

Optimization of the preventive maintenance plan of a series components system

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Abstract

One of the most critical problems in preventive maintenance is the determination of the optimum frequency to perform preventive maintenance in equipment, in order to ensure its availability. In this paper, we propose an algorithm to solve the previous problem for equipment that exhibit linearly increasing hazard rate and constant repair rate. Based on this algorithm, we have developed another one to solve the problem of maintenance management of a series system based on preventive maintenance over the different system components. We assume that all components of the system still exhibit linearly increasing hazard rate and constant repair rate and that preventive maintenance would bring the system to the as good as new condition. We define a cost function for maintenance tasks (preventive and corrective) for the system. The algorithm calculates the interval of time between preventive maintenance actions for each component, minimizing the costs, and in such a way that the total downtime, in a certain period of time, does not exceed a predetermined value.

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1. Introduction

A brief bibliographic review (Andrews and Moss [1], Elsayed [2], McCormick [3] and Modarres et al [4]), is enough to conclude that the discipline known as reliability was developed to provide methods that can guarantee that any product or service will function efficiently when its user needs it. From this point of view, reliability theory incorporates techniques to determine what can go wrong, what should be done in order to prevent that something goes wrong, and, if something goes wrong, what should be done so that there is a quick recovery and consequences are minimal.

So, reliability has several meanings. However, it is usually associated with the ability of a system to perform successfully a certain function. To measure quantitatively the reliability of a system a probabilistic metric, which we state next, is used.

Reliability of a system is the probability that a system will operate without failure for a stated period of time under specified conditions.

Another measure of the performance of a system is its availability that reflects the proportion of time that we expect it

to be operational. Availability of a system is the probability to guarantee the intended function, that is, the probability that the system is normal at time t . The availability of a system is a decreasing function of the failure rate and it is an increasing function of the repair rate.

According to Elsayed [2], reliability of a system depends mainly on the quality and reliability of its components and in the implementation and accomplishment of a suitable preventive maintenance and inspection program. If failures, degradation and aging are characteristics of any system, however, it is possible to prolong its useful lifetime and, consequently, delay the wear-out period carrying out maintenance and monitoring programs.

This type of programs leads necessarily to expenses and so we are taken to a maintenance optimization problem.

The main function of planned maintenance is to restore equipment to the 'as good as new' condition; periodical inspections must control equipment condition and both actions will ensure equipment availability. In order to do so it is necessary to determine:

1. Frequency of the maintenance, substitutions and inspections.
2. Rules of the components replacements.
3. Effect of the technological changes on the replacement decisions.

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4. The size of the maintenance staff.
5. The optimum inventory levels of spare parts.

There are several strategies for maintenance; the one we have just described and that naturally frames in what has been stated is known as Reliability Centered Maintenance—RCM. Gertsbakh [5] reviews some of the most popular models of preventive maintenance.

In theory, maintenance management, facing the problems stated above, could have benefited from the advent of a large area in operations research, called maintenance optimization. This area was founded in the early sixties by researchers like Barlow and Proschan. Basically, a maintenance optimization model is a mathematical model in which both costs and benefits of maintenance are quantified and in which an optimal balance between both is obtained. Well-known models originating from this period are the so-called age and the block replacement models.

Valdez-Flores and Feldman [6] present a comprehensive review of these approaches. Dekker [7] gives an overview of applications of maintenance optimization models published so far and Duffuaa [8] describes various advanced mathematical models in this area that have ‘high potential of being applied to improve maintenance operations’.

As we have mentioned already, one of the most critical problems in preventive maintenance is the determination of the optimum frequency to perform preventive maintenance in equipment, in order to ensure its availability. In this paper, we propose an algorithm to solve the previous problem for equipments that exhibit linearly increasing hazard rate and constant repair rate. Based on this algorithm, we have developed another one to optimize maintenance management of a series system based on preventive maintenance over the different system components. This is a problem with many applications in real systems and there are not many practical solutions for it. We assume that all components of the system still exhibit linearly increasing hazard rate and constant repair rate and that preventive maintenance would bring the system to the as good as new condition. We define a cost function for maintenance tasks (preventive and corrective) for the system. The algorithm calculates the interval of time between preventive maintenance actions for each component, minimizing the costs, and in such a way that the total downtime, in a certain period of time, does not exceed a predetermined value.

Duarte and Craveiro [9] presented a formulation for this problem but in a different frame. They have developed an algorithm for the maintenance management of a series system based on preventive maintenance over the different system components, in order to guarantee a pre-determinate reliability level.

2. Previous concepts and results

In this section, we present the classical concept of availability, while describing how to calculate it.

Pointwise availability of a system at time t , $A(t)$, is the probability of the system being in a working state (operating

properly) at time t . The unavailability of the system, $Q(t)$, is $Q(t) = 1 - A(t)$.

The pointwise availability of a system that has constant failure rate λ and constant repair rate μ is

$$A(t) = \frac{\mu}{\mu + \lambda} + \frac{\lambda}{\mu + \lambda} \exp[-(\mu + \lambda)t] \tag{1}$$

and the limiting availability is

$$A = \lim_{t \rightarrow +\infty} A(t) = \frac{\mu}{\mu + \lambda} \tag{2}$$

The second term in formula (1) decreases rapidly to zero as time t increases; therefore we can state

$$A(t) \approx \frac{\mu}{\mu + \lambda}$$

and this means that the availability of such a system is almost constant.

2.1. Example

A system is found to exhibit a constant failure rate of 0.000816 failures per hour and a constant repair rate of 0.02 repairs per hour.

Using formula (1), the availability of such a system (see Fig. 1) is obtained as

$$A(t) = 0.9608 + 3.9201 \times 10^{-2} \exp(-2.0816 \times 10^{-2} t)$$

and the limiting availability is

$$\lim_{t \rightarrow \infty} A(t) = 0.9608 \quad \blacksquare$$

It should be noticed that, this case, we do not have almost any variation in the value of component’s availability for $t > 200$.

We can therefore conclude that, to guarantee a value of availability A , known the constant repair rate, μ , the value of the constant failure rate of the system it will have to satisfy the relationship

$$A \approx \frac{\mu}{\mu + \lambda} \Leftrightarrow \lambda \approx \frac{\mu(1 - A)}{A} \tag{3}$$

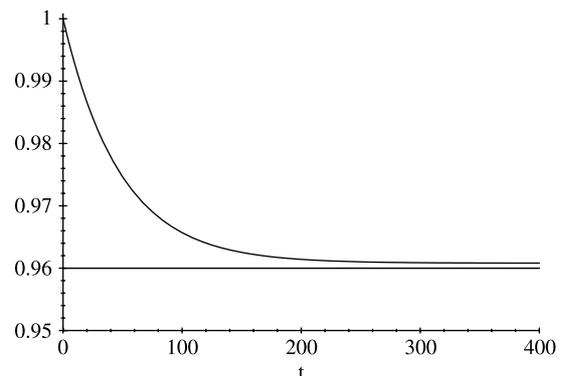


Fig. 1. The availability function.

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