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Extended great deluge algorithm for the imperfect preventive maintenance optimization of multi-state systems

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Abstract

This paper deals with preventive maintenance optimization problem for multi-state systems (MSS). This problem was initially addressed and solved by Levitin and Lisnianski [Optimization of imperfect preventive maintenance for multi-state systems. Reliab Eng Syst Saf 2000;67:193–203]. It consists on finding an optimal sequence of maintenance actions which minimizes maintenance cost while providing the desired system reliability level. This paper proposes an approach which improves the results obtained by genetic algorithm (GENITOR) in Levitin and Lisnianski [Optimization of imperfect preventive maintenance for multi-state systems. Reliab Eng Syst Saf 2000;67:193–203]. The considered MSS have a range of performance levels and their reliability is defined to be the ability to meet a given demand. This reliability is evaluated by using the universal generating function technique. An optimization method based on the extended great deluge algorithm is proposed. This method has the advantage over other methods to be simple and requires less effort for its implementation. The developed algorithm is compared to than in Levitin and Lisnianski [Optimization of imperfect preventive maintenance for multi-state systems. Reliab Eng Syst Saf 2000;67:193–203] by using a reference example and two newly generated examples. This comparison shows that the extended great deluge gives the best solutions (i.e. those with minimal costs) for 8 instances among 10.

Keywords: Multi-state systems; Preventive maintenance; Universal generating function; Extended great deluge algorithm

1. Introduction

Redundancy and maintenance are methods used to improve system reliability. In the existing literature, to guarantee a given required system reliability level under cost constraint, researchers solve the problems of redundancy optimization or maintenance optimization either jointly or separately.

This paper deals with preventive maintenance optimization of multi-state systems. A system is called a multi-state system (MSS) if it is capable of assuming a range of performance levels, varying from perfect functioning to complete failure. Due to their applicability in many industrial areas, the maintenance of MSS has received a growing attention in the existing literature. Gürler and Kaya [2] develop a maintenance policy for a multi-component system where the lifetime assigned to each component is given by several stages. An approximate approach based on renewal theory is proposed in order to derive the long-run average cost function per unit time, which is optimized by numerical methods. In [3], under state-deteriorating assumption, Hsieh and Chiu develop an optimal maintenance policy for a multi-state deteriorating standby production system. A component that ensures the system to be operational deteriorates during the production process. At a given deteriorating state, this component is replaced by a standby component and sent to the maintenance service center. The optimal maintenance policy is determined by means of the number of the standby components and the optimal state where the

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replacement of the deteriorating components should be performed. In the work of Su and Chang [4], a model of MSS with state-dependent cost is considered. The state space of the system is partitioned into two subsets: the first allows to represent all states of normal operations while the second is characterized by the single failure state. A periodic maintenance model is developed and the optimal cycle time of maintenance actions is determined over a specific finite horizon. In [5], Lam and his coauthors consider monotone process model for a multi-state degenerative system with one working state and k failure states. More recently, in [6], Lam considers a one-component MSS for which the state space is characterized by k working states and l failure states. For such a system, a monotone process maintenance model is studied. Under some assumptions, it is shown that this model can be applied to multi-state deteriorating system and multi-state improving system. A replacement policy N is adopted, which is based on the failure number of the system. An analytical approach is used to determine the optimal replacement policy. In [7], Zhang et al. also consider a multi-state deteriorating system with k failure states and one working state. Replacement policy N is exploited and the optimal replacement time is derived to maximize the long-run average profit per time unit. In [8], Levitin and Lisnianski generalize the replacement schedule optimization problem to MSS. In [8], an MSS is given as a set of components in a series–parallel configuration. The system as well as its components are characterized by various performance levels and the system reliability is defined as the ability of the system to meet a demand. The optimal number of component replacements corresponds to that which ensure the desired level of the system reliability level by minimizing the sum of maintenance cost and the cost of unsupplied demand. A genetic algorithm is adopted as an optimization technique. Within this kind of MSS, Levitin and Lisnianski [1] solve the preventive maintenance optimization problem. Components of the system are characterized by their corresponding hazard function and the preventive maintenance actions may have the ability to reduce the effective age of components. A genetic algorithm is used to derive, for a given system lifetime, the optimal sequence of maintenance actions that ensure the desired system reliability level. Another existing solution technique of this problem is ant colony optimization [9]. However, the best-published results have been provided by genetic algorithm [1].

As MSS applicability is becoming more and more important, while requiring short development schedules and very high reliability, it is becoming increasingly important to develop efficient solutions to preventive maintenance optimization problem for MSS. By exploiting the model proposed in [1], to solve the imperfect preventive maintenance optimization problem for MSS, this paper presents an efficient algorithm inspired from the extended great deluge metaheuristic [10]. This algorithm performs well and is competitive with that proposed in [1]. This is demonstrated by the solutions found by the proposed algorithm.

The remainder of this paper is organized as follows. In the next section, MSS reliability definition and estimation are presented. Section 3 addresses the preventive maintenance model. Section 4 presents the MSS model and the problem formulation. The optimization method is given in Section 5. Numerical results are presented in Section 6. Conclusion is given in Section 7.

2. MSS reliability estimation by using universal moment generating functions

Consider an MSS composed of a number of failure-prone components. Each component is characterized by a range of performance levels from complete failure up to perfect functioning. The entire system is assumed to have K different states corresponding to different output performance levels. Within MSS, reliability is related to the ability of the system to satisfy, at a given time t, the required performance level (*demand*). According to [11], MSS reliability is given as follows:

$$R(t, W) = \Pr\{G(t) \geqslant W\}, \tag{1}$$

where $G(t)$ represents the output performance of the system at time t, and W is the required performance level.

Let G_k be the output performance level of the system kth state and $q_k(t)$ be the probability $\Pr\{G(t) = G_k\}$ (for $k = 1, \ldots, K$), it follows that the output performance distribution (OPD) of the system can be determined on the basis of two sets $\mathbf{G}$ and $\mathbf{q}$ such that

$$\mathbf{G} = \{G_k : 1 \leqslant k \leqslant K\} \tag{2}$$

and

$$\mathbf{q} = \{q_k(t) : 1 \leqslant k \leqslant K\}. \tag{3}$$

According to Eqs. (1)–(3), the MSS reliability can be expressed as the probability that the system is confined, during the time interval $[0, t]$, in those states for which the output performance level is greater than or equal to the demand W. That is

$$R(t, W) = \Pr\{G(t) \geqslant W\} = \sum_{G_k \geqslant W} q_k(t). \tag{4}$$

To evaluate the MSS reliability, several approaches have been developed in the literature. However, when dealing with optimization problems, such as the one studied in this paper, it is important to have an efficient and fast procedure to estimate the MSS reliability. A procedure based on the universal z-transform as a modern mathematical technique is developed in [12] and widely exploited within MSS performance measure evaluation. In the literature, the universal z-transform is also called universal moment generating function (UMGF) and denoted as u-function or z-function. More details on the usage of the UMGF in MSS performance measure evaluation can be