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On a dynamic preventive maintenance policy for a system under inspection

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Abstract

The purpose of this article is to propose both state and time-dependent preventive maintenance policy for a multi-state deteriorating system, which is equipped with inspection equipment(s) connected to a computer center. After the system being identified as state x at nd through computation by the computer center after inspection (or measurement) via equipment(s), one maintenance action with the minimum expected total cost since nd till Nd (where $N = n + K$ for a fixed integer $0 < K < \infty$) will be chosen from the set A_x of alternatives also with the help of the computer center. In real case, the expected total costs since nd till Nd will be time-dependent and so is the maintenance action chosen at nd. A numerical example is given to illustrate such a maintenance policy for a Markovian deteriorating system to describe its state dependent aspect only for simplicity reason. Due to the fact that both equipment measurement and computer computation take time, the preventive maintenance policy for a sufficiently small d may be used in fact as the one under continuous inspection.

Keywords: Preventive maintenance; Inspection; Markov chain model; Operation cost

1. Introduction

Extensive reviews of various maintenance policies on a deteriorating system can be found in Refs. [1–3]. Such policies can be classified into two classes: the 1st class deals with a system without inspection equipment and the 2nd class deals with a system equipped with inspection equipment(s), which is (possibly) connected to a computer center.

The 1st class is to deal with a two state system. This follows from the fact that the action is taken upon failure only under such no inspection equipment case. The age replacement policy (i.e. replacement upon failure or at age) [4] and their extensions by including minimal repair such as Refs. [5–10] belong to such a class. The block replacement policy (i.e. replacement at kT for $k = 1, 2\ldots$ or upon failure) and the failure replacement policy (i.e. replacement upon failure) also belong to such a class [11–13]. The scheduled maintenance policies through predicting failure time statistically also belong to this class [14,15].

The 2nd class is to deal with a multi-state deteriorating system provided with inspection equipment(s) (with states in deteriorating order $1 < 2 < \cdots < i < \cdots < j < \cdots < L$, 1: perfect,…,$L$: complete failure). Each state of the system must be identified through inspection for example at each nd. Then the optimal maintenance action can be decided at nd for the system by minimizing the objective function such as the expected total cost per life cycle, the expected total cost per unit time, etc. Hence, it is only the 2nd class on preventive maintenance policies. Lam and Yeh [16] proposed a control-limit replacement policy under continuous inspection so that replacement is taken optimally whenever the threshold state j^* is identified by inspection or the complete failure L is observed. Lam and Yeh [12] proposed another control-limit replacement policy under inspection at each nd so that the replacement takes places at nd whenever the system state x at nd satisfies $j \le x \le L$ for a threshold state j, to determine the optimal (d^*, j^*). Chiang and Yuan [17,18] proposed other control-limit preventive maintenance policies under continuous and periodic inspection, respectively, by determining two threshold states $i^* < j^*$ $(1 < i^* < j^* < L)$ so that the optimal action is that repair (resp. replacement, do-nothing) is taken whenever

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Nomenclature

$C_n(w_{ik})$	expected total cost per each w_{ik} at nd ($=$ cost of w_{ik} per unit time $\times$ expected spent time for w_{ik})
$o_n(i)$	expected total cost during $(nd,(n+1)d)$ due to minimal repairs or scrap given system state i at nd
d	period of inspection
D	system state
H	healthy index
$o_n(i)$	expected total cost during $(nd,\ (n+1)d)$ due to minimal repairs or scrap given system state i at nd
$O_n(w_{ik})$	expected total cost during$(nd,\ (n+1)d)$ due to minimal repairs or scrap but given w_{ik} upon system state i at nd
p_{ij}	transition probability
R_L	disposal/or replacement cost upon system L
β	discount factor
$\tau_{n;N}(a_n(i))$	the minimal expected total cost during $[nd,\ Nd]$ given the action $a_n(i)$ upon system state i at nd

the system state is identified as x so that $i^* \le x < j^*$ (resp. $j^* \le x \le L$: otherwise). Wood [19] proposed a control-limit rule that requires restoration of the system whenever the damage exceeds a certain level under continuous inspection. Such methods have to assume that the system before taking any maintenance policy satisfies a continuous-time Markov chain. Also, the threshold state(s) thus obtained and so the optimal maintenance action taken is state dependent only (i.e. not time-dependent). Jardine et al. [20] and Makis and Jardine [21] proposed an optimal dynamic (i.e. time-dependent too) replacement policy for condition-based maintenance. Wildeman et al. [22] proposed another dynamic preventive maintenance policy that takes a long-time tentative plan as a basis for a subsequent adaptation according to available information on the short term by a rolling-horizon approach.

The purpose of this article is to propose a both state and time-dependent preventive maintenance policy for a multi-state deteriorating system, which is assumed to satisfy:

1. Its quality or healthy index H can be characterized by its parameters (Fig. 1) completely in a formula [23].
2. The values of such system parameters at each nd for a fixed d can be measured immediately (i.e. in negligible time) via inspection equipments(s), which are connected to a computer center.
3. The value of H is calculated and the system state (or quality level) thus identified both at each nd by the computer center immediately.
4. The expected total cost since each nd till Nd $(N = n + K)$ under each maintenance action taken at nd can be calculated by the computer center immediately.
5. The one with minimal expected total cost since nd till Nd is chosen immediately by the computer as the optimal action at nd.

Such a dynamic preventive maintenance policy can be illustrated in a flow chart in Fig. 1. In Refs. [17,18], the percentage of defectives among products, which the system produces, is in fact taken as the system healthy index H, their control-limit preventive maintenance policies cannot prevent the production system from products defectives effectively as the proposed one here.

Such a d may either mean the period of inspections or be chosen to be sufficiently small to mean continuous inspection case (due to both inspection and computation by computer need time).

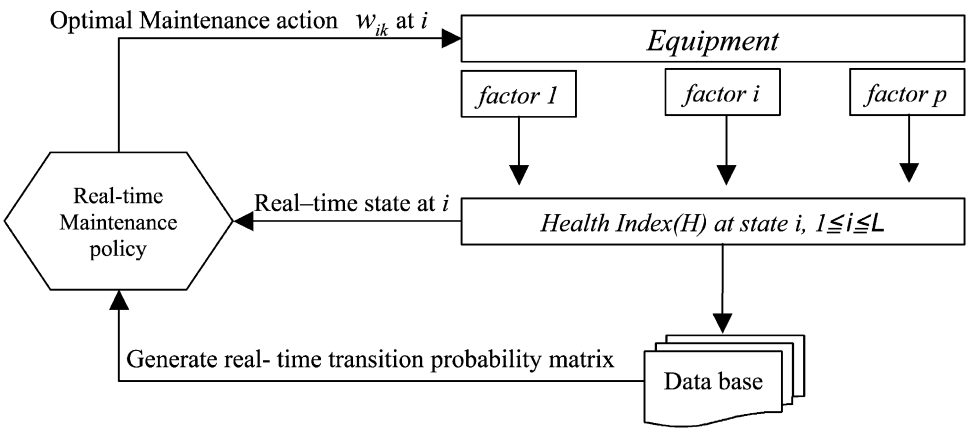

Fig. 1. The diagram of the dynamic preventive maintenance policy.