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Prevent Maintenance in a Series System: The Uptime, Downtime and Costs

[1]R. Sivaraman, [2]Dr. Sonal Bharti
[1]Ph.D. Research Scholar in Mathematics, [2]Head, Department of Mathematics
Sri Satya Sai University of Technology and Medical Sciences, Bhopal, Madhya Pradesh

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Abstract - To reduce the system down time, failed spare units can replace units in repairable systems with redundancy Repairmen or manufacturer attends the failed units for corrective maintenances. Failed units are returned for re - use. In this chapter, we consider a series system with spares and we assume that repaired units are as good as new. Since, preventive maintenance will take less time and tends to be cheaper. It can be profitable to perform preventive maintenance in order to return it to its as good as new state in the situation of increasing failure rates. In this mode, we use age - replacement policy for machines If the age or a machine has reached a certain value M_{pm}, it is taken out for preventive maintenance and replaced by a spare unit. Here we derive an approximation scheme to calculate the expected uptime, the expected downtime and the expected costs per time unit of the system given the total number or units.

Keywords: Exponential Distribution, Expected Downtime cost, Preventive Maintenance Costs, Different overhaul costs.

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1. INTRODUCTION

In this paper, we consider a series system of order s with N spares. It is assumed that spares do not fail while in storage. Here we will find out preventive maintenance in a series system or order s with N spares older units fail frequently and their running costs increase with age, If any unit or series system of order s has exceeded a certain age, we replace it by n spare unit and the replaced unit is then recommended for preventive overhaul If the unit fails before it has reached the age at which it is replaced, a corrective overhaul is performed. It is assumed that compensation is made in the running costs for minor failures for which a minimal repair is done.

Preventive overhaul might be cheaper because it can be planned while failure might be costly and dangerous during operation. Performing preventive maintenance because it takes substantially less time than corrective maintenance can increase the expected up time. Possible running costs can be controlled also 1w performing preventive maintenance.

Many studies describe some of the characteristics of the 1 out of n system with different assumptions underlying the derivations or exact and approximate formulae. The assumptions are made often memory less properties within the system. For example, Brouwers assumes exponential failure time and repair time distributions to derive probabilistic descriptions of irregular system downtime and Vander Heijden assumed exponential repair times to derive a scheme to calculate approximations for the reliability.

These assumptions can have a bad effect on the performance of the model. Smith and Dekker compared the performance of their model with an exponential model. It assumed that the repair time has an exponential distribution and there is a constant failure rate up to the time of preventive maintenance for the approximation of the availability. They derived the uptime and downtime of a 1 out of 2 system with Markovian degrading units. Here preventive maintenance is carried out if the state of the operating unit exceeds a certain threshold.

In our model we assume that preventive and corrective overhaul each takes a constant time and there is always sufficient capacity (no queuing), we consider constant costs for preventive maintenance and corrective maintenance where corrective maintenance is highest. Variable downtime costs and age dependent running costs are assumed. We have to determine the age of a unit should be replaced for preventive maintenance to minimize the long run average costs.

2. THE DESCRIPTION OF THE SYSTEM AND NOMENCLATURE

We consider a series system of order s with N spares. It is assumed that spares do not fail while in storages, we suppose that the lifetime distribution of a unit, f (T), has an increasing failure rates. Any operating unit of the series system of order s is replaced immediately by a spare unit if it has reached a certain age M_{pm} and preventive maintenance is performed on the unit. A corrective overhaul is performed if a unit fails before M_{pm}. A unit will be as good as new after a preventive maintenance or a corrective maintenance.

Costs play an important role in the model. Let the constant costs C and C for a corrective maintenance and a preventive maintenance respectively. We assume that there are variable costs for downtime C_d and the age dependent running costs Cr (T) where T is the age of unit.. The purpose of the model is to compute the optimal moment for preventive maintenance M_{pm} with respect to the long run average costs and the optimal number of standby units (spare units).

Some important notations are listed below:

PM : Preventive maintenance,
CM : Corrective maintenance,
T : Age of an operating unit,

f(T) : Probability of failure before age T,
M_{pm} : The age at which a unit is replaced preventively,
U_{pm} : Time required maintaining a unit preventively,
U_{cm} : Time required maintaining a unit preventively,
U : Maintenance time if $U_{pm} = U_{cm}$
C_p : Constant costs for a preventive maintenance,
C_c : Constant costs for a corrective maintenance,
C_d : Costs for system downtime per unit of time,
C_r (T) : Running costs at age T,
S_{up} : Uptime of the system (random variable),
S_{down} : Downtime of the system (random variable).

3. THE EXPECTED UPTIME OF THE SYSTEM

We assume that preventive maintenance time U_{pm} and corrective maintenance time U_{cm} are both equal to U *i* .e. U_{PM} U_{cm} = U. We consider the decision moment M_{pm} to account for preventive maintenance. If any operating unit out of s units reaches the at the age M_{pm}, we replace it for performing preventive maintenance.

The distribution functions of the failure time of any unit as follows:

$$f_{Mpm}(T) = \begin{cases} f(T) & T \le M_{pm}, \\ 1 & T > M_{pm}. \end{cases}$$

Assume that the system *is* up for some time and s new units start operating in series at these particular moments. The probability that the system will run smoothly for another T times units is equal to the probability that all operating units will reach age T plus the probability that if any unit out of s units fails after **t** times units (t < T) it is replaced by spare unit which keeps the system up together with other units until time T. Operating points are assumed as renewal points at which a unit starts. If any operating unit fails with age **t,** then the probability that a spare unit is available, will be equal to the probability that N - I units have kept the system in running state for longer than U - **t** time units such that at least the N^{th} unit that failed before the last unit is now available.

Here the reliability of the system can be written approximately as

$$P\{S_{up} > T\} \approx \sum_{i=l}^{S}\left(1 - f_{iM_{pm}}(T)\right) + \int_0^T \sum_{i=1}^{S}\left(1 - f^{*(N-1)}{}_{iM_{pm}}(U-t)\right) P\{S_{up} > T-t\}.\,df_{M_{pm}}(t)$$

And hence

$$E[S_{up}] = \int_0^\infty P\,\{S_{up} > T\}dT \approx \int_0^\infty \{\sum_{i=1}^{S}\left(1 - f_{iM_{pm}}(T)\right) + \int_0^T \sum_{i=1}^{S}\left(1 - f^{*(N-1)}{}_{iM_{pm}}(U-t)\right) P\{S_{up} > T-t\}.\,df_{M_{pm}}(t)$$

$$= \sum_{i=1}^{S} L_{iM_{pm}} + \int_0^\infty \int_t^\infty \sum_{i=1}^{S}\left(1 - f^{*(N-1)}{}_{iM_{pm}}(U-t)\right) P\,\{S_{up} > T-t\}dT.\,df_{M_{pm}}(t)$$

$$= \sum_{i=1}^{S} L_{iM_{pm}} + E[S_{up}]\sum_{i=1}^{S}\left(1 - f^{*(N)}{}_{iM_{pm}}(U)\right).\,E[S_{up}][1 - \sum_{i=1}^{S}\left(1 - f^{*(N)}{}_{iM_{pm}}(U)\right) = \sum_{i=1}^{S} L_{iM_{pm}}$$

Or

$$E[S_{up}] = \frac{\sum_{i=1}^{S} L_{iM_{pm}}}{1 - \sum_{i=1}^{S}\left(1 - f^{*(N)}{}_{iM_{pm}}(U)\right)}$$

Where expected lifetime of a unit L_{Mpm} is defined as

$$L_{M_{pm}} = \int_0^\infty \left[1 - L_{M_{pm}}(t)\right] dt = \int_0^{L_{M_{pm}}} \left[1 - L_{M_{pm}}(t)\right] dt,$$

Here sign *N indicates a N-fold convolution.

$$f^{N}{}_{M_{pm}}(U) = \int_0^U f^{*(N-1)}{}_{M_{pm}}(U-t)\,df_{M_{pm}}(t), \qquad N = 1, 2, 3, \ldots$$

And

$$f^{*(0)}(T) = \begin{cases} 1 & \text{if } T > 0 \\ 0 & \end{cases}$$

if T≤ 0

4. THE EXPECTED DOWNTIME

We assume that if at any moment there are less than s units in the system then system downtime starts i.e. ir the system has been up for more than U time units, the system downtime begins. If the uptime of the past N failures together have been less than U-T, then the downtime will be greater than T if the system fail suddenly. Hence the probability of downtime can be defined approximately as follows:

$$P\{S_{down} > T\} \approx \sum_{i=1}^{S} f^{*N}{}_{iM_{pm}}(U-t) / \sum_{i=1}^{S} f^{*N}{}_{iM_{pm}}(U)$$

and hence

$$E\{S_{down}\} \approx \int_0^U \sum_{i=1}^{S} f^{*N}{}_{iM_{pm}}(U-t) / \sum_{i=1}^{S} f^{*N}{}_{iM_{pm}}(U) \ldots (2)$$

The Expected Costs Per Time Unit:

Units may be considered for preventive and corrective maintenance during the uptime or the system. $f_{M_{pm}}(M_{pm})$ and 1- $f_{M_{pm}}(M_{pm})$ will be long-term proportions of these two types of maintenance for corrective maintenance and preventive maintenance. The expected number of times that a unit has failed or reached the age M_{pm} until the arbitrary time E [S_{up}**]** is approximately equal to the expected number of times that either preventive maintenance or corrective maintenance will be carried out during the up-cycle (say $Q_{M_{pm}}$**).** Thus

$$Q_{M_{pm}} \approx \sum_{n=1}^{\infty} f^{*N}{}_{iM_{pm}}(E[S_{up}]) \approx \frac{E[S_{up}]}{L_{M_{pm}}}$$

Now we define renewals as the times at which an uptime starts. Hence the expected costs per unit of time in the long run are equal to the expected costs per renewal cycle divided by the expected duration of a renewal cycle according to the renewal reward theory. So due to preventive maintenance (C_p), corrective maintenance (C_c) and downtime (C_d), the approximation for the long run average costs becomes.

$$\frac{\left(C_c \sum_{i=1}^{S} f_{iM_{pm}}(M_{pm}) + C_p \sum_{i=1}^{S}(1 - f_{iM_{pm}}(M_{pm}))\right) Q_{M_{pm}} + C_d E[S_{down}]}{E[S_{up}] + E[S_{down}]}$$

If we consider that there are running costs dependent on the age or .he operating units then the moment at which we replace any operating unit out of s units influences the average running costs, we suppose that C_r (T) is the marginal running costs if a unit has age T, then during an uptime the average running costs per unit are

$$\frac{1}{L_{M_{pm}}} \int_0^{\infty} C_r(T)\left\{1 - f_{M_{pm}}(T)\right\} dT.$$

Hence the total long - run average costs can be defined approximately as follows:

$$\frac{\left(C_c \sum_{i=1}^{S} f_{iM_{pm}}(M_{pm}) + C_p \sum_{i=1}^{S}(1 - f_{iM_{pm}}(M_{pm}))\right) Q_{M_{pm}} + C_d E[S_{down}] + Q_{M_{pm}} \int_0^{\infty} C_r(T)\left\{1 - f_{M_{pm}}(T)\right\} dT.}{E[S_{up}] + E[S_{down}]}$$

Different Overhaul Times:

Now we assume two different repair times:

U_{cm} for corrective maintenance and U_{pm} for preventive maintenance, with condition $U_{cm} < U_{pm} + M_{pm}$.

The expected uptime becomes

$$E[S_{up}] \approx \frac{\sum_{i=1}^{S} L_{iM_{pm}}}{1 - \sum_{i=1}^{S}\left[1 - \left\{f_i(M_{pm}) f^{*N}{}_{iM_{pm}}(U_{cm}) + \left(1 - f_i(M_{pm})\right) f^{*N}{}_{iM_{pm}}(U_{pm})\right\}\right]}$$

In a similar fashion, the expected downtime can be written approximately as follows:

$$E[S_{down}] \approx \frac{\int_0^U \sum_{i=1}^{S} f_{iM_{pm}}{}^{*N}(U-T)\, dT}{\sum_{i=1}^{S} f_i(M_{pm}) f_{iM_{pm}}{}^{*N}(U_{cm}) + \sum_{i=1}^{S}(1 - f_i(M_{pm}))\, f_{iM_{pm}}{}^{*N}(U_{pm})}$$

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