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New method to minimize the preventive maintenance cost of series–parallel systems

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Abstract

General preventive maintenance model for input components of a system, which improves the reliability to 'as good as new,' was used to optimize the maintenance cost. The cost function of a maintenance policy was minimized under given availability constraint. An algorithm for first inspection vector of times was described and used on selected system example. A special ratio-criterion, based on the time dependent Birnbaum importance factor, was used to generate the ordered sequence of first inspection times. Basic system availability calculations of the paper were done by using simulation approach with parallel simulation algorithm for availability analysis. These calculations, based on direct Monte Carlo technique, were applied within the programming tool Matlab. A genetic algorithm optimization technique was used and briefly described to create the Matlab's algorithm to solve the problem of finding the best maintenance policy with a given restriction. Adjacent problem, which we called 'reliability assurance,' was also theoretically solved, concerning the increase of the cost when asymptotic availability value conforms to a given availability constraint.

Keywords: Preventive maintenance; Cost; Availability; Optimization; Reliability; Monte Carlo

1. Introduction

The evolution of system reliability depends on its structure as well as on the evolution of the reliability of its elements. The latter is a function of the element age on a system's operating life. Element ageing is strongly affected by maintenance activities performed on the system. Preventive maintenance (PM) consists of actions that improve the condition of system elements before they fail. PM actions such as the replacement of an element by a new one, cleaning, adjustment, etc. either return the element to its initial condition and the element becomes 'as good as new' or reduce the age of the element. In some cases, the PM activity does not affect the state of the element but ensures that the element is in operating condition. In this case the element remains 'as bad as old.'

Optimizing the policy of preliminary planned PM actions is the subject of much research activities. In the past, the economic aspects of preventive and corrective maintenance have been extensively studied for monitored components in which failures are immediately detected and subsequently repaired. Far less attention has been paid to the economics of systems in which failures are dormant and detected only by periodic testing or inspections. Such systems are especially common in industrial safety and protection systems. For these kind of systems, both the availability evaluation models and the cost factors assessment differ considerably from those of monitored components [1].

This paper develops availability and cost models for systems with periodically inspected and maintained components subjected to some maintenance strategy.

The aim of our research is to optimize, for each component of a system, the maintenance policy minimizing the cost function, with respect to the availability constraint such as $A(t) \geq A_0$, for all t, $0 < t \leq T_M$, and a given mission time T_M.

A genetic algorithm (GA) is used as an optimization technique. GA is used to solve the above-mentioned

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problem, i.e. to find the best maintenance policy using a simulation approach to assess the availability of the studied system. The solution comprises both the availability and the cost evaluation.

Properties of the applied simulation program were intensively studied in Ref. [2]. The Matlab program was also successfully used in Ref. [3] for the reliability and availability optimization based on design of a Distribution Area System under Maintenance. New improvements of the simulation program focused on enhancing of computational efficiency were implemented into the program recently, including, e.g. a parallel computing algorithm.

A similar optimization problem applied on series–parallel multi-state system was studied in Ref. [4] taking into account imperfect component PM actions. This model uses universal z-transform for reliability calculations (universal moment generating function) but the duration of the PM activity is neglected. In Ref. [4], the optimization procedure is also based on a heuristic GA. We propose in this paper to study the example from Ref. [4] and others to prove the efficiency of our model.

This introduction is followed by seven sections, which present successively the PM model for general series–parallel systems, the problem formulation, the availability calculation based on simulation technique and analytic solution of the adjacent problem, the cost optimization technique (GA), the results and illustrative data, the result comments and a conclusion.

Notations.

WRV worst reliability value
N total number of components
$\mathbf{T_0} = (T_0(1), T_0(2), \ldots, T_0(N))$ first inspection time vector
$\mathbf{T_0^{ord}} = (T_0^{(1)}, T_0^{(2)}, \ldots, T_0^{(N)})$ ordered first inspection time vector; $T_0^{(1)} \le T_0^{(2)} \le \cdots \le T_0^{(N)}$
$\mathbf{T_P} = (T_P(1), T_P(2), \ldots, T_P(N))$ solution vector of system component inspection periods
T_M mission time
$C(e(i,k))$ cost of one inspection of ith component in the kth parallel subsystem
$A(t)$ system availability at the time t
A_0 availability constraint—lower limit

2. Preventive maintenance model for general series–parallel systems

2.1. Maintenance model for basic components

In the paper we will assume that the PM actions improve the reliability of basic component to as good as new. It means that the component's age is restored to zero. The model is demonstrated in Fig. 1, where T_F is random time to failure. Each T_F is demarcated by two conversely oriented arrows, identically with inspection periods T_P.

The problem to find the optimal vector $\mathbf{T_P}$ is closely connected with another problem, i.e. to find the optimal first inspection time vector $\mathbf{T_0}$. Of course, it makes no sense to carry out inspections in the beginning of the life of a system, when both the system and its basic components are very reliable. Consequently, the preliminary calculations must be realized to find the optimal T_0 for each of basic components. The optimal vector $\mathbf{T_0}$ must be constructed so that it takes into account both cost and reliability view.

2.2. General series–parallel structure

Optimal PM plan is found for a general series–parallel structure that is shown in Fig. 2.

2.3. Cost model

Cost of the above-mentioned PM policy of a given system is simply given by summarizing each of the PM inspections done on the components that are under maintenance

$$C_{PM} = \sum_{k=1}^{K} \sum_{i=1}^{E_k} \sum_{j=1}^{n_{e(i,k)}} C_j(e(i,k)).$$

$n_{e(i,k)}$ represents the total number of inspections of the ith component in the kth parallel subsystem in the course of mission time;
$C_j(e(i,k))$ is the cost of the jth inspection of the ith component in kth parallel subsystem;
E_k is the number of components in given kth parallel subsystem;
K is the number of parallel subsystems;

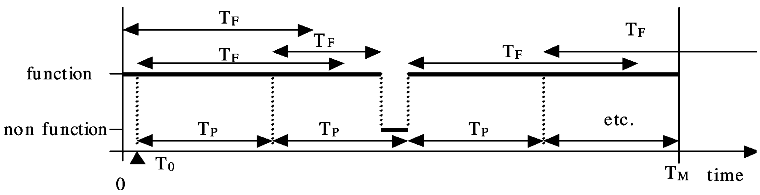

Fig. 1. PM model for periodically tested elements.