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Profit comparison of a cold standby system with Priority to repair over preventive maintenance and server failure during repair

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Abstract
The main motive of this present paper is to analyze the comparison between two reliability models. For that, one unit is operative and the other unit is kept as spare in cold standby. The operative unit undergoes for preventive maintenance before its complete failure while repair of the unit is conducted at its complete failure. Also, Priority is given to repair of the unit over preventive maintenance. All repair activities are tackled by a single server who visits the system immediately when required and the server may failure during repair only. All random variables are uncorrelated and statistically independent to each other. The distributions of failure time of the unit and server follows negative exponential while the distributions of repair time of the unit and treatment time of the server are taken as arbitrary. The expressions for various measures of system effectiveness are derived in steady state using semi-Markov process and regenerative point technique. The graphical behavior of MTSF, availability and profit function with respect to failure rate for fixed values of other parameters. The profit comparison of the present model has also been made with that of the model in which no such type of priority is given.

Keywords: cold standby system, repair, preventive maintenance

1. Introduction

In the modern scenario of global competition that the industries become fully conscious to produce reliable system which give us the maximum profit. Most of the researcher Kadyan *et al*. (2010) [4, 5] and Sureria *et al*. (2012) [2] have carried out cost-benefit analysis of systems respectively with the idea of priority to repair and priority to software replacement over hardware repair.

To strengthen the existing literature, the present paper is devoted to examine the effect of priority on profit incurred to a system of two identical units have been analyzed stochastically with the concepts of preventive maintenance of the unit, server failure and priority to repair over preventive maintenance. Initially, one unit is operative and the other unit is kept as spare in cold standby. The operative unit undergoes for preventive maintenance before its complete failure while repair of the unit is conducted at its complete failure. All repair activities are tackled by a single server who visits the system immediately when required. The system is observed at suitable regenerative epochs using semi-Markov process and regenerative point technique to derive the expressions for some reliability and economic measures such as mean time to system failure (MTSF),availability, expected number of repair, expected number of preventive maintenance of server and busy period analysis. The numerical results for a particular case are obtained to depict the behavior of MTSF, availability and profit of the system model. The profit of the present model has also been compared with that of the model discussed by Nandal and Malik (2017) [1].

2. Notations

E	:	Set of regenerative states
$\bar{E}$	:	Set of non-regenerative states
λ	:	Constant failure rate
FUr /FWr	:	The unit is failed and under repair/waiting for repair
SFUt/SFUT	:	The server is failed and under treatment/continuously under treatment from previous state
FUR/FWR	:	The unit is failed and under repair / waiting for repair continuously from previous state
g (t)/G(t)	:	pdf/cdf of repair time of the unit
f (t)/F(t)	:	pdf/cdf of preventive maintenance time of the unit
w (t)/W(t)	:	pdf/cdf of arrival time of the server

q_{ij} (t)/ Q_{ij}(t) : pdf / cdf of passage time from regenerative state Si to a regenerative stateSj or to a failed state Sj without visiting any other regenerative state in (0, t]

$q_{ij.kr}$ (t)/$Q_{ij.kr}$(t) : pdf/cdf of direct transition time from regenerative state Si to a regenerative state Sj or to a failed state Sj visiting state Sk, Sr once in (0, t]

M_i (t) : Probability that the system up initially in state $S_i \in E$ is up at time t without visiting to any regenerative state

W_i (t) : Probability that the server is busy in the state S_i up to time 't' without making any transition to any other regenerative state or returning to the same state one or more non-regenerative states.

μ_i : The mean sojourn time in state S_i which is given by $\mu_i = E(T) = \int_0^\infty P(T > t)\, dt = \sum_j m_{ij}$, where T denotes the time to system failure.

m_{ij} : Contribution to mean sojourn time (μ_i) in state S_i when system transits directly to state S_j so that $\mu_i = \sum_j m_{ij}$ and $m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*\prime}(0)$

&/© : Symbol for Laplace-Stieltjes convolution/Laplace convolution

*/** : Symbol for Laplace Transformation /Laplace Stieltjes Transformation

3. System Description

A stochastic model of a system having two identical units has been developed with the ideas of priority to repair over preventive maintenance and server failure during repair. The block diagram for the system model is shown in Fig.:1

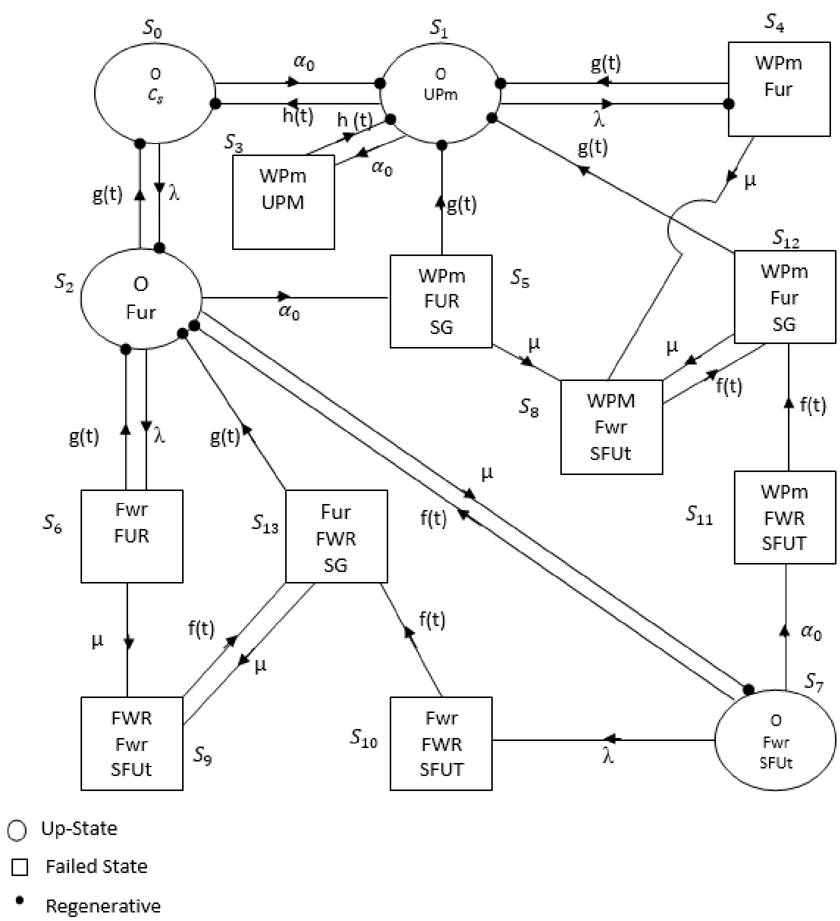

Fig 1: State Transition Diagram

The system mode1 (figure 1) has the following transition states:

- Regenerative States: $S_0,\ S_1,\ S_{2,}\ S_4 and\ S_7$
- Non-regenerative: $S_{3,},\ S_5\ S_{6,} S_8, S_9, S_{10}, S_{11}, S_{12}\ and\ S_{13}$

We have the following expressions for transition probabilities:

$p_{ij} = Q_{ij}(\infty) = \int_0^{\infty} q_{ij}\,(t)dt$

$p_{01} = \frac{\alpha_0}{\lambda+\alpha_0}$ $\quad p_{02} = \frac{\lambda}{\lambda+\alpha_0}$ $\quad p_{10} = h^*(\lambda+\alpha_0)$

$p_{13} = \frac{\alpha_0}{\lambda+\alpha_0}[1-h^*(\lambda+\alpha_0)]$ $\quad p_{14} = \frac{\lambda}{\lambda+\alpha_0}[1-h^*(\lambda+\alpha_0)]$

$p_{20} = g^*(\mu+\lambda+\alpha_0)$ $\quad p_{25} = \frac{\alpha_0}{\mu+\lambda+\alpha_0}[1-g^*(\mu+\lambda+\alpha_0)]$

$p_{26} = \frac{\lambda}{\mu+\lambda+\alpha_0}[1-g^*(\mu+\lambda+\alpha_0)]$ $\quad p_{27} = \frac{\mu}{\mu+\lambda+\alpha_0}[1-g^*(\mu+\lambda+\alpha_0)]$

$p_{31} = h^*(0)\quad p_{41} = g^*(\mu)\quad p_{51} = g^*(\mu)$

$p_{58} = 1-g^*(\mu)\ p_{48} = 1-g^*(\mu)\quad p_{72} = f^*(\lambda+\alpha_0)$

$p_{62} = g^*(\mu) p_{69} = 1-g^*(\mu)$

$p_{7,10} = \frac{\lambda}{\lambda+\alpha_0}[1-f^*(\lambda+\alpha_0)]$ $\quad p_{7,11} = \frac{\alpha_0}{\lambda+\alpha_0}[1-f^*(\lambda+\alpha_0)]$

$p_{8,12} = p_{9,13} = p_{10,13} = p_{11,2} = f^*(0)$ $\quad p_{12,1} = p_{13,2} = g^*(\mu)$

$p_{12,8} = p_{13,9} = 1-g^*(\mu)$

For $h(t) = \gamma e^{-\gamma t}, g(t) = \beta e^{-\beta t}\ and f(t) = \alpha e^{-\alpha t}$ (1)

For a perfect distribution

$p_{01}+p_{02} = p_{10}+p_{13}+p_{14} = p_{20}+p_{25}+p_{26}+p_{27} = p_{31} =$
$p_{41}+p_{48} = p_{51}+p_{58} = p_{62}+p_{69} = p_{72}+p_{7,10}+p_{7,11} = p_{8,12} = p_{9,13} = p_{10,13} = p_{11,12} = p_{12,1}+p_{12,8} = p_{13,2}+p_{13,9} = 1$ (2)

4. Mean Sojourn Times (MST)

$\mu_0 = \frac{1}{\alpha_0+\lambda}\quad \mu_1 = \frac{1}{\Upsilon+\alpha_0+\lambda}\quad \mu_2 = \frac{1}{\beta+\alpha_0+\lambda+\mu}\quad \mu_3 = \frac{1}{\Upsilon}$

$\mu_4 = \mu_5 = \mu_6 = \mu_{12} = \mu_{13} = \frac{1}{\beta+\mu}\quad \mu_7 = \frac{1}{\alpha+\alpha_0+\lambda}$

$\mu_8 = \mu_9 = \mu_{10} = \mu_{11} = \frac{1}{\alpha}$

$\mu_0 = m_{01}+m_{02}\quad \mu_1 = m_{10}+m_{13}+m_{14}\quad \mu_2 = m_{20}+m_{25}+m_{26}+m_{27}$

$\mu_3 = m_{31}\quad \mu_4 = m_{41}\quad \mu_5 = m_{51}+m_{58}$

$\mu_6 = m_{62}+m_{69}\quad \mu_7 = m_{72}+m_{7,10}+m_{7,11}\ \mu_8 = m_{8,12}$

$\mu_9 = m_{9,13}\quad \mu_{10} = m_{10,13}\quad \mu_{11} = m_{11,12}$

$\mu_{12} = m_{12,1}+m_{12,8}\ \mu_{13} = m_{13,2}+m_{13,9}$

$\mu_1' = m_{10}+m_{14}+m_{11.3}$

$\mu_2' = m_{20}+m_{21.5}+m_{21.5(8,12)^n}+m_{22.6}+m_{22.6(9,13)^n}+m_{27}$

$\mu_4' = m_{41}+m_{41.(8,12)^n}$

$\mu_7' = m_{71.11,12}+m_{71.11(12,8)^n}+m_{72}+m_{72.(10,13)}+m_{72.10(13,9)^n}$ (3)

5. Reliability and Mean Time to System Failure (MTSF)

Let $\phi_i(t)$ be the cdf of first passage time from regenerative state Si to a failed state.

Regarding the failed state as absorbing state, we have the following recursive relations for $\phi_i(t)$:

The expressions for $\pi_i(t)$ are as follows:

$\pi_0(t) = Q_{01}(t)Ⓢ\phi_1(t)+Q_{02}(t)Ⓢ\phi_2(t)$

$\pi_1(t) = Q_{01}(t)Ⓢ\phi_0(t)+Q_{13}(t)+Q_{14}(t)$

$\pi_2(t) = Q_{20}(t)Ⓢ\phi_0(t)+Q_{27}(t)Ⓢ\pi_7(t)+Q_{25}(t)+Q_{26}(t)$

$\pi_7(t) = Q_{72}(t)Ⓢ\phi_2(t)+Q_{7,10}(t)+Q_{7,11}(t)$ (4)

Let us take LST of above relations (4) and solving for $\pi_0^{**}(s)$

We have

$R^*(s) = \frac{1-\phi_0^{**}(s)}{s}$ (5)

And,

$MTSF = \lim_{s\to 0}\frac{1-\phi_0^{**}(s)}{s} = \frac{N_1}{D_1}$ (6)

Where, $N_1 = (1-p_{27}p_{72})(\mu_0+p_{01}\mu_1)+p_{02}(\mu_2+p_{27}\mu_7)$

And, $D_1 = (1-p_{01}p_{10})(1-p_{27}p_{72})-p_{02}p_{20}$

6. Long Run (Steady State)Availability

Let $A_i(t)$ be the probability that the system is in up-state at instant 't' given that the system entered regenerative state Si at t = 0.The recursive relations for $A_i(t)$ are given as:

$$A_0(t) = M_0(t) + q_{01}(t)©A_1(t) + q_{02}(t)©A_2(t)$$

$$A_1(t) = M_1(t) + q_{10}(t)©A_0(t) + q_{11.3}(t)©A_1(t) + q_{14}(t)©A_4(t)$$

$$A_2(t) = M_2(t) + q_{20}(t)©A_0(t) + \left(q_{21.5}(t) + q_{21.5(8,12)^n}(t)\right)©A_1(t) + \left(q_{22.6}(t) + q_{22.6(9,13)^n}(t)\right)©A_2(t) + q_{27}(t)©A_7(t)$$

$$A_4(t) = \left(q_{41}(t) + q_{41(12,8)^n}(t)\right)©A_1(t)$$

$$A_7(t) = M_7(t) + \left(q_{71.11,12}(t) + q_{71.11(12,8)^n}(t)\right)©A_1(t) + \left(q_{72}(t) + q_{72.10,13}(t) + q_{72.10(13,9)^n}(t)\right)©A_2(t) \quad (7)$$

Where,

$M_0(t) = e^{-(\lambda+\alpha_0)t}$ $\qquad M_1(t) = e^{-(\lambda+\alpha_0)t}\overline{H(t)}$

$M_2(t) = e^{-(\mu+\lambda+\alpha_0)t}\overline{G(t)}$ $\qquad M_4(t) = e^{-\mu t}\overline{G(t)}$

$M_7(t) = e^{-(\lambda+\alpha_0)t}\overline{F(t)}$

Let us take LST of relations (7) and solving for $A_0^*(s)$.

The steady state availability is given by

$$A_0(\infty) = \lim_{s\to 0} s\,A_0^*(s) = \frac{N_2}{D_2}$$

Where,

$$N_2 = \left(p_{20} + p_{25} + p_{27}p_{7,11}\right)p_{01}\mu_0 + p_{02}p_{10}(\mu_2 + p_{27}\mu_7) + (p_{01}p_{20} + p_{25} + p_{27}p_{7,11})\mu_1$$

$$D_2 = \left(p_{20} + p_{25} + p_{27}p_{7,11}\right)p_{01}\mu_0 + p_{02}p_{10}(\mu_2' + p_{27}\mu_7') + (p_{01}p_{20} + p_{25} + p_{27}p_{7,11})(\mu_1' + p_{14}\mu_4)$$

7. Busy Period of the Server Due to Repair in the Long Run

Let $B_i^R(t)$ be the probability that the server is busy in repair the unit at an instant't' given

that the system entered regenerative state Si at t=0.The recursive relations for $B_i^R(t)$ are as follows:

$$B_0^R(t) = q_{01}(t)©B_1^R(t) + q_{02}(t)©B_2^R(t)$$

$$B_1^R(t) = q_{10}(t)©B_0^R(t) + q_{11.3}(t)©B_1^R(t) + q_{14}(t)©B_4^R(t)$$

$$B_2^R(t) = W_2^R(t) + q_{20}(t)©B_0^R(t) + \left(q_{21.5}(t) + q_{21.5(8,12)^n}(t)\right)©B_1^R(t) + \left(q_{22.6}(t) + q_{22.6(9,13)^n}(t)\right)©B_2^R(t) + q_{27}(t)©B_7^R(t)$$

$$B_4^R(t) = W_4^R(t) + + \left(q_{41}(t) + q_{41(8,12)^n}(t)\right)©B_1^R(t)$$

$$B_7^R(t) = \left(q_{71.11,12}(t) + q_{71.11(12,8)^n}(t)\right)©B_1^R(t) +$$

$$\left(q_{72}(t) + q_{72.10,13}(t) + q_{72.10(13,9)^n}(t)\right)©B_2^R(t) \quad (8)$$

Where,

$$W_2^R(t) = e^{-(\alpha_0+\mu+\lambda)t}\,\overline{G(t)} + (\alpha_0 e^{-\alpha_0 t}©\mu e^{-\mu t}©\text{f(t)}©1)\overline{G(t)} + (\lambda e^{-\lambda t}©\mu e^{-\mu t}©\text{f(t)}©1)\overline{G(t)}$$

$$W_4^R(t) = e^{-\mu t}\overline{G(t)} + (\mu e^{-\mu t}©\text{f(t)}©1)\overline{G(t)}$$

Let us take LT of relations (8) and solving for $B_0^{R*}(s)$.

We get, $B_0^R(\infty) = \lim_{s\to 0} sB_0^{R*}(s) = \frac{N_3}{D_2}$

$$N_3 = W_2^*(0)p_{02}[p_{10} + p_{14}(1 - p_{7,11})] + W_4^*(0)p_{14}(p_{01}p_{20} + p_{27}p_{7,11})$$

And, D_2 is already specified

8. Busy Period of the Server due to Preventive Maintenance (PM) in the Long Run

Let $B_i^P(t)$ be the probability that the server is busy in preventive maintenance the unit at an instant't' given that the system entered regenerative state Si at t=0.The expressions for $B_i^P(t)$ are given as under:

$$B_0^P(t) = q_{01}(t)©B_1^P(t) + q_{02}(t)©B_2^P(t)$$

$$B_1^P(t) = W_1^P(t) + q_{10}(t)©B_0^P(t) + q_{11.3}(t)©B_1^P(t) + q_{14}(t)©B_4^P(t)$$

$$B_2^P(t) = q_{20}(t)©B_0^P(t) + \left(q_{21.5}(t) + q_{21.5(8,12)^n}(t)\right)©B_1^P(t) + \left(q_{22.6}(t) + q_{22.6(9,13)^n}(t)\right)©B_2^P(t) + q_{27}(t)©B_7^P(t)$$

$$B_4^P(t) = \left(q_{41}(t) + q_{41(8,12)^n}(t)\right)©B_1^P(t)$$

$$B_7^P(t) = \left(q_{71.11,12}(t) + q_{71.11(12,8)^n}(t)\right)©B_1^P(t) +$$

$$\left(q_{72}(t) + q_{72.10,13}(t) + q_{72.10(13,9)^n}(t)\right)©B_2^P(t) \quad (9)$$

Where, $W_1^P(t) = e^{-(\alpha_0+\lambda)t}\,\overline{H(t)} + (\alpha_0 e^{-\alpha_0 t}©1)\overline{H(t)}$

Let us takeLT of relations (9) and solving for $B_0^{P*}(s)$.

We get, $B_0^P(\infty) = \lim_{s\to 0} sB_0^{P*}(s) = \frac{N_4}{D_2}$

$N_4 = W_1^{P*}(0)[p_{01}p_{20} + p_{25} + p_{27}p_{7,11}]$ and D_2 is already specified.

9. Expected Number of Repairs (ENR) of the unit in the Long Run

Let $R_i(t)$ be the expected number of repairs by the server in (0, t] given that the system entered the regenerative state Si at t = 0.

The recursive relations for $R_i(t)$ are given as:

$$R_0(t) = Q_{01}(t)Ⓢ R_1(t) + Q_{02}(t)Ⓢ R_2(t)$$
$$R_1(t) = Q_{10}(t)Ⓢ R_0(t) + Q_{11.3}(t)Ⓢ R_1(t) + Q_{14}(t)© R_4(t)$$
$$R_2(t) = Q_{20}(t)Ⓢ(1 + R_0(t)) + \left(Q_{21.5}(t) + Q_{21.5(8,12)^n}(t)\right)Ⓢ\left(1 + R_1(t)\right) + \left(Q_{22.6}(t) + Q_{22.6(9,13)^n}(t)\right)Ⓢ\left(1 + R_2(t)\right) + Q_{27}(t)Ⓢ R_7(t)$$
$$R_4(t) = \left(Q_{41}(t) + Q_{41(8,12)^n}(t)\right)Ⓢ\left(1 + R_1(t)\right)$$
$$R_7(t) = \left(Q_{71.11,12}(t) + Q_{71.11(12,8)^n}(t)\right)Ⓢ\left(1 + R_1(t)\right) + Q_{72}(t)Ⓢ R_2(t) + \left(Q_{72.10,13}(t) + Q_{72.10(13,9)^n}(t)\right)Ⓢ(1 + R_2(t)) \quad (10)$$

Let us take LST of relations (10) and solving for $R_0^{**}(s)$.

We get, $R_0 = \lim_{s\to 0} sR_0^{**}(s) = \frac{N_5}{D_2}$

Where, $N_5 = p_{14}[p_{01}p_{02} + p_{25} + p_{27}p_{7,11}(p_{01} - p_{02}p_{25})] + p_{02}p_{10}(1 - p_{27}p_{72})$

And D_2 is already specified.

10. Expected Number of Preventive Maintenance (PM) of the unit in the Long Run

Let $PM_i(t)$be the expected number of repairs by the server in (0, t] given that the system entered the regenerative state Si at t = 0.
The recursive relations for $PM_i(t)$are given as:

$$PM_0(t) = Q_{01}(t)Ⓢ PM_1(t) + Q_{02}(t)Ⓢ PM_2(t)$$
$$PM_1(t) = Q_{10}(t)Ⓢ(1 + PM_0(t)) + Q_{11.3}(t)Ⓢ(1 + PM_1(t)) + Q_{14}(t)Ⓢ PM_4(t)$$
$$PM_2(t) = Q_{20}(t)Ⓢ PM_0(t)) + \left(Q_{21.5}(t) + Q_{21.5(8,12)^n}(t)\right)Ⓢ PM_1(t) + \left(Q_{22.6}(t) + Q_{22.6(9,13)^n}(t)\right)Ⓢ PM_2(t) + Q_{27}(t)Ⓢ PM_7(t)$$
$$PM_4(t) = \left(Q_{41}(t) + Q_{41(8,12)^n}(t)\right)Ⓢ PM_1(t)$$
$$PM_7(t) = \left(Q_{71.11,12}(t) + Q_{71.11(12,8)^n}(t)\right)Ⓢ PM_1(t) + \left(Q_{72}(t) + Q_{72.10,13}(t) + Q_{72.10(13,9)^n}(t)\right)Ⓢ PM_2(t) \quad (11)$$

Let us take LST of relations (11) and solving for $PM_0^{**}(s)$.

We get, $PM_0 = \lim_{s\to 0} sPM_0^{**}(s) = \frac{N_6}{D_2}$

Where, $N_6 = (p_{10} + p_{13}p_{31})(p_{01}p_{20} + p_{25} + p_{27}p_{7,11})$ and D_2 is already specified.

11. Expected Number of Treatments (ENT) Given to the Server in the Long Run

Let $T_i(t)$ be the expected number of treatments given to the server in (0, t] given that the system entered the regenerative state S_i at t = 0. The recursive relations for $T_i(t)$ are given as:

$$T_0(t) = Q_{01}(t)Ⓢ T_1(t) + Q_{02}(t)Ⓢ T_2(t)$$
$$T_1(t) = Q_{10}(t)Ⓢ T_0(t) + Q_{11.3}(t)Ⓢ T_1(t) + Q_{14}(t)Ⓢ T_4(t)$$
$$T_2(t) = Q_{20}(t)Ⓢ T_0(t) + Q_{21.5}(t)Ⓢ T_1(t) + Q_{21.5(8,12)^n}(t)Ⓢ(1 + T_2(t)) + Q_{22.6}(t)Ⓢ T_2(t) + Q_{22.6(9,13)^n}(t)Ⓢ(1 + T_2(t)) + Q_{27}(t)Ⓢ T_7(t)$$
$$T_4(t) = Q_{41}(t)Ⓢ T_1(t) + Q_{41(8,12)^n}(t)Ⓢ(1 + T_1(t))$$
$$T_7(t) = (Q_{71.11,12}(t) + Q_{71.11(12,8)^n}(t))Ⓢ(1 + T_1(t)) + Q_{72}(t) + Q_{72.10,13}(t) + Q_{72.10(13,9)^n}(t))Ⓢ(1 + T_2(t)) \quad (12)$$

Let us take LST of relations (12) and solving for $T_0^{**}(s)$. The expected no. of repairs per unit time by the server are giving by

We get, $T_0 = \lim_{s\to 0} sT_0^{**}(s) = \frac{N_7}{D_2}$

Where,

$N_7 = p_{01}p_{14}p_{48}(p_{20} + p_{25} + p_{27}p_{7,11}) + p_{02}[(p_{10} + p_{14})(p_{25}p_{58} + p_{26}p_{69} + p_{27}) + p_{14}\{p_{25}p_{58} + p_{26}p_{69} - p_{48}p_{25} + p_{27}(1 + p_{25}p_{7,11})\}]$

And, D_2 is already specified

12. Profit Analysis

The profit of the system model can be obtained as:

$P \;\; = K_0A_0 - K_1B_0^R - K_4B_0^P - K_2R_0 - K_5PM_0 - K_3T_0$

P = Profit of the system model
K_0 = Revenue per unit up-time of the system
K_1 = Cost per unit time for which server is busy due to repair
K_2 = Cost per unit time repair
K_3 = Cost per unit time for treatment of the server
K_4 = Cost per unit time for which server is busy due to preventive maintenance

K_5 = Cost per unit time for preventive maintenance of the server

13. Particular Cases

Let us take $g(t) = \beta e^{-\beta t}$, $f(t) = \alpha e^{-\alpha t}$ $h(t) = \Upsilon e^{-\Upsilon t}$

$p_{01} = \frac{\alpha_0}{\lambda+\alpha_0}$ $p_{02} = \frac{\lambda}{\lambda+\alpha_0}$ $p_{10} = \frac{\Upsilon}{\Upsilon+\lambda+\alpha_0}$

$p_{13} = \frac{\alpha_0}{\Upsilon+\lambda+\alpha_0}$ $p_{14} = \frac{\lambda}{\Upsilon+\lambda+\alpha_0}$ $p_{20} = \frac{\beta}{\beta+\mu+\lambda+\alpha_0}$

$p_{25} = \frac{\alpha_0}{\beta+\mu+\lambda+\alpha_0}$ $p_{26} = \frac{\lambda}{\beta+\mu+\lambda+\alpha_0}$ $p_{27} = \frac{\mu}{\beta+\mu+\lambda+\alpha_0}$

$p_{31} = p_{42} = p_{8,12} = p_{9,13} = p_{10,13} = p_{11,12} = 1$

$p_{51} = \frac{\beta}{\beta+\mu}$ $p_{58} = \frac{\mu}{\beta+\mu}$ $p_{62} = \frac{\beta}{\beta+\mu}$

$p_{69} = \frac{\mu}{\beta+\mu}$ $p_{72} = \frac{\alpha}{\alpha+\lambda+\alpha_0}$ $p_{7,10} = \frac{\lambda}{\alpha+\lambda+\alpha_0}$

$p_{7,11} = \frac{\alpha_0}{\alpha+\lambda+\alpha_0}$ $p_{12,1} = \frac{\beta}{\beta+\mu}$ $p_{12,8} = \frac{\mu}{\beta+\mu}$ $p_{13,2} = \frac{\beta}{\beta+\mu}$ $p_{13,9} = \frac{\mu}{\beta+\mu}$ $\mu_0 = \frac{1}{\lambda+\alpha_0}$

$\mu_1 = \frac{1}{\Upsilon+\lambda+\alpha_0}$ $\mu_2 = \frac{1}{\beta+\mu+\lambda+\alpha_0}$ $\mu_3 = \mu_4 = \frac{1}{\Upsilon}$

$\mu_7 = \frac{1}{\alpha+\lambda+\alpha_0}$ $\mu_8 = \mu_9 = \mu_{10} = \mu_{11} = \frac{1}{\alpha}$ $\mu_6 = \mu_5 = \mu_{12} = \mu_{13} = \frac{1}{\beta+\mu}$

$\mu_1' = \frac{1}{\Upsilon}$ $\mu_2' = \frac{\alpha\beta+(\alpha_0+\lambda)(\alpha+\mu)}{\alpha\beta(\beta+\mu+\lambda+\alpha_0)}$ $\mu_7' = \frac{\alpha\beta+(\alpha_0+\lambda)(\alpha+\beta+\mu)}{\alpha\beta(\lambda+\alpha_0+\alpha)}$

$MTSF = \frac{N_1}{D_1}$, $Availability(A_0) = \frac{N_2}{D_2}$

$B_0^R = \frac{N_3}{D_2}$ $B_0^P = \frac{N_4}{D_2}$ $R_0 = \frac{N_5}{D_2}$

$P_0 = \frac{N_6}{D_2}$ $T_0 = \frac{N_7}{D_2}$

Where,

$$N_1 = (\gamma+\lambda+2\alpha_0)[(\beta+\lambda+\mu+\alpha_0)(\alpha+\lambda+\alpha_0)-\mu\alpha]+\lambda(\gamma+\lambda+\alpha_0)(\alpha+\lambda+\mu+\alpha_0)$$

$$D_1 = [(\lambda+\alpha_0)(\gamma+\lambda+\alpha_0)-\gamma\alpha_0][(\beta+\lambda+\mu+\alpha_0)(\alpha+\lambda+\alpha_0)-\mu\alpha]-\lambda\beta(\gamma+\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)$$

$$N_2 = \frac{[(\gamma+\alpha_0)(\beta+\mu)+\lambda\alpha_0][(\beta+\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)+\mu(\lambda+\alpha_0)]}{(\lambda+\alpha_0)(\beta+\mu)(\gamma+\alpha_0+\lambda)(\alpha+\lambda+\alpha_0)(\beta+\mu+\lambda+\alpha_0)}$$

$$D_2 = \frac{\begin{array}{c}(\beta+\mu)\beta\alpha\Upsilon^2\{(\beta+\alpha_0)(\alpha+\lambda+\alpha_0)\mu\alpha_0\}+\\ \lambda\Upsilon^2[(\alpha+\lambda+\alpha_0)\{\alpha\beta(\beta+\mu)+\alpha\beta+(\alpha\mu+\lambda\beta)(\alpha+\beta+\mu)\}+\mu(\beta+\mu)\\ \{\beta\alpha+(\lambda+\alpha_0)(\alpha+\beta+\mu)\}]+(\beta+\mu)\alpha_0\{\beta\alpha(\gamma+\alpha_0)+\lambda\Upsilon(\alpha+\mu)\}\\ \{(\alpha+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\mu(\lambda+\alpha_0)\end{array}}{\alpha\beta\Upsilon(\beta+\mu)(\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)(\gamma+\alpha_0+\lambda)(\beta+\mu+\lambda+\alpha_0)}$$

$$\lambda(\beta+\mu)\{\beta\mu+(\lambda+\alpha_0)(\beta+\mu+\lambda+\alpha_0)\}\{(\alpha+\lambda)(\Upsilon+\lambda)+\Upsilon\alpha_0\}$$

$$N_3 = \frac{\beta(\lambda+\alpha_0)\lambda\alpha_0\{\beta\alpha+(\beta+\mu)(\lambda+\alpha_0)\}}{\beta(\beta+\mu)(\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)(\mu+\lambda+\alpha_0)(\gamma+\alpha_0+\lambda)(\beta+\mu+\lambda+\alpha_0)}$$

$$N_4 = \frac{\alpha_0(\Upsilon+\alpha_0)\{(\alpha+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\mu(\lambda+\alpha_0)\}}{\Upsilon(\lambda+\alpha_0)(\beta+\lambda+\alpha_0)(\alpha+\alpha_0+\lambda)(\beta+\mu+\lambda+\alpha_0)}$$

$$N_5 = \frac{\lambda\alpha_0\{(\beta+\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)+\mu\alpha_0(1-\lambda)\}}{(\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)(\gamma+\alpha_0+\lambda)(\beta+\lambda+\mu+\alpha_0)}$$

$$N_6 = \frac{\alpha_0(\gamma+\alpha_0)\{(\beta+\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)+\mu(\lambda+\alpha_0)}{(\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)(\gamma+\alpha_0+\lambda)(\beta+\lambda+\mu+\alpha_0)}$$

$$N_7 = \frac{\begin{array}{c}(\alpha+\lambda+\alpha_0)(\beta+\lambda+\mu+\alpha_0)[\mu\lambda\alpha_0\{(\beta+\alpha_0)(\alpha+\lambda+\alpha_0)+\mu\alpha_0\}+\\ \lambda(\Upsilon+\lambda)\{\mu(\lambda+\alpha_0)+\mu(\beta+\mu)\}]+\lambda\mu(\lambda+\alpha_0)[(\beta+\mu)\{(\beta+\lambda+\mu+\alpha_0)(\alpha+\lambda+\alpha_0)\\ +{\alpha_0}^2\}+\lambda(\beta+\lambda+\mu+\alpha_0)(\alpha+\lambda+\alpha_0)]\end{array}}{(\lambda+\alpha_0)(\beta+\mu)(\gamma+\alpha_0+\lambda)(\beta+\lambda+\mu+\alpha_0)^2(\alpha+\lambda+\alpha_0)}$$

14. Graphical Representation of Reliability Measures

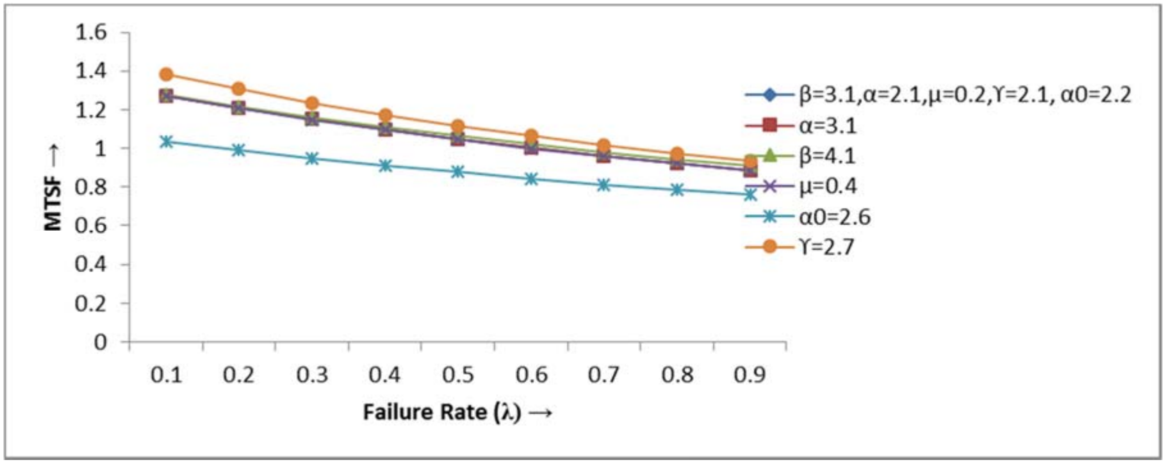

Fig 2: MTSF Vs Failure Rate

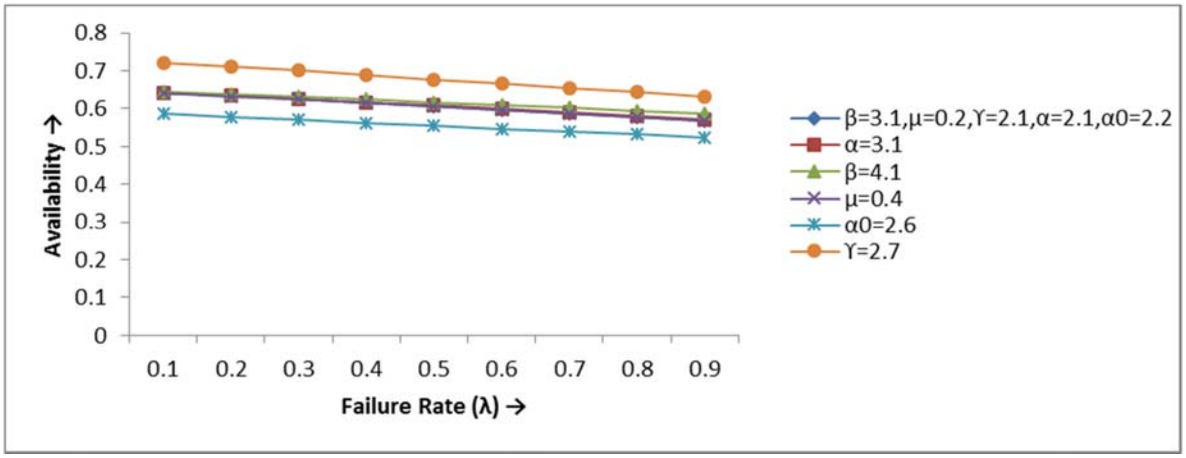

Fig 3: Availability Vs Failure Rate

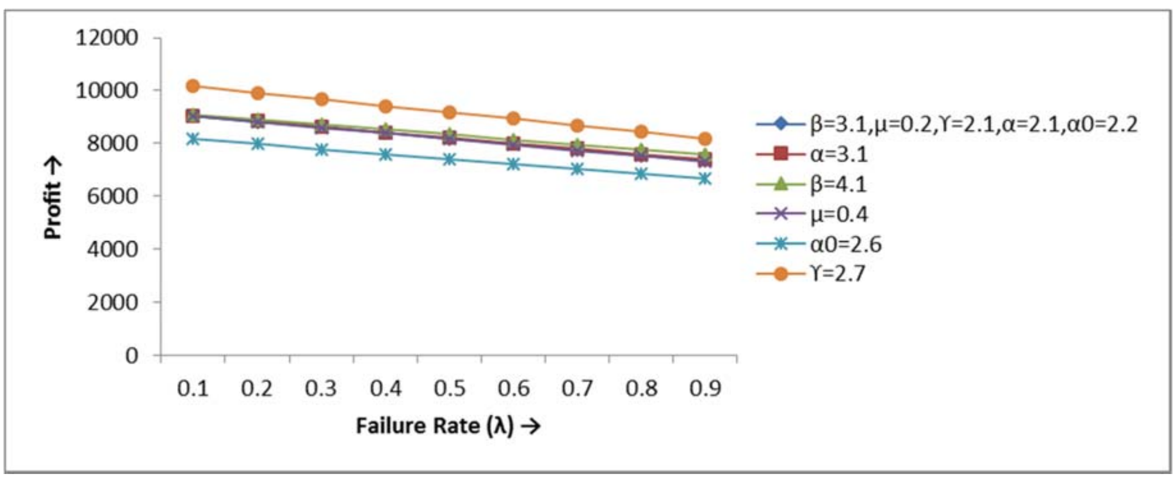

Fig 4: Profit Vs Failure Rate

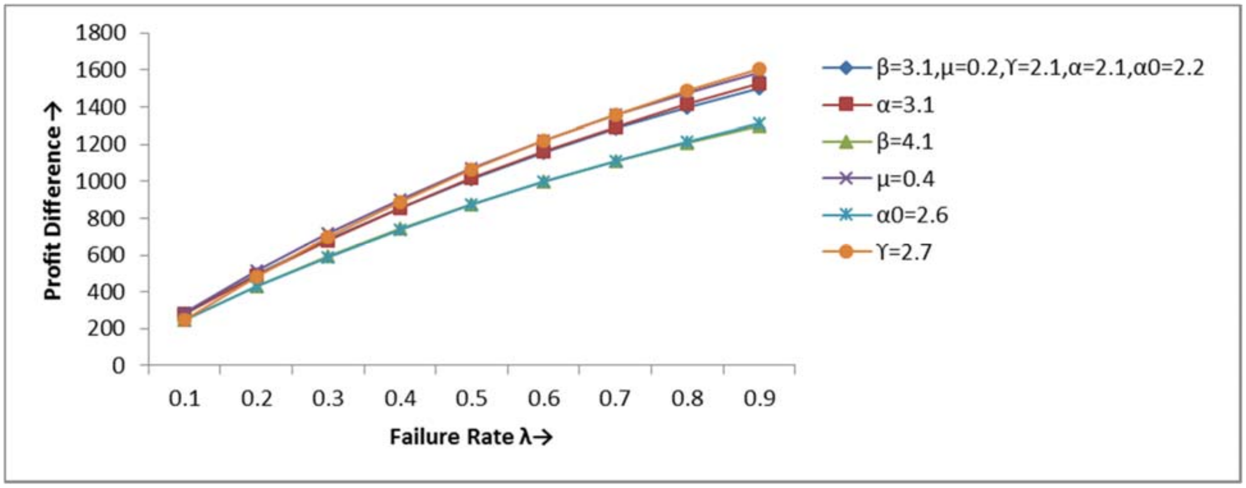

Fig 5: Profit Difference Vs Failure Rate

15. Conclusion

a) Giving arbitrary values to the parameters and costs, the numerical results for availability and profit function are obtained to show the graphical behaviour with respect to failure rate (λ) keeping fixed values of others parameters including $K_0 = 15000$, $K_1 = 3000$, $K_2 = 1000$, $K_3 = 500$, $K_4 = 400$ and $K_5 = 200$ as shown respectively in figures 2 &3. It is observed that profit of the system model go on decreasing with the increase of the failure rates of the unit and server, the rate by which unit under goes for preventive maintenance while there is a positive increment in their values with the increase of treatment rate of the server (α), repair rate (β) and preventive maintenance rate of the unit (γ) in fig. 4.

b) Comparative Study of the Profit of the System Models

The profit of the present model has been compared with that of the model in which no such priority is given. The graph of the profit difference as shown in figure 5 indicates that profit difference goes on increasing with the increase of failure rate of the unit while it declines with the increase of repair rate of the unit and the rate by which unit under goes for preventive maintenance. The study for the particular values of the parameters shows that present model is profitable. Hence, it is concluded that the idea of priority to repair over preventive maintenance is useful in making the system more effective and profitable to use.

16. Reference

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