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Optimal inspection and preventive maintenance of units with revealed and unrevealed failures

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Abstract

The maintenance of a single unit system that alternates operating and idle periods is studied. In the former case the failures are detected as soon as they occur and only by special testing or inspection in the latter. This paper aims at minimizing the cost per unit of time for an infinite time span by selection of a unique interval, for both inspection and maintenance. A special feature of this model is the possibility of a less than perfect testing as the inspections may fail and give a wrong result. It is further assumed that both preventive and corrective maintenance make the unit as good as new with the durations of inspections and maintenances being negligible. The existence of an optimum interval and how it depends on both the cost parameters and the reliability characteristics of the unit is discussed.

Keywords: Age-replacement; Cost rate; Imperfect testing; Optimum maintenance; Revealed failure

1. Introduction

It is well known that the effectiveness of a system depends on both the quality of its design as well as the proper maintenance actions to prevent it from failing. In fact, the choice of scheduled maintenance policies which are optimum from an economic point of view constitutes a predominating approach in reliability theory. A wide and recent study of preventive maintenance models can be found in Ref. [9].

When dealing with maintenance models the features of the failures play a primary role: the classical age and block replacement policies [5] are useful for failures that are detected as soon as they occur (revealed failures); in this situation repairs can be immediately initiated. The opposite case corresponds to unrevealed failures, that is, those, which remain undiscovered unless some kind of inspection or testing is carried out. This usually happens in stored equipment, standby units, or devices that operate rarely as security systems. Badía et al. [10] analyzed the existence of a cost optimizing policy within the context of an inspection model which involves corrective maintenance whenever a failure is detected, and having no effect in the unit reliability otherwise. In Ref. [11] a preventive maintenance procedure is considered where inspections and maintenance actions take place at different times. Maintenance policies that can be used under unrevealed failures are found in Refs. [2–4,7,8].

Gertsbakh [1] considers an intermediate situation where failures are sometimes revealed and sometimes not as it often happens in computers. The results of computations may seem reasonable although they are wrong due to a hidden defect in the computer, which will be discovered by means of special checking. Gertsbakh [9] (see chapter 2) presents a failure detecting device which may exhibit an imperfect signaling with α being the probability of sending a signal about the failure. At the same time an inspection policy is proposed and the probability of a failure remaining undiscovered, $1-\beta$, is also assumed. In our work there is no failure signaling mechanism but failures manifest themselves when the unit is operating or are detected by special tests in case the unit is in the standby mode. The parameters denoted in the former model by α and β play now the role of $1-p$ and $1-\beta$. We introduce the possibility of false alarms during inspections, not considered previously, and deal with a cost function instead of the unit availability.

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Nomenclature

α	probability of a type I inspection error
β	probability of a type II inspection error
δ	$1/(1-\beta)$
c_0	cost of inspection
c_n	cost of preventive maintenance
c_r	cost of corrective maintenance ($c_n < c_r$)
c_I	cost of a type I error
c_d	cost-rate derived from down-time
τ	random length of a cycle
$C(\tau)$	random cost of a cycle
$Q(T)$	objective cost function
X	random time to failure of the unit
X_T	random time to failure of the unit under preventive maintenance at age T
$F(t)$	Cdf of X
$R(t)$	reliability function of X; $R(t) = 1 - F(t)$
$r(t)$	hazard rate (or failure rate) corresponding to X
$m(t)$	mean residual life corresponding to X
$\mu = E[X]$	mean time to failure
K_1	random number of inspections previous to failure
K_2	random number of inspections after failure until its detection
n_I	random number of false alarms in a cycle
H	random down-time period: time span from the occurrence of a failure until its detection
T	age for inspection and maintenance
T^*	optimum age for inspection and maintenance
p	probability of unrevealed failure
Z	random variable that indicates the failure type: $Z = 0$ corresponds to an unrevealed failure and $Z = 1$ to a revealed failure, so that $P(Z = 0) = p$

This paper develops an inspection policy along with a maintenance procedure for a single unit system whose failures are revealed or not in a random way. In fact we consider that they are unrevealed with probability p or revealed otherwise. This model turns out to be a mixture of the age-replacement policy and a maintenance procedure for unrevealed failures.

The basic assumptions are

1. Unrevealed failures are only detected by inspection or testing.
2. Inspections may not be perfect, that is, they may fail giving an erroneous result: after inspection it can be wrongly concluded that a failure has occurred or, on the contrary, a failure may remain undiscovered. Both types of inspection errors correspond, respectively, to type I and type II statistical errors. Mistaken checks occur, for example, when carrying out tests to detect breast cancer or in assessing the effect that fatigue causes on mechanisms fracture. In general, wrong inspections may happen whenever a system is examined due to testing device failure.
3. Tests have no effect on the unit reliability. Depending on the test result, a preventive or corrective maintenance is carried out. Both types of maintenance restore the unit to an 'as good as new' condition.
4. Times of test and maintenance are considered negligible.

2. The model

Whenever a failure is revealed, a corrective maintenance takes place. If the unit reaches age T and no failure has been observed, it is inspected to look for a concealed one. If after inspection it is concluded that a failure has occurred, a corrective maintenance is carried out and a preventive maintenance otherwise. Therefore, testing and preventive maintenance occurs at periodic times NT, $(N = 1, 2, \ldots)$ only for unrevealed failures. However, in case of a revealed failure, the policy corresponds to an inspection along with a preventive maintenance at the age T. It is important to point out that in the case $p = 0$, that is, when all the failures are of the revealed type, this maintenance is equivalent to an age replacement policy.

The cost per unit of time for an infinite horizon is considered as the objective cost function $Q(T)$. We aim at determining the optimum testing time, T^*, under the previous maintenance policy minimizing $Q(T)$ which can