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Optimizing replacement policy for a cold-standby system with waiting repair times

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ABSTRACT

This paper presents the formulas of the expected long-run cost per unit time for a cold-standby system composed of two identical components with perfect switching. When a component fails, a repairman will be called in to bring the component back to a certain working state. The time to repair is composed of two different time periods: waiting time and real repair time. The waiting time starts from the failure of a component to the start of repair, and the real repair time is the time between the start to repair and the completion of the repair. We also assume that the time to repair can either include only real repair time with a probability p, or include both waiting and real repair times with a probability $1-p$. Special cases are discussed when both working times and real repair times are assumed to be *geometric processes*, and the waiting time is assumed to be a renewal process. The expected long-run cost per unit time is derived and a numerical example is given to demonstrate the usefulness of the derived expression.

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0. Introduction

A two-component cold-standby system is composed of a primary component and a backup component, where the backup component is only called upon when the primary component fails. Cold-standby systems are commonly used for non-critical applications. However, cold-standby systems are one of most important structures in the reliability engineering and have been widely applied in reality. An example of such a system is the data backup system in computer networks.

Reliability analysis and maintenance policy optimisation for cold-standby systems has attracted attentions from many researchers. Zhang and Wang [11,12] and Zhang et al. [10] derived the expected long-run cost per unit time for a repairable system consisting of two identical components and one repairman when a geometric process depicting working times is assumed. Utkin [5] proposed imprecise reliability models of cold-standby systems when he assumed that arbitrary probability distributions of the component time to failure are possible and they are restricted only by available information in the form of lower and upper probabilities of some events. Coit [1] described a solution methodology to optimal design configurations for non-repairable series–parallel systems with cold-standby redundancy when he assumed non-constant component hazard functions and imperfect switching. Yu et al. [9] considers a framework to optimally design a maintainable previous term cold-stand by next term system, and determine the maintenance policy and the reliability character of the components.

Due to various reasons, repair might start immediately after a component fails. In some scenarios, from the failure of a component to the completion of repair, there might be two periods: waiting time and real repair time. The waiting time starts from the failure of the component to the start of repair; and the real repair time is the time between the start to repair

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and the completion of the repair. This is especially true for cold-standby systems as they are not critical enough for a standby repairman be equipped for it. For example, when a component fails to work, its owner will call its contracted maintenance company or return the component to its suppler for repair. The waiting time can be the time spent by repairmen from their working place to the place where the component fails, or the time on delivering the failed component to its supplier. Usually, the waiting time can be seen as a random variable independent of the age of the component, whereas the real repair time can become longer and longer when the component becomes older. On the other hand, the working time of the component can become shorter and shorter due to various reasons such as ageing and deterioration. Such working and real repair time patterns can be depicted by geometric processes as many authors have studied [2–4,7,8,10–13].

The geometric processes introduced by Lam [4] define an alternative to the non-homogeneous Poisson processes: a sequence of random variables $\{X_k, k = 1,2,\ldots\}$ is a geometric process if the distribution function of X_k is given by $F(a^{k-1}t)$ for $k = 1,2,\ldots$ and a is a positive constant. Wang and Pham [6] later refer the geometric process as a quasi-renewal process. Finkelstein [2] develops a very similar model: he defines a general deteriorating renewal process such that $F_{k+1}(t) \leqslant F_k(t)$. Wu and Clements-Croome [7] extend the geometric process by replacing its parameter a^{k-1} with $a_1a^{k-1} + b_1b^{k-1}$, where $a > 1$ and $0 < b < 1$. The geometric process has been applied in reliability analysis and maintenance policy optimisation for various systems by many authors; for example, see Wang and Pham [6], and Wu and Clements-Croome [8].

This paper presents the formulas of the expected long-run cost per unit time for a cold-standby system that consists of two identical components with perfect switching. When a component fails, a repairman will be called in to bring the component back to a certain working state. The time to repair is composed of two different time periods: waiting time and real repair time. The waiting time starts from the component failure to the start to repair, and the real repair time is the time between the start to repair and the completion of the repair. Both the working times and real repair times are assumed to be *geometric processes*, and the waiting time is assumed to be a renewal process. We also assume that the time to repair can either include only real repair time with a probability p, or include both waiting time and real repair time with a probability $1 - p$. The expected long-run cost per unit time is derived and a numerical example is given to demonstrate the usefulness of the derived expression.

The paper is structured as follows. The coming section introduces geometric processes defined by Lam [4], denotation and assumptions. Section 3 discusses special cases. Section 4 offers numerical examples. Concluding remarks are offered in the last section.

1. Definitions and model assumptions

This section first borrows the definition of the geometric process from Lam [4], and then makes assumptions for the paper.

1.1. Definition

Definition 1. Assume ξ, η are the two random variables. For arbitrary real number α, there is

$$P(\xi \geqslant \alpha) > P(\eta \geqslant \alpha),$$

then ξ is called stochastically bigger than η. Similarly, if ξ stochastically smaller than η.

Definition 2 [4]. Assume that $\{X_n, n = 1,2,\ldots\}$ is a sequence of independent non-negative random variables. If the distribution function of X_n is $F(a^{n-1}t)$, for some $a > 0$ and all, $n = 1,2,\ldots$, then $\{X_n, n = 1,2,\ldots\}$ is called a geometric process.

Obviously,

if $a > 1$, then $\{X_n, n = 1,2,\ldots\}$ is stochastically decreasing,
if $a < 1$, then $\{X_n, n = 1,2,\ldots\}$ is stochastically increasing, and
if $a = 1$, $\{X_n, n = 1,2,\ldots\}$ is a renewal process.

1.2. Assumptions and denotation

The following assumptions are assumed to hold in what follows.

A. At the beginning, both components are new, component 1 is working and component 2 is under cold standby.
B. When both of the two components are in good condition, one is working and the other is under cold standby. When the working component fails, a repairman repairs the failed component immediately with probability p, or repairs it with a waiting time with probability $1 - p$. As soon as the working component fails, the standby one will start to work. Assume the switching is perfect. After the failed one has been repaired, it is either put in use the other one fails or put in standby if the other is working. If one fails while the other is still under repair, the failed one must wait for repair until the repair for the first failed is completed.

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