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Cost benefit study of two-unit system with dual maintenance under guarantee period

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Abstract

This paper explain stochastic model having dual non-identical units. Here a routine inspection is carried out on the operating unit after doing a normal maintenance. It is also assumed that the operative unit is inspected if another unit is failed. After inspection either the unit is maintained or assumed to be failed after inspection. The decisions about failed unit is done by taking the concept of guarantee period. It is also considered that the unit under maintenance would not fail. After guarantee period, it is to be decided that whether minor replacement or major replacement. A new concept of paid maintenance is taken in this second part. This system is analyzed to determine various reliability measures by using mathematical tools MTSF/MTBF Markov chain, Markov Process. It is assumed that a repaired and replaced unit is good as new.

Keywords: Maintenance, Availability, Busy period, Inspection, Repair,Replacement

INTRODUCTION

In order to develop a good reliability program for a system, the system must have good reliability specifications. These specification most, if not all, of the conditions in the reliability definition including MTSF, limitations, operating environment instances, this will require a detailed description of how the system is expected to perform reliability- wise. A proper balance of financial goals and realistic performance are necessary to develop a detailed and balanced reliability specification. Another important foundation for a reliability program is the development of universally agreed upon definitions of the system failure. It should be fairly obvious whether a product has failed or not.

Reliability testing is the cornerstone of a reliability program. It provides the most detailed forms of data in that the data are collected can be carefully controlled and monitored. Furthermore, the reliability tests can be designed to uncover suspected failure modes and other problems.

The development of the new systems is directly or indirectly associated with improvement in the old systems and hence the efficiency. Thus assessment of reliability of equipment is of great importance in the context of rapidly growing technology and its further development. A large number of studies have been carried out to evaluate the reliability by taking two-unit models under different conditions.

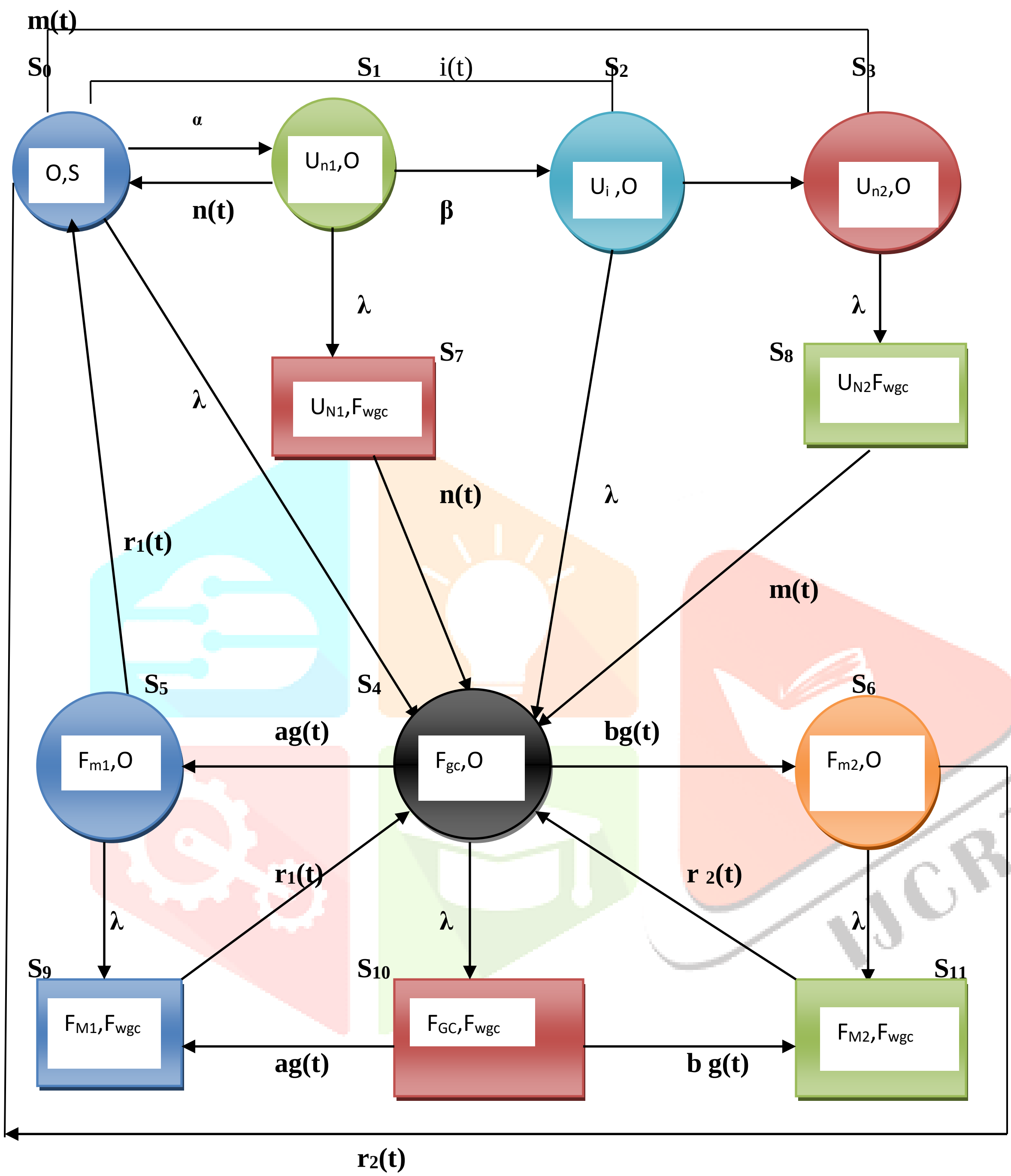
This paper explain stochastic model having dual non-identical units. Here a routine inspection is carried out on the operating unit after doing a normal maintenance. It is also assumed that the operative unit is inspected if another unit is failed. After inspection either the unit is maintained or assumed to be failed after inspection. The decisions about failed unit is done by taking the concept of guarantee period. It is also considered that the unit under maintenance would not fail. After guarantee period, it is to be decided that whether minor replacement or major replacement. A new concept of paid maintenance is taken in this second part. This system is analyzed to determine various reliability measures by using mathematical tools MTSF/MTBF Markov chain, Markov Process. It is assumed that a repaired and replaced unit is good as new.

Description of system and Assumption:-

In this paper, an operative unit is analyzed after a bound or definite period of its functioning and it is decided whether unit can run further or demand certain maintenance. A new concept of normal maintenance and major maintenance are introduced in this part.

- The system consists of two indistinguishable units - Initially one unit is functional and second unit is kept as cold standby.
- System is supposed to be in Up-state if one unit is working and in down state if no unit is working.
- Each unit of the system has two stages - normal operative or failed.
- Firstly working unit is analyzed for normal maintenance before taken routine inspection.
- After routine inspection it is to be decided that whether the unit needs major maintenance or the unit is unsuccessful under guarantee period.
- A unit under maintenance would not fail.
- Check the guarantee of the failed unit, either it is in under the guarantee period or not.
- If the unit is in the guarantee period, the failed unit is minor maintenance and if the unit is not under the guarantee period then it is major maintenance.

State Transition Diagram



Notations

U_{n1}:	Normal maintenance
α :	Invariant normal maintenance rate of unit
i(t):	pdf of inspection time period of a unsuccessful unit
I(t):	cdf of inspection time period of a unsuccessful unit
β :	probability that unit is in under maintenance
U_i	Invariant inspection rate of unit
$U_{M1}U_{M2}$:	Maintenance of unit is continuous
F_{m1}:	unsuccessful unit under minor maintenance
F_{m2}:	unsuccessful unit under major maintenance
F_{gc}:	unsuccessful unit under guarantee check
F_{wgc}:	unsuccessful unit waiting for guarantee check
m(t)	Maintenance rate
$r_1(t)$	Minor maintenance rate
$r_2(t)$	Major maintenance rate
A:	$\{1- m^*(\lambda)\}$
B:	$\{1- g^*(\lambda)\}$
C:	$\{1- r_1^*(\lambda)\}$
D:	$\{1- r_2^*(\lambda)\}$

The system can be in any of the following states with respect of the above symbol RS_0 = (O,S) RS_1 = (U_{n1},O)

RS_2 = (U_i, O) RS_3 = (F_{n2},O)

RS_4 = (F_{gc},O) RS_5 = (F_{m1}, O)

RS_6 = (F_{m2}, O) RS_7 = (F_{N1}, F_{wgc})

RS_8 = (F_{N2}, F_{wgc}) RS_9 = (U_{M1}, F_{wgc})

RS_{10} = (F_{M2}, F_{wgc}) RS_9 = (F_{GC}, F_{wgc})

Transition Probabilities

The era of entering into states $\{RS_0, RS_1, RS_2, RS_3, RS_4, RS_5, RS_6\}$ are Renewed states. The change of state probabilities from RS_k to RS_l states are given by Q_{kl} and in the steady states Tp_{kl} denotes the change of state probability from states RS_k to RS_l are given under

Tp_{01} = $\alpha/(\alpha+\lambda)$ Tp_{04} = $\lambda/(\alpha+\lambda)$

Tp_{10} = $n*(\beta+\lambda)$ Tp_{12} = $\beta\{1- n^*(\beta+\lambda)\}/((\beta+\lambda))$

Tp_{17} = $\lambda\{1- n^*(\beta+\lambda)\}/((\beta+\lambda))$ Tp_{20} = $i*(\gamma+\lambda)$

Tp_{23} = $\gamma\{1- n^*(\gamma+\lambda)\}/((\gamma+\lambda))$ Tp_{12} = $\lambda\{1- n^*(\gamma+\lambda)\}/((\gamma+\lambda))$

Tp_{30} = $m^*(\lambda)$ Tp_{38} = A

$Tp_{1}{}^{7}{}_{4}$ = $\lambda\{1- n^*(\beta+\lambda)\}/((\beta+\lambda))$ $Tp_{3}{}^{8}{}_{4}$ = A

Tp_{45} = $ag^*(\lambda)$ Tp_{46} = $bg^*(\lambda)$

$Tp_{4,10}$ = B $Tp_{4}{}^{10,9}{}_{4}$= B

$Tp_{4}{}^{10,11}{}_{4}$= B Tp_{50} = $r_1^*(\lambda)$

Tp_{59} = C $Tp_{5}{}^{9}{}_{4}$ = C

Tp_{60} = $r_2^*(\lambda)$ $Tp_{6}{}^{11}{}_{4}$ = D

$Tp_{6,11}$ = D

With the help of following calculated values, we can easily check that

$$Tp_{01} + Tp_{04} = 1$$
$$Tp_{10} + Tp_{12} + Tp_{17} = 1$$
$$Tp_{20} + Tp_{23} + Tp_{24} = 1$$
$$Tp_{30} + Tp_{38} = 1$$
$$Tp_{17} = Tp_{1}{}^{7}{}_{4}$$
$$Tp_{38} = Tp_{3}{}^{8}{}_{4}$$
$$Tp_{45} + Tp_{46} + Tp_{4,10} = 1$$
$$Tp_{4'10} = Tp_{4}{}^{10,9}{}_{4}$$
$$Tp_{4'10} = Tp_{4}{}^{10,11}{}_{4}$$
$$Tp_{50} + Tp_{59} = 1$$
$$Tp_{59} = Tp_{5}{}^{9}{}_{4}$$
$$Tp_{60} + Tp_{6,11} = 1$$
$$Tp_{6'11} = Tp_{6'}{}^{11}{}_{4}$$

Mean Sojourn Times

To compute mean value of stay/sojourn time $\mu_k(t)$ for state RS_k, let T_k be sojourn time for state RS_k. Then

$$\mu_k(t) = \lim_{t\to\infty} \int_0^t P[t : 0 < t < T]dt$$

So that in steady state we have following relations

$\mu_0 = 1/\alpha+\lambda$ $\mu_1 = \{1 - n^*(\beta+\lambda)\}/(\beta+\lambda)$

$\mu_2 = \{1 - i^*(\gamma+\lambda)\}/(\gamma+\lambda)$ $\mu_3 = A/\lambda$

$\mu_4 = B/\lambda$ $\mu_5 = C/\lambda$

$\mu_6 = D/\lambda$

The unconditional mean time is mathematically given by

$$m_{kl} = \int_0^\infty tdQ_{kl}(t) = -q_{kl}{}^{*}(s)'/_{at\ s=0}$$

So that

$m_{01} = \alpha/(\alpha+\lambda)^2$ $m_{04} = \lambda/(\alpha+\lambda)^2$

$m_{10} = -n^{*'}(\beta+\lambda)$

$m_{12} = [\beta\{1 - n^*(\beta+\lambda)\}/(\beta+\lambda)n^2] + \beta n^{*'}(\beta+\lambda)/(\beta+\lambda)$

$m_{17} = [\lambda\{1 - n^*(\beta+\lambda)\}/(\beta+\lambda)n^2] + \lambda n^{*'}(\beta+\lambda)/(\beta+\lambda)$

$m_{20} = -i^{*'}(\gamma+\lambda)$

$m_{23} = [\gamma\{1 - i^*(\gamma+\lambda)\}/(\gamma+\lambda)^2] + \gamma i^{*'}(\gamma+\lambda)/(\gamma+\lambda)$

$m_{24} = [\lambda\{1 - i^*(\gamma+\lambda)\}/(\gamma+\lambda)^2] + \gamma i^{*'}(\gamma+\lambda)/(\gamma+\lambda)$

$m_{30} = -m^{*'}(\lambda)$ $m_{38} = A/\lambda - m^{*'}(\lambda)$

$m_{45} = -ag^{*'}(\lambda)$ $m_{46} = -bg^{*'}(\lambda)$

$m_{4,10} = A/\lambda - g^{*'}(\lambda)$ $m_{50} = -r_1{}^{*'}(\lambda)$

$m_{59} = C/\lambda - r_1{}^{*'}(\lambda)$ $m_{60} = -r_2{}^{*'}(\lambda)$

$m_{6,11} = D/\lambda - r_2{}^{*'}(\lambda)$

It can be easily verified that

$$m_{01} + m_{04} = \mu_0$$
$$m_{10} + m_{12} + m_{17} = \mu_1$$
$$m_{20} + m_{23} + m_{24} = \mu_2$$
$$m_{30} + m_{38} = \mu_3$$
$$m_{40} + m_{46} + m_{4,10} = \mu_4$$
$$m_{50} + m_{59} = \mu_5$$
$$m_{60} + m_{6,11} = \mu_6$$

Mean Time to System Failure

The recursive relations for (MTSF) are given by the following equations

$$\Omega_0 = Q_{01} \odot \Omega_1 + Q_{04} \odot \Omega_4$$
$$\Omega_1 = Q_{10} \odot \Omega_0 + Q_{12} \odot \Omega_2 + Q_{17}$$
$$\Omega_2 = Q_{20} \odot \Omega_0 + Q_{23} \odot \Omega_3 + Q_{24} \odot \Omega_4$$
$$\Omega_3 = Q_{30} \odot \Omega_0 + Q_{38}$$
$$\Omega_4 = Q_{45} \odot \Omega_5 + Q_{46} \odot \Omega_6 + Q_{4,10}$$
$$\Omega_5 = Q_{50} \odot \Omega_0 + Q_{59}$$
$$\Omega_6 = Q_{60} \odot \Omega_0 + Q_{6,11}$$

Here Ω_i and q_{kl} are all function of t

Above these equation can be Solving by taking L. S.T and solving for $\Omega_0^{**}(s)$,

we get $\Omega_0^{**}(s) = U(s) / V(s)$

Where

$$\text{MTSF} = \Omega_0 = \lim_{s\to 0}[\{1-\Omega_0^{**}(s)\}/s]$$
$$= \{V'(0)-U'(0)\}/V(0)$$
$$= \frac{U}{V}$$

After solving, we have

$$U(s) = -[\, q_{01}\, q_{17} + q_{01}\, q_{12} q_{23} q_{38} + q_{01}\, q_{12}\, q_{24}\, q_{4,10} + q_{01}\, q_{12}\, q_{24}\, q_{45} q_{59} + q_{01}\, q_{12}\, q_{24} q_{46}\, q_{6,11} + q_{04}\, q_{4,10} + q_{04}\, q_{45}\, q_{59} + q_{04}\, q_{46}\, q_{6,11}\,]$$

$$V(s) = -1 + q_{01}\, q_{10} + q_{01}\, q_{12} q_{20} + q_{01}\, q_{12}\, q_{23}\, q_{30} + q_{01}\, q_{12}\, q_{24}\, q_{45} q_{50} + q_{01}\, q_{12}\, q_{24} q_{46}\, q_{60} + q_{04}\, q_{45}\, q_{50} + q_{04}\, q_{46}\, q_{60}\,]$$

Where

$$U = V'(0)-U'(0) = -[\,1+Tp_{01}\,\mu_1 + Tp_{01}\, Tp_{12}\,\mu_2 + Tp_{01}\, Tp_{12}\, Tp_{23}\mu_3 + (Tp_{04}+Tp_{01}\, Tp_{12}\, Tp_{24})(\mu_5+Tp_{45}\mu_5+Tp_{46}\mu_6)]$$

$$V = V(0) = -1+Tp_{01}\, Tp_{10} + Tp_{12}\, Tp_{01}\,(Tp_{20} + Tp_{23}\, Tp_{30}) - (Tp_{01}\, Tp_{12}\, Tp_{24} + Tp_{04})(Tp_{45}\, Tp_{50} + Tp_{46}\, Tp_{60})$$

Availability of the system -(A*v*)-

The recursive relations for the availability $Av_i(t)$ at each point of the system is given by

$$Av_0 = q_{01}\ \Delta\ Av_1 + q_{04}\ \Delta\ Av_2 + \Psi_0$$
$$Av_1 = q_{10}\ \Delta\ Av_0 + q_{12}\ \Delta\ Av_2 + q_1{}^7{}_4\ \Delta\ Av_4 + \Psi_1$$
$$Av_2 = q_{20}\ \Delta\ Av_0 + q_{23}\,\Delta\ Av_3 + q_{24}\ \Delta\ Av_4 + \Psi_2$$
$$Av_3 = q_{30}\ \Delta\ Av_0 + q_3{}^8{}_4\,\Delta\ Av_4 + \Psi_3$$
$$Av_4 = q_{45}\ \Delta\ Av_5 + q_{46}\ \Delta\ Av_6 + (q_4{}^{(10,9)}{}_3 + q_4{}^{(10,11)}{}_4)\ \Delta\ Av_4 + \Psi_4$$
$$Av_5 = q_{50}\ \Delta\ Av_0 + q_5{}^{(9)}{}_4\,\Delta\ Av_4 + \Psi_5$$
$$Av_6 = q_{60}\ \Delta\ Av_0 + q_6{}^{(11)}{}_4\,\Delta\ Av_3 + \Psi_6$$

Here Av_i, Ψ and q_{kl} are all function of t

Where $\Psi_0 = \mu_0$ $\Psi_1 = \mu_1$

$\Psi_2 = \mu_2$ $\Psi_3 = \mu_3$

$\Psi_4 = \mu_4$ $\Psi_5 = \mu_5$

$\Psi_6 = \mu_6$

Now solving these equations by taking Laplace transform and solving for $Av_0^*(s)$,we get

$$Av_0^*(t) = U_1(s)/V_1(s)$$

The steady states availability is given by

$$Av_0^{**} = U_1(0) / V_1(0)$$

Where

$U_1(0) = -[\{\mu_0+\mu_1 Tp_{01}+(Tp_{12}\ Tp_{01}+Tp_{04})\mu_2 + (Tp_{12}\,Tp_{01}\,Tp_{23}+\ Tp_{04}\,Tp_{23})\mu_3\}+(Tp_{45}\,Tp_{50} + Tp_{46}\,Tp_{60}) +(\mu_4+Tp_{45}\,\mu_5+Tp_{46}\mu_6)\ \{(Tp_{23}\,Tp_3{}^8{}_4(Tp_{12}+Tp_{01}+Tp_{04}) \quad +Tp_{01}(Tp_{12}\,Tp_{24}+ Tp_1{}^7{}_4\ \}]$

And $V_1(0)=0$

$V_1'(0) = -\ [(1+Tp_{01}\,Tp_{12} + \mu_0\,(Tp_{01}\,Tp_{12}\,Tp_{23}+ Tp_{04}\,Tp_{23})\mu_3)\ (Tp_{45}\,Tp_{50}+Tp_{46}\,Tp_{60}) + (Tp_{01}\,Tp_{12}\,Tp_{23}\,Tp_3{}^8{}_4 + Tp_{01}\,Tp_{12}\,Tp_{24} + Tp_{01}\,Tp_1{}^7{}_4+ Tp_{04}\,Tp_{23}\,Tp_3{}^8{}_4 + Tp_{04}\,Tp_{24})$
$(\mu_4+ Tp_{45}\mu_5 + Tp_{46}\mu_6)$ ……………………………….(a)

Normal Maintenance Time

The recursive relations are

$Nm_0 = q_{01}\ \Delta\ Nm_1 + q_{04}\ \Delta\ Nm_2$

$Nm_1 = q_{10}\ \Delta\ Nm_0 + q_{12}\ \Delta\ Nm_2 + q_1{}^7{}_4\ \Delta\ Nm_4 + \tilde{N}$

$Nm_2 = q_{20}\ \Delta\ Nm_0 + q_{23}\,\Delta\ Nm_3 + q_{24}\,\Delta\ Nm_4$

$Nm_3 = q_{30}\ \Delta\ Nm_0 + q_3{}^8{}_4\,\Delta\ Nm_4$

$Nm_4 = q_{45}\ \Delta\ Nm_5 + q_{46}\,\Delta\,Nm_6 + (q_4{}^{(10,9)}{}_3 + q_4{}^{(10,11)}{}_4)\ \ \Delta\ Nm_4$

$Nm_5 = q_{50}\ \Delta\ Nm_0 + q_5{}^{(9)}{}_4\,\Delta\ Nm_4$

$Nm_6 = q_{60}\ \Delta\ Nm_0 + q_6{}^{(11)}{}_4\,\Delta\ Nm_3$

Here Nm_i ,Ñ and q_{kl} are all function of t

Now solving these equations by taking Laplace transform and find $¶_0^*(s)$, we get

$¶_0^*(s) = U_2(s)/V_1(s)$

Then for steady states

$$¶_0^{**} = \lim_{s\to 0}\ (s¶_0^*(s)) = U_2(0) / V_1`(0)$$

Where $U_2(0) = -\ \tilde{N}\ Tp_{01}(Tp_{45}\,Tp_{50}+ Tp_{46}\,Tp_{60})$

$V_1'(0)$ is specified in eq. (a).

Paid Maintenance Time

The recursive relations are

$Mm_0 = q_{01}\ \Delta\ Mm_1 + q_{04}\ \Delta\ Mm_2$

$Mm_1 = q_{10}\ \Delta\ Mm_0 + q_{12}\ \Delta\ Mm_2 + q_1{}^7{}_4\ \Delta\ Mm_4 + £$

$Mm_2 = q_{20}\ \Delta\ Mm_0 + q_{23}\,\Delta\ Mm_3 + q_{24}\,\Delta\ Mm_4$

$Mm_3 = q_{30}\ \Delta\ Mm_0 + q_3{}^8{}_4\,\Delta\ Mm_4 + ŋ$

$Mm_4 = q_{45}\ \Delta\ Mm_5 + q_{46}\,\Delta\,Mm_6 + (q_4{}^{(10,9)}{}_3 + q_4{}^{(10,11)}{}_4)\ \ \Delta\ Mm_4$

$Mm_5 = q_{50}\ \Delta\ Mm_0 + q_5{}^{(9)}{}_4\,\Delta\ Mm_4$

$Mm_6 = q_{60}\ \Delta\ Mm_0 + q_6{}^{(11)}{}_4\,\Delta\ Mm_3$

Here Mm_i ,£ and q_{kl} are all function of t

Now solving these equations by taking Laplace transform and find $\acute{M}_0^*(s)$, we get

$\acute{M}_0^*(s) = U_3(s)/V_1(s)$

Then for steady states

$$\acute{M}_0^{**} = \lim_{s\to 0}\ (s\,\acute{M}_0^*(s)) = U_3(0) / V_1`(0)$$

and

$U_3(0) = -\,£[Tp_{45}\,Tp_{50} + Tp_{46}\,Tp_{60}\,]\,[\,Tp_{01}\,Tp_{12}\,Tp_{23} + Tp_{04}\,Tp_{24}]$

$V_1'(0)$ is specified in eq. (a).

Minor Replacement Time

The recursive relations are

$Mr_0 = q_{01}\ \Delta\ Mr_1 + q_{04}\ \Delta\ Mr_2$

$Mr_1 = q_{10}\ \Delta\ Mr_0 + q_{12}\ \Delta\ Mr_2 + q_1{}^7{}_4\ \Delta\ Mr_4 + §$

$Mr_2 = q_{20}\ \Delta\ Mr_0 + q_{23}\,\Delta\ Mr_3 + q_{24}\ \Delta\ Mr_4$

$Mr_3 = q_{30}\ \Delta\ Mr_0 + q_3{}^8{}_4\,\Delta\ Mr_4 + ɱ$

$Mr_4 = q_{45}\ \Delta\ Mr_5 + q_{46}\ \Delta\ Mr_6 + (q_4{}^{(10,9)}{}_3 + q_4{}^{(10,11)}{}_4)\ \ \Delta\ Mr_4$

$Mr_5 = q_{50}\ \Delta\ Mr_0 + q_5{}^{(9)}{}_4\,\Delta\ Mr_4$

$Mr_6 = q_{60}\ \Delta\ Mr_0 + q_6{}^{(11)}{}_4\,\Delta\ Mr_3$

Here Mr_i ,§ and q_{kl} are all function of t

Now solving these equations by taking Laplace transform and find $Ir_0{}^*(s)$, we get

$Mr_0{}^*(t) = U_4(s) / V_1(s)$

$Mr_0{}^{**} = \lim_{s\to 0}\ (s\ Mr_0{}^*(s)) = U_4(0) / V_1`(0)$

Where

$U_4(0) = -Tp_{45}\ \mathbf{§}\ [Tp_{01}\,Tp_{12}\,Tp_{23}\,Tp_3{}^8{}_4 + Tp_{01}\,Tp_{12}\,Tp_{24} + Tp_{01}\ Tp_1{}^{(7)}{}_4 – Tp_{04}\ Tp_{23}\ Tp_3{}^{(8)}{}_4 + Tp_{04}\,Tp_{24})]$

and

$V_1'(0)$ is specified in eq. (a)

Major Replacement Time

The recursive relations are

$Mj_0 = q_{01}\ \Delta\ Mj_1 + q_{04}\ \Delta\ Mj_2$

$Mj_1 = q_{10}\ \Delta\ Mj_0 + q_{12}\ \Delta\ Mj_2 + q_1{}^7{}_4\ \Delta\ Mj_4$

$Mj_2 = q_{20}\ \Delta\ Mj_0 + q_{23}\,\Delta\ Mj_3 + q_{24}\ \Delta\ Mj_4$

$Mj_3 = q_{30}\ \Delta\ Mj_0 + q_3{}^8{}_4\,\Delta\ Mj_4 + ɱ$

$Mj_4 = q_{45}\ \Delta\ Mj_5 + q_{46}\ \Delta\ Mj_6 + (q_4{}^{(10,9)}{}_3 + q_4{}^{(10,11)}{}_4)\ \ \Delta\ Mj_4$

$Mj_5 = q_{50}\ \Delta\ Mj_0 + q_5{}^{(9)}{}_4\,\Delta\ Mj_4$

$Mj_6 = q_{60}\ \Delta\ Mj_0 + q_6{}^{(11)}{}_4\,\Delta\ Mj_3 + Ƕ$

Here Mj_i ,ɱ and q_{kl} are all function of t

Now solving these equations by taking Laplace transform and find $\hat{R}_0{}^*(s)$, we get

$Mj_0{}^*(t) = [\,U_5\,(s)\,/V_1(s)]$

$Mj_0{}^{**} = \lim_{s\to 0}\ (sMj_0{}^*(s))$

$= [\,U_5\,(0)\,/V_1(0)]$

Where

$U_5(0) = \mathbf{Ƕ}\ Tp_{46}\ [Tp_{01}\,Tp_{12}\,Tp_{23}\ Tp_3{}^{(8)}{}_4 + Tp_{01}\ Tp_{12}\,Tp_{24} + Tp_{01}\ Tp_1{}^{(7)}{}_4 + Tp_{04}\,Tp_{23}\ Tp_3{}^{(8)}{}_4 + Tp_{04}\ Tp_{24}\ ]$

And $V_1'(0)$ is specified in eq. (a)

Inspection Time

The recursive relations are

$IT_0 = q_{01}\ \Delta\ IT_1 + q_{04}\ \Delta\ IT_2$

$IT_1 = q_{10}\ \Delta\ IT_0 + q_{12}\ \Delta\ IT_2 + q_1{}^7{}_4\ \Delta\ IT_4$

$IT_2 = q_{20}\ \Delta\ IT_0 + q_{23}\,\Delta\ IT_3 + q_{24}\ \Delta\ IT_4 + Ѫ$

$IT_3 = q_{30}\ \Delta\ IT_0 + q_3{}^8{}_4\,\Delta\ IT_4 + ɱ$

$IT_4 = q_{45}\ \Delta\ IT_5 + q_{46}\ \Delta\ Mj_6 + (q_4{}^{(10,9)}{}_3 + q_4{}^{(10,11)}{}_4)\ \ \Delta\ IT_4$

$IT_5 = q_{50}\ \Delta\ IT_0 + q_5{}^{(9)}{}_4\,\Delta\ IT_4$

$IT_6 = q_{60} \, \Delta \, IT_0 + q_6^{(11)}{}_4 \, \Delta \, IT_3 + Ƕ$

Here IT_i , ƕ and q_{kl} are all function of t

Now solving these equations by taking Laplace transform and find $\hat{R}_{p0}^{*}(s)$, we get

$IT_0^{*}(t) = U_6(s) / V_1(s)$

In the unvarying state,

$$IT_0^{**} = \lim_{s\to 0} (s\, IT_0^{*}(s))$$

$$= U_6(0) / V_1`(0)$$

Where

$U_6(0) = -$ ƕ $(p_{01}p_{12} + p_{04})(p_{45}p_{50} + p_{46}p_{60})$

And

$V_1'(0)$ is specified in eq. (a)

Busy Period of Repairman :-

Inspection Time + Normal Maintenance Time + Paid Maintenance Time + Minor Replacement Time + Major Replacement Time

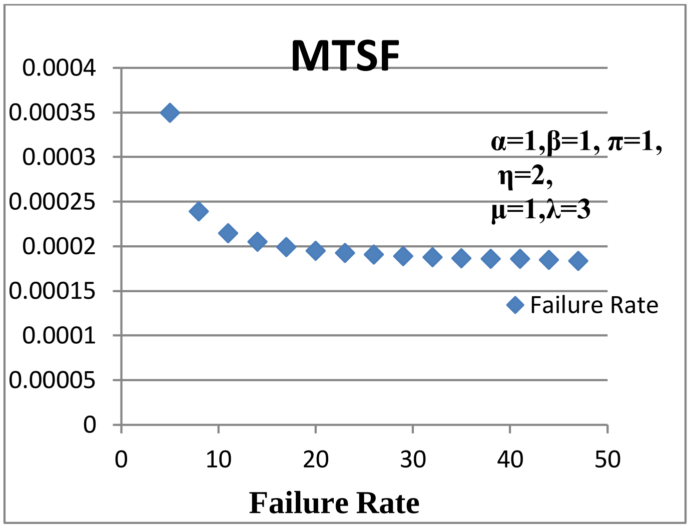
Particular cases:

If we take repair rate and inspection time as negative binomial distributions as

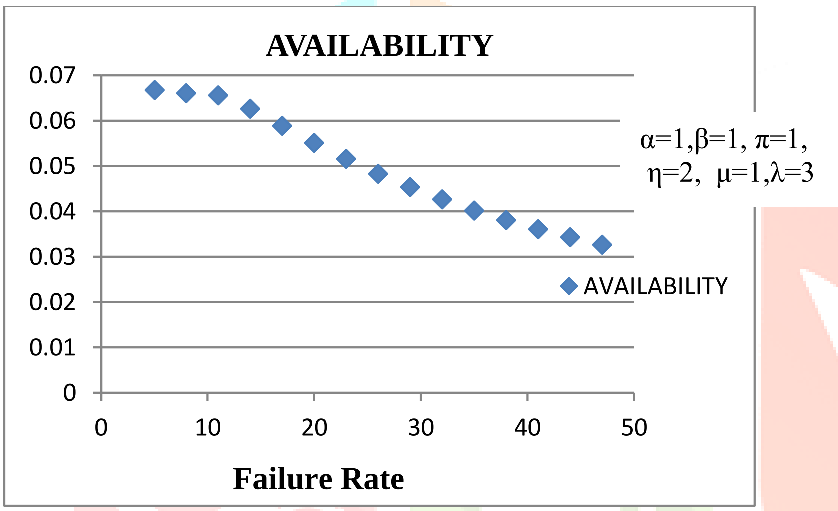
g(t)	=	$\theta e^{-\theta t}$	m(t)	=	$\pi e^{-\pi t}$
i(t)	=	$\delta e^{-\delta t}$	n(t)	=	$\gamma e^{-\gamma t}$
$r_1(t)$	=	$\mu e^{-\mu t}$	$r_2(t)$	=	$\rho e^{-\rho t}$
k	=	$\alpha+\lambda$	w	=	$\lambda+\gamma+\delta$
e	=	$\beta+\lambda+\gamma$	f	=	$\lambda+\rho$
h	=	$\lambda+\pi$	j	=	$\lambda+\theta$
x	=	$\lambda+\mu$			

Then we get,

Tp_{01}	=	α/k	Tp_{04}	=	λ/k
Tp_{10}	=	γ / e	Tp_{12}	=	β / e
Tp_{17}	=	λ / e	Tp_{20}	=	δ/w
Tp_{23}	=	γ/ w	Tp_{24}	=	λ / w
Tp_{30}	=	π / h	Tp_{38}	=	λ / h
$Tp_{1}{}^{7}{}_{4}$	=	λ / e	$Tp_{3}{}^{8}{}_{4}$	=	λ / h
Tp_{45}	=	$a\theta/ j$	Tp_{46}	=	$b\theta / j$
$Tp_{4,10}$	=	λ / j	Tp_{50}	=	μ / x
Tp_{59}	=	λ / x	$Tp_{5}{}^{9}{}_{4}$	=	λ / x
Tp_{60}	=	ρ / f	$Tp_{6,11}$	=	λ / f
μ_0	=	$1 / k$	μ_1	=	$1/ e$
μ_2	=	$1/ w$	μ_3	=	$1/ h$
μ_4	=	$1/ j$	μ_5	=	$1/ x$
μ_6	=	$1/f$			



Failure rate vs MTSF graph



Failure rate vs Availability

CONCLUSION:

In this paper, a new conception of maintenance, repair and was taken together in system to avoid the loss of production and extensive damage for safety reasons. Also routine inspection concept also taken with these assumptions. By the particular cases, we conclude that

For the invariant value of $\alpha=1,\beta=1,\mu=1,\pi=1,\eta=2, \lambda=3$

MTSF goes on increases with the increase of failure rate.

Availability goes on decreases very sharply with the increases of failure rate.

Thus above conclusions help to get the desirable results in the field of design, development and production of individual production.

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