. If the system fails before reaching the PM time after the condition is satisfied, the system is maintained correctly (CM). The illustration of this maintenance policy is shown in Fig. 1. The time that there is at least one minimal cut set consisting of only one working component is represented by \(L_{OW}\) and the time of system failure is \(L_{SF}\). Define a random variable \(X = L_{SF} - L_{OW}\), representing the time difference between \(L_{OW}\) and \(L_{SF}\). If \(X < T_{CM}\), the renewal time is ended by PM and the system is maintained preventively (see Fig. 1a). Otherwise, if \(X < T_{CM}\), the renewal time is ended by CM and the system is maintained correctly (see Fig. 1b).
The component failures leading to the system failure are varied because there are many possible paths leading to the system failure. Since the time interval $T_{Cr}$ starts from time $L_{OW}$, which is the time that there is at least one minimal cut set consisting of only one working component, the information about the component states in time $L_{OW}$ is important.

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References


Fig. 1 Illustration of the condition-based maintenance policy
(a) PM occurs and (b) CM occurs