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Stress-reducing preventive maintenance model for a unit under stressful environment

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ABSTRACT

We develop a preventive maintenance (PM) model for a unit operated under stressful environment. The PM model in this paper consists of a failure rate model and two cost models to determine the optimal PM scheduling which minimizes a cost rate. The assumption for the proposed model is that stressful environment accelerates the failure of the unit and periodic maintenances reduce stress from outside. The failure rate model handles the maintenance effect of PM using improvement and stress factors. The cost models are categorized into two failure recognition cases: immediate failure recognition and periodic failure detection. The optimal PM scheduling is obtained by considering the trade-off between the related cost and the lifetime of a unit in our model setting. The practical usage of our proposed model is tested through a numerical example.

1. Introduction

Some units are exposed to a stressful environment, the stressful environment causes unit failure more often than in general or recommended environment. For example, the PDP-TV monitors installed at the platform of subway stations for providing the transportation information is operating under too much dust and trembling. The dusty and trembling condition in a platform may cause the malfunction of monitors more often than in normal conditions because the dust inside of monitors interrupts heat radiation and the trembling loosens part connections.

For a unit under stressful environment, of necessity, various preventive maintenance (PM) activities for reducing the environmental stress are employed to prevent failure and prolong the unit lifetime. The PDP-TV monitors at the platform of subway stations are also maintained by periodic cleaning and screw-tightening the parts inside of them.

The aim of this paper is to propose a PM model for a unit under stressful environment. In a stressful operating condition, the unit deteriorate more intensively and fail more often than a normal condition [1,2]. Some PM activities are employed to protect the unit from the stressful environment. Those are especially effective when the unit operates under a stressful environment since those work for making the operating condition less stressful. In this paper, we focus on a PM model that reduces the stress of an operating environment but does not change the inherent failure rate of a unit.

The proposed PM model of this paper consists of a failure rate model and two cost models to determine the optimal PM scheduling which minimizes a cost rate. The failure rate model handles the maintenance effect of PM using improvement and stress factors. The improvement factor expresses the degree of improvement by PM, and the stress factor measures the stress of operation environment. The cost models are developed under age-dependent periodic PM policy, in which a unit is preventively maintained at each fixed time point. The cost models are categorized into two failure recognition cases: immediate failure recognition and periodic failure detection. The optimal PM scheduling which is minimizing cost rate is obtained under considering the related cost and parameters in our model setting.

This paper is organized as follows. Section 2 presents the related research literatures and introduces the assumption and the outline of our proposed PM model. Sections 3 and 4 describe the failure rate model and two cost models, respectively. We show some numerical examples of the optimal PM scheduling determination given a Weibull failure distribution in Section 5. Section 6 provides the concluding remarks.

2. Background and assumptions

Maintenance enables the economic operation of a unit. Preventive maintenance (PM) for a unit is provided during the lifetime of the unit, while corrective maintenance (CM) is performed to

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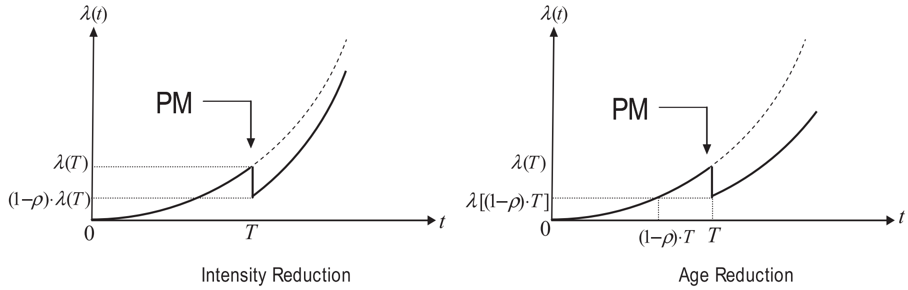

Fig. 1. The concept of intensity reduction and age reduction models.

repair a unit after the unit failure occurred. For the economic operation of a unit, PM as a prior maintenance process pays an attention to the extension of unit lifetime while CM as a posterior maintenance process focuses on the minimization of the unit downtime (recovery time).

Since Barlow and Hunter [3] showed the existence of the economical optimal PM scheduling under two basic PM policies, many authors have been interested in PM modeling to analyze various PM policies [4,5], recently, more complicated PM model considering various maintenance parameters is introduced [6–13].

Many PM models have tried to explain mathematically the effect of PM for determining the optimum of policies. Chan and Downs [14] introduced the concept of imperfect maintenance, which means the condition of a unit after PM becomes younger. Malik [15] proposed the concept of proportional age reduction, Nakagawa [16–18] and Murthy and Nguyen [19] developed the optimal PM policy considering imperfect PM effect. Lie and Chun [20] suggested that the degree of improvement of a unit is expressed as an improvement factor as a policy variable, Nakagwa [18] provided a model reducing intensity and age in sequential imperfect preventive maintenance policies. Doyen and Gaudoin [24] classifies and investigates the intensity reduction and age reduction models.

Fig. 1 shows that the effects of intensity reduction and age reduction which are expressed as the decrement of failure rate by 100ρ percentage where $\rho\,(0 \le \rho \le 1)$ is the improvement factor rate. PM makes a unit as good as new (AGAN) when $\rho = 0$ and as bad as old (ABAO) when $\rho = 1$.

As in previous researches on PM, we assume that the failure rate of a unit decreases after a PM. However, we add the following two assumptions in our proposed PM model. First, a unit operates under stressful environment which accelerates the failure of the unit. Second, the PM in this paper is limited to the activities that only reduce the exogenous stress from working environment.

The first assumption claims that the stressful environment accelerates unit deterioration more intensively than normal environment. Finkelstein [1] introduced a virtual age based on the fact that a unit's deterioration depends on an environment and the corresponding virtual age can be older than the calendar age. Finkelstein [2] applied a statistical virtual age for the accelerated failure test. This assumption implies that this PM model is especially meaningful when the unit is required to operate under stressful environment.

Second, PM can reduce the environmental stress in addition to improving inherent unit conditions to prolong the unit lifetime. PM dealing with the unit itself can improve inherent unit conditions such as part-replacement and overhaul, however, some PM activities are taking care of stresses from outside such as the renewal and cleaning of working condition. Canfield [21] also insisted PM reduces stress and only major PM can change instantaneous level of degradation of the unit. As in the second assumption, we consider the activities dealing with stresses from outside such as cleaning and greasing, but exclude the activities improving the inherent unit condition such as part replacement.

In the accelerated failure model, the relationship between the time to failure under stressful environment, t_s, and the time to failure under normal external environment, t_n, can be represented as [22,23]

$$E[t_n] = kE[t_s], \text{ \& Zero Width Space; \& Zero Width Space; } k > 1, \tag{1}$$

where k is the degree of stress from environment. Eq. (1) implies that the unit under normal environment can work k times longer than the unit under stressful environment. We can set the relationship between the probability distribution functions of random variables t_n and t_s, $F_n(t)$ and $F_s(t)$, respectively, as

$$F_s(t) = F_n(k \times t), \quad k > 1. \tag{2}$$

From Eq. (2), the relationship between the corresponding failure rate functions is obtained as

$$l_s(t) = k \times l_n(k \times t), \quad k > 1 \tag{3}$$

In general, the failure rate of a unit does not decrease with time and the failure rate under stressful environment is larger than that under normal environment.

As afore mentioned, the PM activities in this paper can only reduce the stress from operation environment and do not affect inherent unit conditions so that PM can lower the failure rate of the unit under stressful environment down to the failure rate under normal environment at the most.

3. The failure rate model

In this section, we develop a failure rate model for a unit under stressful environment. The following notations are used throughout this paper.

- t_i ith PM time ($t_0 = 0$)
- $\lambda^i(t)$ failure rate function after the ith PM
- $f^i(t)$ probability density function corresponding to $\lambda^i(t)$
- $\lambda_s(t)$ failure rate function under stressful environment, $\lambda_s(t) = \lambda^0(t)$
- $\lambda_n(t)$ inherent failure rate (under normal environment)
- ρ improvement factor, $0 \le \rho \le 1$
- k stress factor
- T_M PM period
- T_I Inspection period
- C_M PM cost
- C_I Inspection cost
- C_B Breakdown penalty cost
- C_R Replacement cost

When a unit works in stressful environment, the unit has higher failure rate than the unit works in normal environment