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Cost-Benefit Analysis of a Cold Standby System with Preventive Maintenance and Repair Subject to Inspection

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Abstract

A cold standby system of two-identical units is studied under the aspects of preventive maintenance and repair. Each unit has two modes- normal and complete failure. There is a single server who visits the system immediately to carryout repair activities. The server conducts preventive maintenance of the operative unit after a pre-specific time '*t*'. The failed unit undergoes for inspection to see the feasibility of its repair. If repair of the unit is not feasible, it is replaced immediately by new-one. The random variables are statistically independent. The unit works as new after preventive maintenance and repair. The failure time and time by which unit undergoes for preventive maintenance follow negative exponentially distribution while the distributions for inspection and repair times are taken as arbitrary with different probability density functions. The semi-Markov process and regenerative technique are adopted to derive the expressions for several reliability measures. The trend for MTSF, availability and profit function have been observed graphically for arbitrary values of various parameters and costs.

Keywords: Cold standby system, preventive maintenance, inspection, repair, replacement, cost-benefit analysis.

1. Introduction

The technique of redundancy in cold standby has been adopted by the researchers including Gopalan and Naidu (1982) and Singh (1989) to improve the performance of repairable systems. The performance of such systems can be improved further by employing proper repair facilities at proper stage of operation and different levels of damages. The preventive maintenance has been considered as one of the effective strategy to enhance the service life of the system. Kumar (2011) carried out cost benefit analysis of a redundant system by conducting inspection of the degraded unit. Malik and Anand (2012) analyzed a computer system with inspection and priority for h/w repair activities over s/w replacement. Recently, Malik (2013) investigated a computer system with preventive maintenance. Also, it becomes necessary to conduct inspection of the failed unit to see the feasibility of its repair in order to avoid the unnecessary expenses on repair.

In view of these practical situations in mind, here a cold standby system of two identical units has been examined stochastically in detail under the aspects of preventive maintenance and repair. Each unit has two modes- normal and complete failure. There is a single server who visits the system immediately to carryout repair activities. The server conducts preventive maintenance of the operative unit after a pre-specific time ‘t’. The failed unit undergoes for inspection to see the feasibility of its repair. If repair of the unit is not feasible, it is replaced immediately by new-one. The random variables are statistically independent. The unit works as new after preventive maintenance and repair. The failure time and time by which unit undergoes for preventive maintenance follow negative exponentially distribution while the distributions for inspection and repair times are taken as arbitrary with different probability density functions.

The semi-Markov process and regenerative technique are adopted to derive the expressions for several reliability measures such as transition probabilities, mean sojourn times, mean time to system failure (MTSF), availability, busy period of the server due to preventive maintenance, inspection and repair, expected number of preventive maintenances, inspection and repairs of the unit and profit function. Graphs are drawn to depict the behavior of MTSF, availability and profit function for particular values of various parameters and costs. The application of the present study can be visualized in a water supply system of two identical electric pumps-one is initially working and the other is kept spare in cold standby.

Notations

E_0 : Set of regenerative states.

O/Cs : The unit is operative/cold stand by

α_0 : Maximum constant rate of Operation time

λ : Constant failure rate of the unit.

$f(t)/F(t)$: pdf /cdf of preventive maintenance time

$g(t)/G(t)$: pdf /cdf of repair time of a failed unit

$h(t)/H(t)$: pdf /cdf of inspection time of a failed unit

P_m/WP_m : The unit is under preventive maintenance/waiting for preventive maintenance

PM/FUR : The unit is continuously under preventive maintenance/under repair from previous state

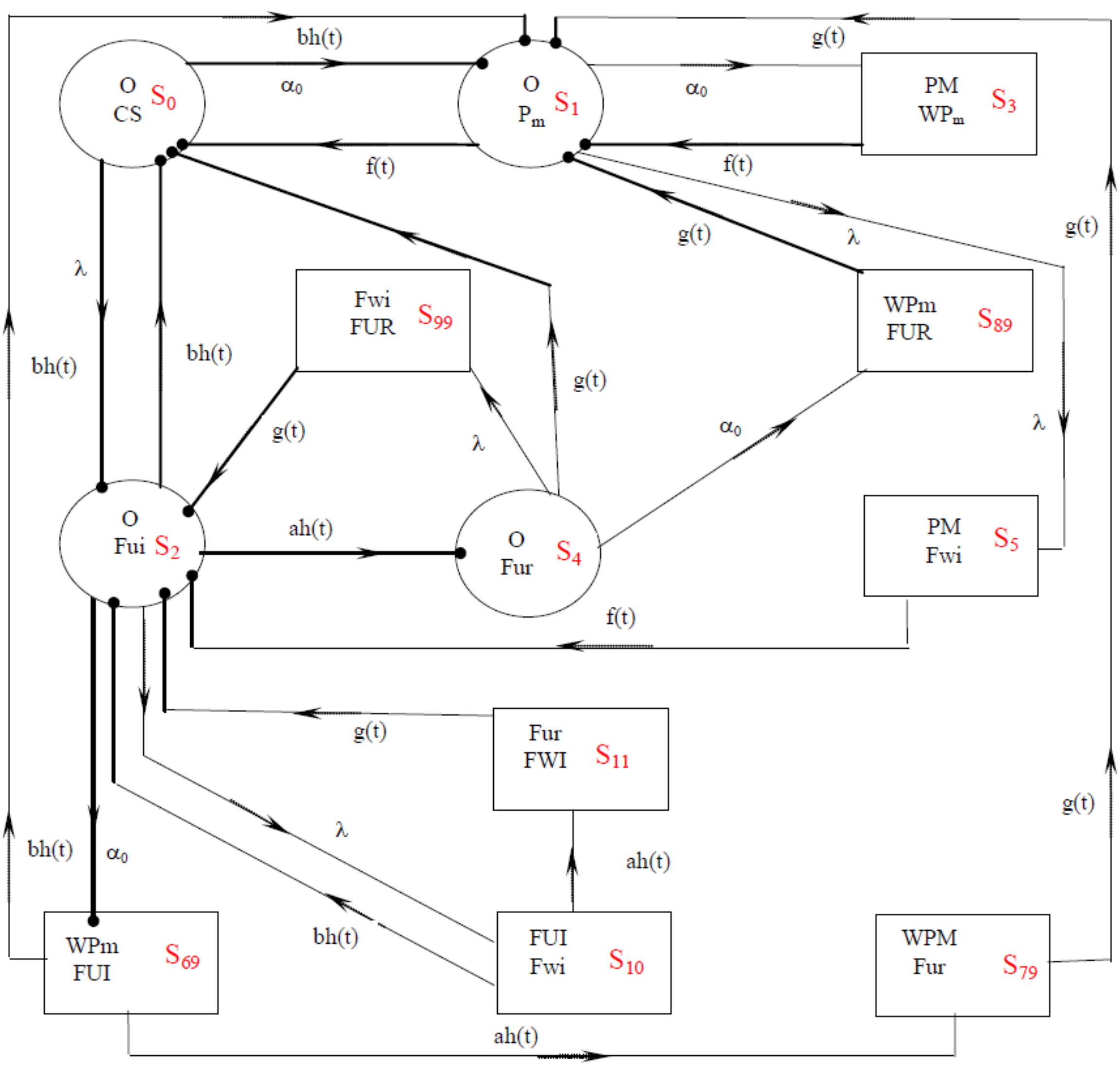

Fig. 1. State transition diagram

Fu_i/Fw_i: The failed unit under inspection/waiting for inspection

Fu_r/Fw_r: The failed unit under repair/waiting for repair

m_{ij}: The unconditional mean time taken by the system to transit from any regenerative state S_i when it (time) is counted from epoch of entrance in to that state S_j. Mathematically it can be written as

$m_{ij} = \int_0^\infty t d[Q_{ij}(t)] = -q_{ij}^{*'}(0)$

μ_i: The mean Sojourn time in state S_i this 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

$W_i(t)$: 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 via one or more regenerative states.

$'$: Indicated alternative results

$\otimes/\oplus$: Symbol for Laplace Stieltjes convolution/Laplace convolution

~/*: Symbol for Laplace Steltjes transform/ Laplace transform

Transition Probabilities and Mean Sojourn Times

Simple probabilistic consideration yield the following expressions for non-zero elements

$$p_{ij} = Q_{ij}(\infty) = \int q_{ij}(t)\,dt \tag{1}$$

$$p_{01} = \frac{\alpha_0}{\alpha_0 + \lambda},\ \ p_{02} = \frac{\lambda}{\alpha_0 + \lambda}, p_{10} = f^*(\alpha_0 + \lambda), p_{13} = p_{11.3} = \frac{\alpha_0}{\alpha_0 + \lambda}[1 - f^*(\alpha_0 + \lambda)]$$

$$p_{15} = \frac{\lambda}{\alpha_0 + \lambda}[1 - f^*(\alpha_0 + \lambda)], p_{12.5} = \frac{\lambda}{\alpha_0 + \lambda}[1 - f^*(\alpha_0 + \lambda)]\ p_{20} = bh^*(\alpha_0 + \lambda),$$

$$p_{24} = ah^*(\alpha_0 + \lambda)\quad p_{26} = \frac{\alpha_0}{\alpha_0 + \lambda}[1 - h^*(\alpha_0 + \lambda)],\ \ p_{22.10} = \frac{\lambda b}{\alpha_0 + \lambda}[1 - h^*(\alpha_0 + \lambda)]$$

$$p_{2.10} = \frac{\lambda}{\alpha_0 + \lambda}[1 - h^*(\alpha_0 + \lambda)], p_{2.1.6} = \frac{\alpha_0}{\alpha_0 + \lambda}[1 - h^*(\alpha_0 + \lambda)]$$

$$p_{21.6,7} = \frac{a\,\alpha_0}{\alpha_0 + \lambda}[1 - h^*(\alpha_0 + \lambda)],\ \ p_{22.10,11} = \frac{a\lambda}{\alpha_0 + \lambda}[1 - h^*(\alpha_0 + \lambda)]$$

$$p_{31} = f^*(0),\ p_{40} = g^*(\alpha_0 + \lambda),\ \ p_{42.9} = \frac{\lambda}{\alpha_0 + \lambda}(1 - g^*(\alpha_0 + \lambda))$$

$$p_{48}=\frac{\alpha_0}{\alpha_0+\lambda}(1-g^*(\alpha_0+\lambda)),\ p_{41.8}=\frac{\alpha_0}{\alpha_0+\lambda}(1-g^*(\alpha_0+\lambda))$$

$$p_{49}=\frac{\lambda}{\alpha_0+\lambda}(1-g^*(\alpha_0+\lambda)),\ p_{52}=f^*(0),\quad p_{61}=bh^*(0),\ p_{67}=ah^*(0),$$

$$p_{71}=p_{81}=p_{92}=p_{11.2}=g^*(0),\ p_{10.2}=bh^*(0),\ p_{10.11}=ah^*(0),\ \ p_{11.2}=g^*(0) \tag{2}$$

It can be easily verified that

$$p_{01}+p_{02}=p_{10}+p_{13}+p_{15}=p_{20}+p_{24}+p_{26}+p_{2.10}=p_{40}+p_{48}+p_{49}=p_{61}+p_{67}=1 \tag{3}$$

The mean sojourn times (μ_i) is the state S_i are

$$\mu_0=\frac{1}{\alpha_0+\lambda},\ \ \mu_1=\frac{1}{\alpha_0+\lambda+\alpha},\ \ \mu_2=\frac{1}{\alpha_0+\lambda+\beta}\ ,\mu_4=\frac{1}{\alpha_0+\lambda+\theta},\mu_1'=\frac{1}{\alpha},\mu_4'=\frac{1}{\theta}\ \text{ and}$$

$$\mu_2'=\frac{\beta\theta+[\theta+a\beta](\lambda+\alpha_0)}{(\alpha_0+\lambda+\beta)\beta\theta} \tag{4}$$

Reliability and Mean Time to System Failure (MTSF)

Let $\phi_i(t)$ be the c.d.f. of first passage time from the regenerative state *i* to a failed state. Regarding the failed state as absorbing state, we have the following recursive relations for $\phi_i(t)$;

$$\phi_i(t)=\sum_j Q_{i,j}(t)\otimes\phi_j(t)+\sum_k Q_{i,k}(t) \tag{5}$$

where *j* is an un-failed regenerative state to which the given regenerative state '*i*' can transit and *k* is failed state to which the state *i* can transit directly. Taking L.S.T. of above relation (5) and solving for $\widetilde{\phi}_0(s)$. We have

$$R^*(s)=\frac{1-\widetilde{\phi}_0(s)}{s} \tag{6}$$

The reliability of the system model can be obtained by taking Laplace inverse transformation of (6).

The mean time to system failure (MTSF) is given by

$$MTSF = \lim_{s\to 0}\frac{1-\widetilde{\phi}_0(s)}{s} = \frac{\mu_0 + \mu_1 p_{01} + \mu_2 p_{02} + \mu_4 p_{02} p_{24}}{1 - p_{01}p_{10} - p_{02}p_{20} - p_{02}p_{24}p_{40}} \tag{7}$$

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 *i* at *t* = 0. The recursive relations for $A_i(t)$ are given as

$$A_i(t) = M_i(t) + \sum_j q_{i,j}(t) \oplus A_j(t) \tag{8}$$

where j is any successive regenerative state to which the regenerative state i can transit through transitions. $M_i(t)$ is the probability that the system is up initially in state $S_i \in E$ is up at time *t* without visiting to any other regenerative state, we have

$$M_0(t) = e^{-(\alpha_0+\lambda)t},\ M_1(t) = e^{-(\alpha_0+\lambda)t}\overline{F(t)},\ M_2(t) = e^{-(\alpha_0+\lambda)t}\overline{H(t)} \text{ and } M_4(t) = e^{-(\alpha_0+\lambda)t}\overline{G(t)} \tag{9}$$

Taking L.T. of above relations (9) and solving for $A_0^*(s)$, the steady state availability is given by

$$A_0(\infty) = \lim_{s\to 0} sA_0^*(s) = \frac{N}{D}; \tag{10}$$

where

$$\begin{aligned} N = {} & \mu_0[(1-p_{11.3})(1-p_{22.10}-p_{22.10,11}) - p_{12.5}(p_{21.6}+p_{21.6,7}) - p_{24}\,p_{42.9}(1-p_{11.3}) - p_{24}p_{12.5}p_{41.8}] \\ & + \mu_1[p_{01}(1-p_{22.10}-p_{22.10,11}) + p_{02}(p_{21.6}+p_{21.6,7}) - p_{24}p_{01}p_{42.9} + p_{24}p_{02}p_{41.8}] \\ & + \mu_2[p_{01}p_{12.5} + p_{02}(1-p_{11.3})] + \mu_4[p_{01}p_{24}p_{12.5} + p_{02}(1-p_{11.3})] \end{aligned}$$

$$\begin{aligned} D = {} & \mu_0[(1-p_{11.3})(1-p_{22.10}-p_{22.10,11}) - p_{24}p_{42.9}(1-p_{11.3}) - p_{24}p_{12.5}p_{41.8} - p_{12.5}(p_{21.6}+p_{21.6,7})] \\ & + \mu_1'[p_{01}(1-p_{22.10}-p_{22.10,11}) + p_{02}(p_{21.6}+p_{12.6,7}) - p_{24}p_{01}p_{42.9} + p_{24}p_{02}p_{41.8}] \\ & + \mu_2'[p_{01}p_{12.5} + p_{02}(1-p_{11.3})] + \mu_4'[p_{01}p_{24}p_{12.5} + p_{02}p_{24}(1-p_{11.3})] \end{aligned}$$

Busy Period Analysis for Server

Let $B_i^p(t)$, $B_i^R(t)$ and $B_i^I(t)$ be the probability that the server is busy in preventive maintenance, repair and inspection of the unit at an instant '*t*' given that system entered state *i* at $t = 0$. The recursive relations for $B_i^p(t)$, $B_i^R(t)$ and $B_i^I(t)$ are as follows:

$$B_i^p(t) = W_i(t) + \sum_j q_{i,j}(t) \oplus B_j^p(t)$$
$$B_i^R(t) = W_i(t) + \sum_j q_{i,j}(t) \oplus B_j^R(t) \qquad (11)$$
$$B_i^I(t) = W_i(t) + \sum_j q_{i,j}(t) \oplus B_j^I(t)$$

where *j* is any successive regenerative state to which the regenerative state i can transit through transitions. $W_i(t)$ be the probability that the server is busy in state S_i due to preventive maintenance up to time '*t*' without making any transition to any other regenerative state or returning to the same via one or more non-regenerative state and so

$$W_1(t) = \{e^{-(\alpha_0+\lambda)t} + (\alpha_0 e^{-(\alpha_0+\lambda)t} \oplus 1) + (\lambda e^{-(\alpha_0+\lambda)t} \oplus 1)\}\overline{F(t)}$$

$$W_2(t) = e^{-(\alpha_0+\lambda)t}\,\overline{H(t)} \text{ and } W_4(t) = \overline{G(t)}$$

Taking Laplace transformation of above relations (11) and solving for $B_0^{*p}(s)$, $B_i^I(s)$ and $B_0^{*R}(s)$, the time for which server is busy due to preventive maintenance, inspection and repair respectively is given by

$$B_0^p(t) = \lim_{s\to 0} sB_0^{*p}(t) = \frac{N_1^p}{D'},\ B_0^R(t) = \lim_{s\to 0} sB_0^{*R}(t) = \frac{N_2^R}{D'} \text{ and } B_0^I(t) = \lim_{s\to 0} sB_0^{*I}(t) = \frac{N_3^I}{D'} \qquad (12)$$

where $N_1^p(t) = W_1^*[p_{01}(1 - p_{22.10} - p_{22.10,11}) + p_{02}(p_{21.6} + p_{21.6,7}) - p_{24}p_{01}p_{42.9} + p_{02}p_{24}p_{41.8}]$,

$N_2^R(t) = W_4^* p_{24}\{p_{01}p_{12.5} + p_{02}(1 - p_{11.3})\}$ and $N_3^I(t) = W_2^*\{p_{01}p_{12.5} + p_{02}(1 - p_{11.3})\}$ and D has already mentioned.

Expected Number of Inspections, Repairs and Preventive Maintenances of the Unit

Let $R_i^I(t)$, $R_i^R(t)$ and $R_i^P(t)$ be the expected number of inspections, repairs and preventive maintenances of unit by the server in (0, *t*] given that the system entered the regenerative state *i* at $t = 0$.

The recursive relations for $R_i^I(t)$, $R_i^R(t)$ and $R_i^P(t)$ are given as

$$R_i^I(t) = \sum_j q_{i,j}(t) \oplus [\delta_j + R_j^I(t)],\quad R_i^R(t) = \sum_j q_{i,j}(t) \oplus [\delta_j + R_j^R(t)] \text{ and}$$

$$R_i^P(t) = \sum_j q_{i,j}(t) \oplus [\delta_j + R_j^P(t)] \tag{13}$$

where j is any regenerative state to which the given regenerative state i transits and δ_j=1, if j is the regenerative state where the server does the job afresh, other wise δ_j = 0. Taking LT of relations (13) and, solving for $\widetilde{R}_0^I(s)$, $\widetilde{R}_0^R(s)$ and $\widetilde{R}_0^p(s)$. The expected no of repairs and preventive maintenances per unit time are respectively given by

$$R_0^I(\infty) = \lim_{s\to 0} s\widetilde{R}_0^I(s) = \frac{N_4^I}{D'}, R_0^R(\infty) = \lim_{s\to 0} s\widetilde{R}_0^R(s) = \frac{N_5^R}{D'} \text{ and } R_0^P(\infty) = \lim_{s\to 0} s\widetilde{R}_0^P(s) = \frac{N_6^P}{D'} \tag{14}$$

where $N_4^I = p_{01}p_{12.5} + p_{02}(1 - p_{11.3})$, $N_5^R = p_{24}(p_{40} + p_{42..9} + p_{41.8})\{p_{01}p_{12.5} + p_{02}(1 - p_{11.3})\}$ and $N_6^P = p_{01}(1 - p_{22.10} - p_{22.10,11}) + p_{02}(p_{21.6} + p_{21.6,7})$ and D has already defined.

Profit Analysis

The profit incurred to the system model in steady state can be obtained as

$$P = K_0A_0 - K_1B_0^P - K_2B_0^R - K_3B_0^I - K_4R_0^R - K_5R_0^P - K_6R_0^I \tag{15}$$

K_0= Revenue per unit up-time of the system

K_1= Cost per unit time for which server is busy due preventive maintenance

K_2= Cost per unit time for which server is busy due to repair

K_3= Cost per unit time for which server is busy due to inspection

K_4= Cost per unit time repair

K_5= Cost per unit time preventive maintenance

K_6= Cost per unit time inspection

Particular Case

Let us take $g(t) = \theta e^{-\theta t}$, $h(t) = \beta e^{-\beta t}$ and $f(t) = \alpha e^{-\alpha t}$, then the following results are obtained:

$$\text{MTSF}=\frac{(\beta+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\lambda+\alpha+\alpha_0)+\alpha_0(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\lambda(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)+a\lambda\beta(\alpha+\lambda+\alpha_0)}{(\theta+\lambda+\alpha_0)[(\lambda+\alpha_0)(\alpha+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)-\alpha\alpha_0(\beta+\lambda+\alpha_0)-\lambda\beta(\lambda+\alpha+\alpha_0)]} \quad (16)$$

Availability

$$A_0=\frac{\alpha\beta\theta(\alpha+\lambda+\alpha_0)(\beta+\alpha_0+\lambda)(\lambda+\alpha_0+\theta)}{a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)]+\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda]} \quad (17)$$

Busy period for preventive maintenance

$$B_0^p=\frac{\alpha_0\beta\theta(\alpha+\lambda+\alpha_0)(\beta+\alpha_0+\lambda)(\lambda+\alpha_0+\theta)}{a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)]+\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda]} \quad (18)$$

Busy period for Repair

$$B_0^R=\frac{a\alpha\beta^2(\alpha+\lambda+\alpha_0)(\lambda+\alpha_0+\theta)}{a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)]+\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda]} \quad (19)$$

Busy period due to Inspection

$$B_0^I=\frac{\lambda\alpha\beta\theta(\alpha+\lambda+\alpha_0)(\lambda+\alpha_0+\theta)}{a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0)+\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)]+\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda]} \quad (20)$$

Expected Number of visits for preventive maintenance

$$R_0^p = \frac{\alpha_0\alpha\beta\theta(\alpha+\lambda+\alpha_0)(\beta+\alpha_0+\lambda)(\lambda+\alpha_0+\theta)}{\begin{array}{r} a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0) \\ +\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)] \\ +\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda] \end{array}} \quad (21)$$

Expected Number of visits for repair

$$R_0^R = \frac{a\lambda\alpha\beta^2\theta(\alpha+\lambda+\alpha_0)(\lambda+\alpha_0+\theta)}{\begin{array}{r} a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0) \\ +\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)] \\ +\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda] \end{array}} \quad (22)$$

Expected Number of Inspection

$$R_0^I = \frac{\lambda\alpha\beta\theta(\alpha+\lambda+\alpha_0)(\beta+\alpha_0+\lambda)(\lambda+\alpha_0+\theta)}{\begin{array}{r} a\alpha\lambda\beta^2(\alpha_0+\lambda+\theta)(\alpha+\lambda+\alpha_0)(1-\theta)+\beta\theta\alpha_0(\alpha+\lambda+\alpha_0)(\theta+\lambda+\alpha_0)(\beta+\lambda+\alpha_0) \\ +\alpha\lambda[\theta\beta+(\alpha_0+\lambda)(\theta+a\beta)(\alpha+\lambda+\alpha_0)(\alpha_0+\lambda+\theta)] \\ +\alpha\beta\theta(\theta+\lambda+\alpha_0)\{(\lambda+\alpha)(\alpha_0+\beta)-\alpha_0\lambda] \end{array}} \quad (23)$$

2. Conclusion

The graphs for mean time to system failure, availability and profit function have been drawn with respect to preventive maintenance rate giving particular values to the parameters and costs as shown respectively in figure 2, 3 and 4. It is observed that the values of these reliability measures go on increasing with the increase of preventive maintenance and repair rates. However, their values decline with the increase of the rate by which unit undergoes for preventive maintenance (α_0) and failure rate (λ). The system model will be in loss for α_0=7, $\lambda = .01$ and $\theta = 2.5$ provided preventive maintenance rate is less than 6.

Finally, it is concluded that a cold stand by system of two identical units can be made more reliable and profitable to use either by conducting its preventive maintenance at the appropriate time or by increasing repair rate of the failed unit rather than to make its replacement by new one.

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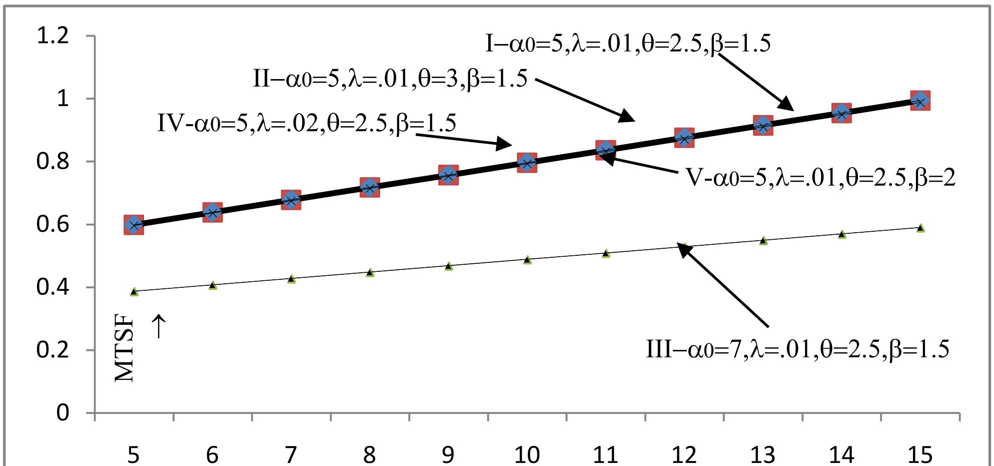

Fig. 2: Premaintive maintenance rate(a) →

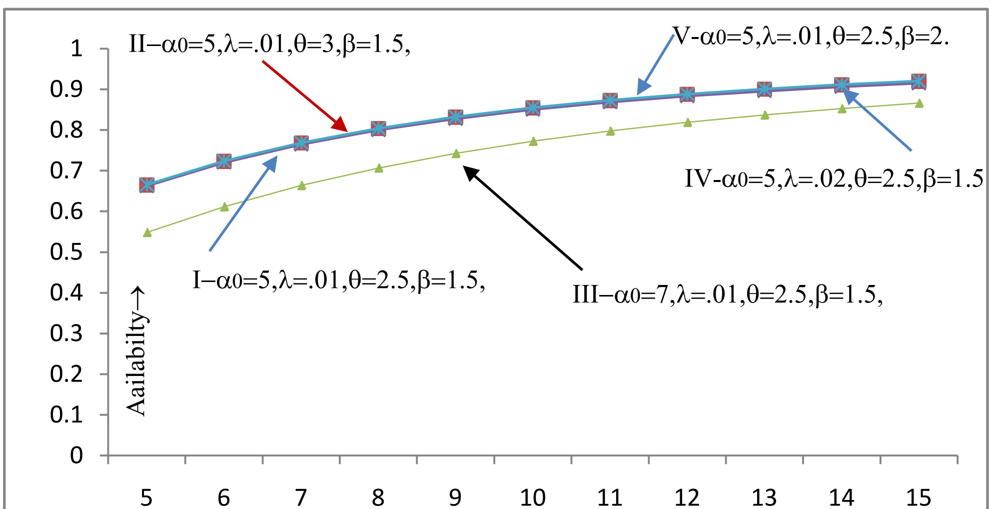

Fig. 3: Premaintive maintenance rate(a) →

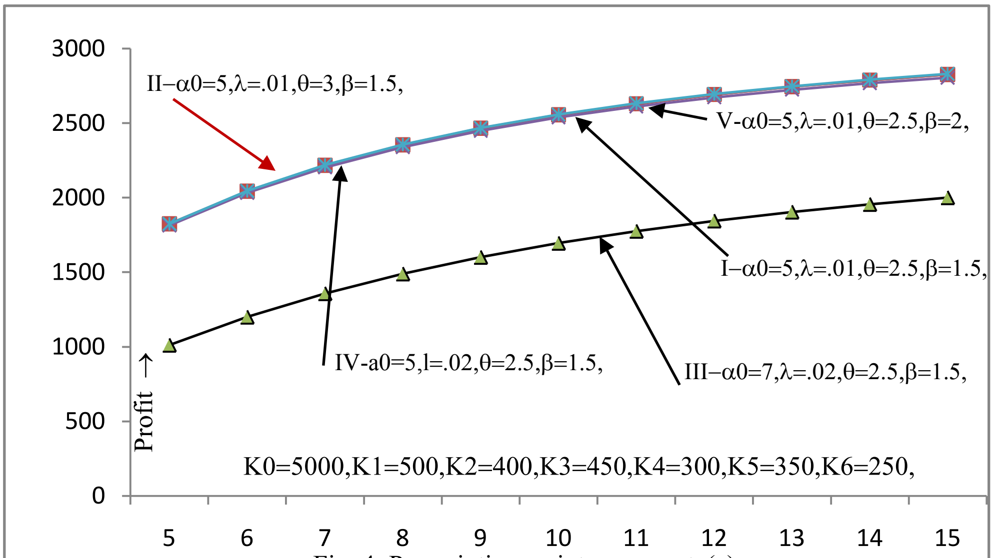

Fig. 4: Premaintive maintenance rate(a) →