Profit Analysis of a Computer System with H/W Repair and S/W Replacement

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ABSTRACT
The main intension of this paper is to make profit analysis of a computer system of two identical units in which one unit is operative and other is kept as cold standby. In each unit, h/w and s/w components fail independently from the normal mode. A single server visits the system immediately whenever needed to carry out repair and replacement of the components. If there is a h/w failure in the unit, then that unit goes immediately under repair. However, only replacement of the s/w in the unit is made by new one whenever s/w fails to meet out the requirements. The failure time of the unit is exponentially distributed while the distributions of repair rate of h/w and replacement rate of the s/w are taken as arbitrary with different probability density functions (pdf). The expressions for several reliability characteristics are derived by making use of semi-Markov process and regenerative point technique. Graphs are drawn for a particular case to highlight the behaviour of some measures of system effectiveness. The results of the present model have also been compared with the results obtained for the model proposed by Malik and Anand [4].

Keywords
Computer System, Independent Failure of H/W and S/W, Repair, Replacement and Profit Analysis.
2000 Mathematics Subject Classification: 90B25 and 60K10

1. INTRODUCTION
The increasing use of computers in all industrial sectors leads to the need to specify and design computing systems which could fulfil the requirements of the targeted applications at the lowest cost. Various requirements have to be taken into accounts whether functional (accuracy of the results and ease of use, etc.) or dependability requirements such as availability or maintainability. For that, a few researchers including Friedman and Tran [1] and Welke et al.[2] tried to develop a combined reliability model for the whole system including both h/w and s/w. Lie et al. [3] developed a model for availability analysis of distributed s/w and h/w components. Recently, Malik and Anand [4] proposed a reliability model of a computer system with independent h/w and s/w failures considering repair of h/w subject to inspection and replacement of s/w components by new one with some replacement rate. It is a known fact that inspection is one of the best method to decide the feasibility of repair and replacement of the failed components in a system. But this increase the down time of the system and also some time replacement of the components by new one may be costly instead of repair. In such a situation repair of the failed components (or units) may be started immediately to enhanced the availability of the system and hence profit.

In view of the above observations and facts, here we analyse a computer system of two identical units in which each unit has independent complete failure of h/w and s/w components from normal mode. Initially one unit is operative and other is kept as cold standby. A single server is made available immediately to do repair of the h/w and making replacement of the s/w. If operative unit is failed due to h/w, then it goes immediately under repair. However, replacement of the s/w component in the unit is made by new one instead of repair whenever s/w fails to meet out the requirements. The random variables are statistically independent and uncorrelated to each other. The switch devices and repairs are perfect. The failure time of the unit due to failure of h/w and s/w components are distributed exponentially while the distributions of replacement and repair rates are taken as arbitrary. To carry out the profit analysis, the numerical results for mean sojourn times, mean time to system failure (MTSF), availability, busy period of the server due to h/w repair and replacement of the s/w components, expected number of replacements due to s/w failures and expected number of visits by the server are obtained using semi-Markov process and regenerative point technique. The graphs for a particular case are drawn to depict the behaviour of MTSF, availability and profit of the system model. The comparison of the results has also been made with the results obtained for the model proposed by Malik and Anand [4][2010]

2. NOTATIONS
E : The set of regenerative states

O : The unit is operative and in normal mode

Cs : The unit is cold standby

λ_1/λ_2 : Constant hardware / software failure rate

FHUr/FHUR : The unit is failed due to hardware and is under repair / under repair continuously from previous state

FHWr /FHWR :The unit is failed due to hardware and is waiting for repair/waiting for repair continuously from previous state

FSURp/FSURP: The unit is failed due to the software and is under replacement/ under replacement continuously from previous state

FSWRp/FSWRP: The unit is failed due to the software and is waiting for replacement / waiting for replacement continuously from previous state

f(t) / F(t) : pdf / cdf of replacement time of the software

g(t) / G(t) : pdf / cdf of repair time of the unit due to hardware failure

q_{ij} (t)/ Q_{ij}(t) :pdf / cdf of passage time from regenerative state i to a regenerative state j or to a failed state j 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 i to a regenerative state j or to a failed state j visiting state k, r once in (0, t]

m_{ij} : Contribution to mean sojourn time (μ_i) in state S_i when system transit directly to state S_j so that $\mu_i = \sum_j m_{ij}$ and

$$m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*\,'}(0)$$

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

~ / * : Symbol for Laplace Steiltjes Transform (LST) / Laplace Transform (LT)

' (desh): Used to represent alternative result

The following are the possible transition states of the system:

S_0= (O, Cs), S_1= (O, FHUr), S_2= (O, FSURp),

S_3= (FHUR, FHWr), S_4= (FHUR, FSWRp), S_5= (FSURP, FSWRp),

S_6= (FHWr, FSURP)

The states S_0–S_2 are regenerative states while the states S_3–S_6 are non-regenerative as shown in figure 1.

3. RELIABILITY INDICES

3.1 Transition Probabilities and Mean Sojourn Times

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

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

$$p_{01} = \frac{a\lambda_1}{a\lambda_1 + b\lambda_2}, \quad p_{02} = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2},$$

$$p_{10} = g^*(a\lambda_1 + b\lambda_2),$$

$$p_{13} = \frac{a\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - g^*(a\lambda_1 + b\lambda_2)\right],$$

$$p_{14} = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - g^*(a\lambda_1 + b\lambda_2)\right],$$

$$p_{20} = f^*(a\lambda_1 + b\lambda_2),$$

$$p_{25} = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - f^*(a\lambda_1 + b\lambda_2)\right],$$

$$p_{26} = \frac{a\lambda_1}{a\lambda_1 + b\lambda_2}\left[1 - f^*(a\lambda_1 + b\lambda_2)\right],$$

$$p_{31} = g^*(s), \quad p_{42} = g^*(s),$$

$$p_{52} = f^*(s), \quad p_{61} = f^*(s) \quad (1)$$

For f(t) = $\theta e^{-\theta t}$ and g(t) = $\alpha e^{-\alpha t}$ we have

$$p_{11.3} = \frac{a\lambda_1}{a\lambda_1 + b\lambda_2 + \alpha}, p_{12.4} = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2 + \alpha}$$

$$p_{21.6} = \frac{a\lambda_1}{a\lambda_1 + b\lambda_2 + \theta}, \quad p_{22.5} = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2 + \theta} \quad (2)$$

It can be easily verified that $p_{01}+p_{02} = p_{10}+p_{13}+p_{14} = p_{20}+p_{25}+p_{26} = p_{31} = p_{42} = p_{52} = p_{61} = p_{10} + p_{11.3} + p_{12.4} = p_{20}+p_{21.6}+p_{22.5} = 1$ (3)

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

$$\mu_0 = \frac{1}{a\lambda_1 + b\lambda_2}, \mu_1 = \frac{1}{a\lambda_1 + b\lambda_2 + \alpha},$$

$$\mu_2 = \frac{1}{a\lambda_1 + b\lambda_2 + \theta} \quad (4)$$

Also

$$m_{01} + m_{02} = \mu_0, m_{10} + m_{13} + m_{14} = \mu_1,$$

$$m_{20} + m_{25} + m_{26} = \mu_2 \quad (5)$$

And

$$m_{10} + m_{11.2} + m_{12.4} = \mu_1' \text{ (Say)}$$

$$m_{20} + m_{21.6} + m_{22.5} = \mu_2' \text{ (Say)} \qquad (6)$$

For f (t) = $\theta e^{-\theta t}$ and g(t) = $\alpha e^{-\alpha t}$, we have

$$\mu_1^1 = \frac{1}{\alpha}, \qquad \mu_2^1 = \frac{1}{\theta} \qquad (7)$$

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

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

ϕ_0(t) = Q_{01}(t)Ⓢ ϕ_1(t) + Q_{02}(t)Ⓢ ϕ_2(t)

ϕ_1(t) = Q_{10}(t)Ⓢ ϕ_0(t) + Q_{13}(t) + Q_{14}(t)

ϕ_2(t) = Q_{20}(t)Ⓢ ϕ_0(t) + Q_{25}(t) + Q_{26}(t) (8)

Taking LST of above relation (8) and solving for $\tilde{\phi}_0(s)$

We have

$$R^*(s) = \frac{1-\tilde{\phi}_0(s)}{s} \qquad (9)$$

The reliability of the system model can be obtained by taking Laplace inverse transform of (9).

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

$$\text{MTSF} = \lim_{s \to o} \frac{1-\tilde{\phi}_0(s)}{s} = \frac{N_1}{D_1} \qquad (10)$$

where

$N_1 = \mu_0 + p_{01}\mu_1 + p_{02}\mu_2$

$D_1 = 1 - p_{01}p_{10} - p_{02}p_{20}$

3.3. 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_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) + $q_{12.4}$(t) © A_2(t)

A_2(t) = M_2(t) + q_{20}(t) © A_0(t) + $q_{21.6}$(t) © A_1(t) + $q_{22.5}$(t) © A_2(t) ....(11)

Where 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

$$M_0(t) = e^{-(a\lambda_1 + b\lambda_2)t}, M_1(t) = e^{-(a\lambda_1 + b\lambda_2)t}\bar{G}(t),$$

$$M_2(t) = e^{-(a\lambda_1 + b\lambda_2)t}\bar{F}(t)$$

Taking LT of above relations (11) and solving for $A_0^*(s)$, the steady state availability is given by

$$A_0(\infty) = \lim_{s \to 0} sA_0^*(s) = \frac{N_2}{D_2} \qquad (12)$$

where

$N_2 = (p_{10}p_{20} + p_{10}\, p_{21.6} + p_{20}p_{12.4})\, \mu_0 + (p_{01}p_{20} + p_{21.6})\, \mu_1 + (p_{10}\, p_{02} + p_{12.4})\mu_2$

And

$D_2 = (p_{10}p_{20} + p_{10}\, p_{21.6} + p_{20}p_{12.4})\, \mu_0 + (p_{01}p_{20} + p_{21.6})\, \mu_1' + (p_{10}\, p_{02} + p_{12.4})\, \mu_2'$ (13)

Let $B_i^H(t)$ be the probability that the server is busy in repairing the unit due to hardware failure at an instant 't' given that the system entered state i at t = 0. The recursive relations $B_i^H(t)$ for are as follows:

B_0^H (t)=(12) q_{01}(t) © B_1^H (t)+ q_{02}(t) © B_2^H (t)

B_1^H (t)= $W_1^H(t)$ + q_{10}(t) © B_0^H (t) + $q_{11.3}$(t) © B_1^H (t) + $q_{12.4}$(t) © B_2^H (t)

B_2^H (t)= q_{20}(t) © B_0^H (t) + $q_{21.6}$(t)(13) © B_1^H (t) + $q_{22.5}$(t) © B_2^H (t) ....(14)

Where W_i^H(t) be the probability that the server is busy in state S_i due to hardware failure up to time t without making any transition to any other regenerative state or returning to the same via one or more non-regenerative states and so

$$W_1^H = e^{-(a\lambda_1 + b\lambda_2)t}\bar{G}(t) + (a\lambda_1 e^{-(a\lambda_1 + b\lambda_2)t} © 1)\bar{G}(t) + (b\lambda_2 e^{-(a\lambda_1 + b\lambda_2)t} © 1)\bar{G}(t)...(15)$$

3.4. Busy Period Analysis for Server

3.4.1 Due to Hardware Failure

3.4.2. Due to replacement of the software

Let B_i^S (t) be the probability that the server is busy due to replacement of the software at an instant 't' given that the system entered the regenerative state i at t = 0. We have the following recursive relations for B_i^S (t):

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

$B_1^S(t)$ =q_{10}(t) © B_0^S (t) + $q_{11.3}$(t) © B_1^S (t) +

$q_{12.4}$(t)) © $B_2^S(t)$

$B_2^S(t)$ = $W_2^S(t)$ +q_{20}(t) © B_0^S (t) + $q_{21.6}$(t) ©

B_1^S (t) + $q_{22.5}$(t) © $B_2^S(t)$ (16)

where W_i^S (t) be the probability that the server is busy in state S_i due to replacement of the software up to time t without making any transition to any other regenerative state or returning to the same via one or more non-regenerative states and so

$$W_2^S(t) = e^{-(a\lambda_1+b\lambda_2)t}\bar{F}(t) + (a\lambda_1 e^{-(a\lambda_1+b\lambda_2)t} © 1)\bar{F}(t) + (b\lambda_2 e^{-(a\lambda_1+b\lambda_2)t} © 1)\bar{F}(t).....(17)$$

Taking L.T. of above relations (14) and (16). And, solving for B_0^{*H} (s) and B_0^{*S} (s), the time for which server is busy due to repair and replacements respectively is given by

$$B_0^H = \lim_{s\to 0} sB_0^{*H}(s) = \frac{N_3^H}{D_2}$$

And

$$B_0^S = \lim_{s\to 0} sB_0^{*S}(s) = \frac{N_3^S}{D_2}$$

where

$$N_3^H = \tilde{W}_1^H(s)[p_{01}p_{20} + p_{21.6}]$$

$$N_3^S = (p_{10}p_{02} + p_{12.4})\tilde{W}_2^S(s)$$

And D_2 is already mentioned.

3.5. Expected Number of Replacements of the Units Due to Software Failure

Let $R_i^S(t)$ be the expected number of replacements of the failed software by the server in (0, t] given that the system entered the regenerative state i at t = 0. The recursive relations for $R_i^S(t)$ are given as

$R_0^S(t)$ = Q_{01}(t) Ⓢ $R_1^S(t)$ + Q_{02}(t) Ⓢ $R_2^S(t)$

$R_1^S(t)$ = Q_{10}(t)Ⓢ $R_0^S(t)$ + $Q_{11.3}$(t)Ⓢ $R_1^S(t)$ +

$Q_{12.4}$(t)Ⓢ $R_2^S(t)$

$R_2^S(t)$ = Q_{20}(t)Ⓢ[1+ $R_0^S(t)$]+ $Q_{21.6}$(t)Ⓢ[1+

$R_1^S(t)$]+ $Q_{22.5}$(t)Ⓢ[1+ $R_2^S(t)$]......(18)

Taking L.S.T. of relations (18) . And, solving for $\tilde{R}_0^S(s)$. The expected numbers of replacements per unit time to the hardware and software failures are given by

(16)

$$R_0^S(\infty) = \lim_{s\to 0} s\tilde{R}_0^S(s) = \frac{N_4^S}{D_2}$$

where

$$N_4^S = p_{02}p_{10} + p_{12.4}$$

And D_2 is already mentioned.

3.6. Expected Number of Visits by the Server

Let N_i(t) be the expected number of visits by the server in (0, t] given that the system entered the regenerative state i at t = 0. The recursive relations for N_i(t) are given as

N_0(t) = Q_{01}(t) Ⓢ[1+N_1(t)] + Q_{02}(t) Ⓢ[1+N_2(t)]

N_1(t) = Q_{10}(t) ⓈN_0(t) + $Q_{11.3}$(t) ⓈN_1(t) + $Q_{12.4}$(t) (18)

ⓈN_2(t)

N_2(t) = Q_{20}(t) ⓈN_0(t) + $Q_{21.6}$(t) ⓈN_1(t) + $Q_{22.5}$(t) (19)

ⓈN_2(t) (19)

Taking LST of relation (19) and solving for $\tilde{N}_0(s)$. The expected number of visits per unit time by the server is given by

$$N_0(\infty) = \lim_{s\to 0} s\tilde{N}_0(s) = \frac{N_5}{D_2}$$

where

$N_5 = p_{10}p_{20}+p_{20}p_{12.4}+ p_{10}\,p_{21.6}$

And D_2 is already specified.

3.7. Economic Analysis

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

$$P = K_0 A_0 - K_1 B_0^H - K_2 B_0^S - K_3 R_0^S - K_4 N_0 \tag{20}$$

where

K_0 = Revenue per unit up-time of the system

K_1 = Cost per unit time for which server is busy due to hardware failure

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

K_3 = Cost per unit replacement of the failed software

K_4 = Cost per unit visit by the server and $A_0, B_0^H, B_0^S, R_0^S, N_0$ are already defined.

3.8. Particular Case

Suppose $g(t) = ae^{-at}$, $f(t) = \theta e^{-\theta t}$

We can obtain the following results

MTSF (T_0) = $\frac{N_1}{D_1}$, Availability (A_0) = $\frac{N_2}{D_2}$

Busy period due to hardware failure $\left(B_0^H\right) = \frac{N_3^H}{D_2}$

Busy period due to software failure $\left(B_0^S\right) = \frac{N_3^S}{D_2}$

Expected number of replacements at software failure $\left(R_0^S\right) = \frac{N_4^S}{D_2}$,where

$$N_1 = \frac{(a\lambda_1 + b\lambda_2 + \alpha)(a\lambda_1 + b\lambda_2 + \theta) + a\lambda_1(a\lambda_1 + b\lambda_2 + \theta) + b\lambda_2(a\lambda_1 + b\lambda_2 + \alpha)}{R_1}$$

$$R_1 = (a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta)(a\lambda_1 + b\lambda_2 + \alpha)$$

$$D_1 = \frac{(a\lambda_1 + 2b\lambda_2 + \theta)(a\lambda_1 + b\lambda_2 + \alpha)(a\lambda_1 + b\lambda_2) - a\lambda_1\alpha(a\lambda_1 + b\lambda_2 + \theta) - b\lambda_2\theta(a\lambda_1 + b\lambda_2 + \alpha)}{R_1}$$

$$D_2 = \frac{\alpha\theta(a\lambda_1\alpha + b\lambda_2\theta + \alpha\theta) + (a\lambda_1\theta + b\lambda_2\alpha)(a\lambda_1 + b\lambda_2 + \alpha)(a\lambda_1 + b\lambda_2 + \theta)}{\alpha\theta R_1}$$

$$N_2 = \frac{(a\lambda_1 + b\lambda_2 + \theta)(a\lambda_1 + b\lambda_2 + \alpha)}{R_1},$$

$$N_3^H = \frac{a\lambda_1(a\lambda_1 + b\lambda_2 + \theta)(a\lambda_1 + b\lambda_2 + \alpha)}{\alpha R_1}$$

$$N_3^S = \frac{b\lambda_2(a\lambda_1 + b\lambda_2 + \alpha)(a\lambda_1 + b\lambda_2 + \theta)}{\theta R_1},$$

$$N_4^S = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2},$$

$$N_5 = \frac{\alpha a\lambda_1 + \theta(\alpha + b\lambda_2)}{(a\lambda_1 + b\lambda_2 + \theta)(a\lambda_1 + b\lambda_2 + \alpha)}$$

4. CONCLUSION

In the present study, the numerical results considering particular values to the parameters are obtained to carry out the profit analysis of a computer system with repair of h/w and replacement of s/w components. The graphs for mean time to system failure (MTSF), availability and profit are drawn with respect to h/w failure rate (λ_1) for the fixed values of other parameters as shown in figures 2, 3 and 4 respectively. It is observed that MTSF goes on increasing when h/w repair rate (α) and s/w replacement rate (θ) increase with a=0.7 and b=0.3. And, it becomes more if we interchange the values of a and b. However, the value of MTSF decreases with the increase of h/w and s/w failure rates.

Figures 2 and 3 indicate that availability and profit decrease with the increase of h/w and s/w failure rates λ1 and λ2 for a=0.7 and b=0.3. But, their values increase with the increase of repair rate (θ) and replacement rate (α). It is also observed that when the values of a and b are interchanged, the system becomes more profitable for λ1 >0.01.

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5. COMPARATIVE STUDY

The concept of inspection is introduce in the model proposed by Malik and Anand [2010] to decide the feasibility of repair of a computer system at its h/w failure. If repair of the h/w component is not feasible to the system, it is replaced immediately by new one. But in the present model repair of the system at its h/w failure is started immediately without getting inspection. The difference of MTSF and profit obtained for both the models are examined graphically as shown in figures 5 and 6. Figure 5 shows that MTSF of the present model is less than that of the model Malik and Anand [2010]. However, if we increase h/w repair rate (α) from 2.5 to 3.5, the MTSF of the present model becomes more. From figure 6, it is analysed that present model is always profitable for λ1>0.03. But we interchange the values of a=0.7 and b=0.3, the model Malik and Anand [2010] becomes more profitable for λ1≤0.03.

Thus, on the basis of the results obtained for a particular case it is suggested that a computer system in which h/w and s/w components fails immediately can be made more reliable and profitable to use by repairing the h/w components immediately with higher rates without conducting inspection.

5. ACKNOWLEDGEMENT
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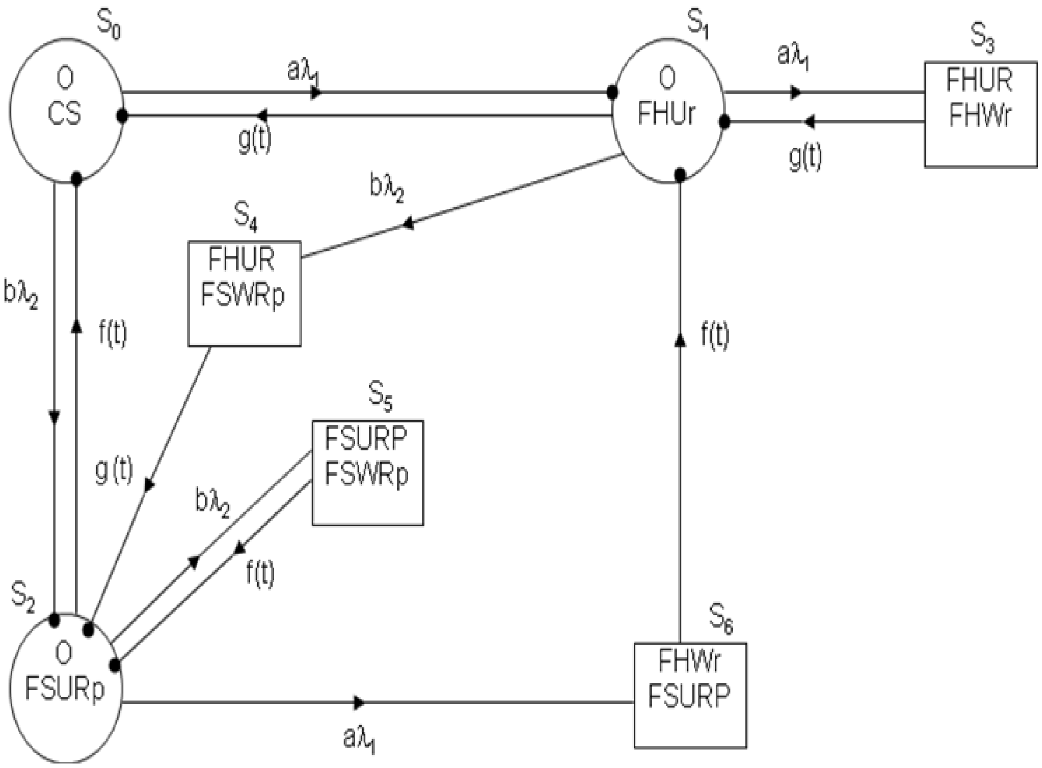

Fig. 1: State Transition Diagram

○ Up-state

□ Failed state

• Regenerative point

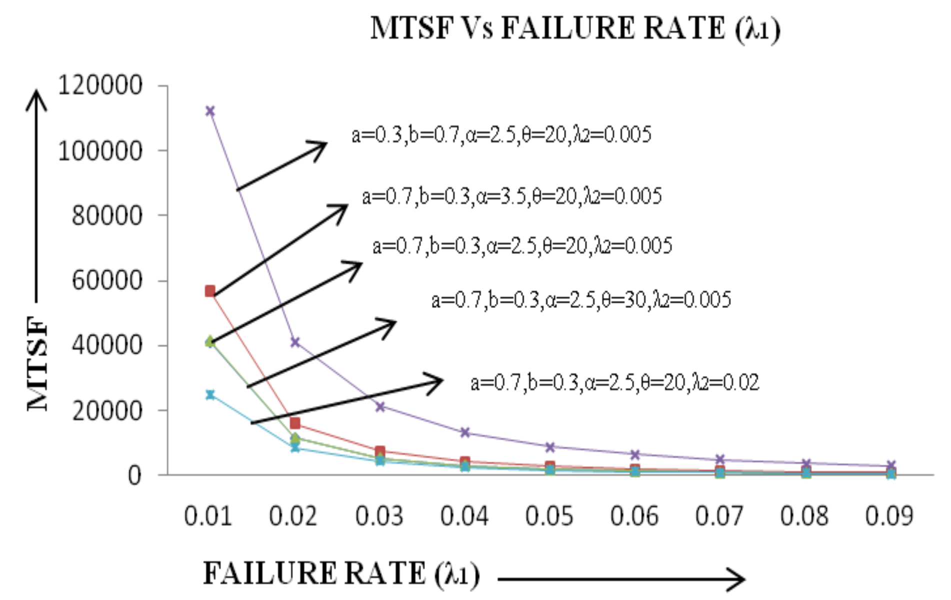
MTSF Vs FAILURE RATE (λ1)
MTSF
120000
100000
80000
60000
40000
20000
0
a=0.3,b=0.7,α=2.5,θ=20,λ2=0.005
a=0.7,b=0.3,α=3.5,θ=20,λ2=0.005
a=0.7,b=0.3,α=2.5,θ=20,λ2=0.005
a=0.7,b=0.3,α=2.5,θ=30,λ2=0.005
a=0.7,b=0.3,α=2.5,θ=20,λ2=0.02
0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09
FAILURE RATE (λ1)

Fig. 2

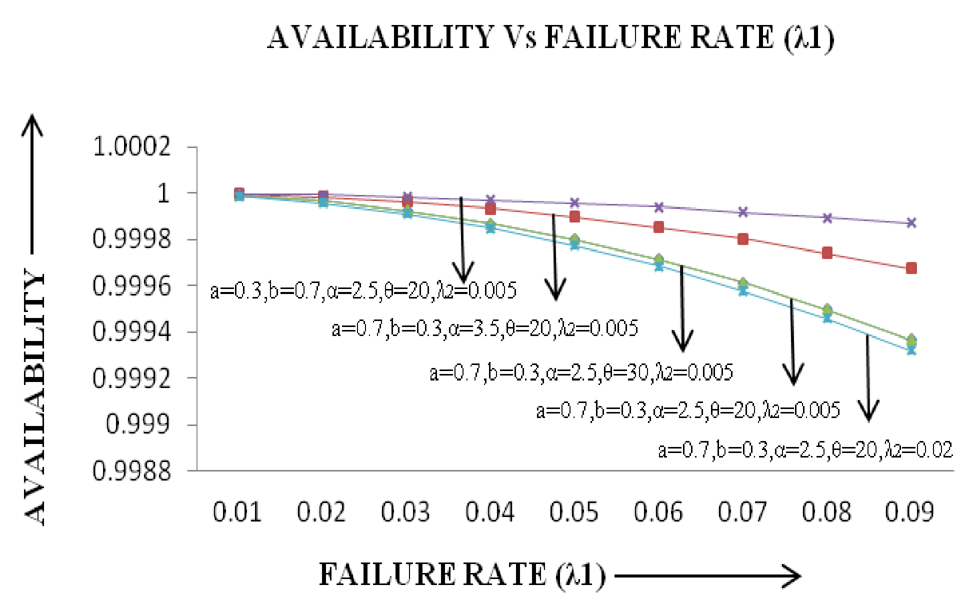
AVAILABILITY Vs FAILURE RATE (λ1)
AVAILABILITY
1.0002
1
0.9998
0.9996
0.9994
0.9992
0.999
0.9988
a=0.3,b=0.7,α=2.5,θ=20,λ2=0.005
a=0.7,b=0.3,α=3.5,θ=20,λ2=0.005
a=0.7,b=0.3,α=2.5,θ=30,λ2=0.005
a=0.7,b=0.3,α=2.5,θ=20,λ2=0.005
a=0.7,b=0.3,α=2.5,θ=20,λ2=0.02
0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09
FAILURE RATE (λ1)

Fig. 3

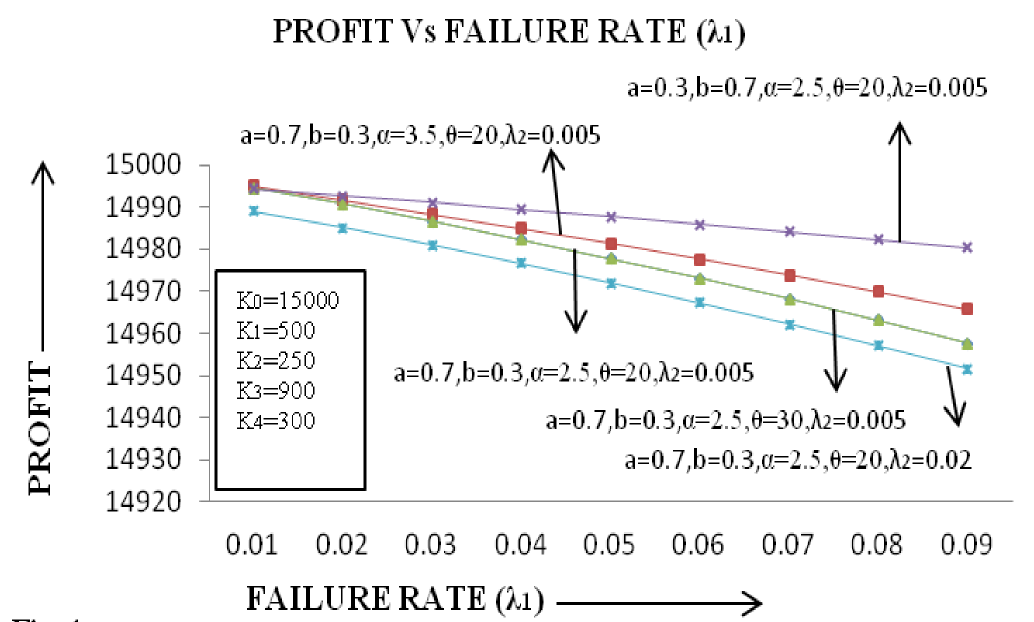

Fig.4

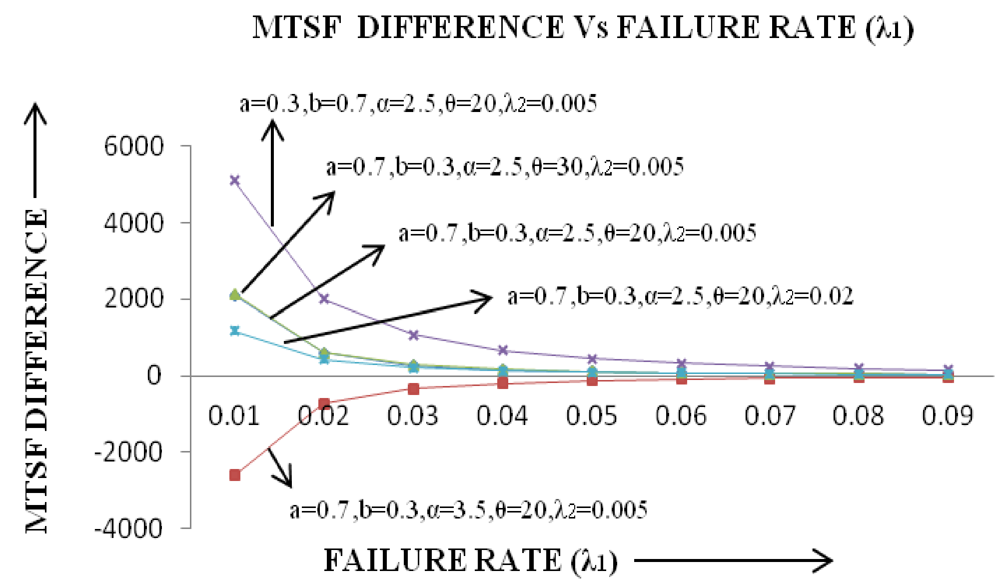

Fig. 5

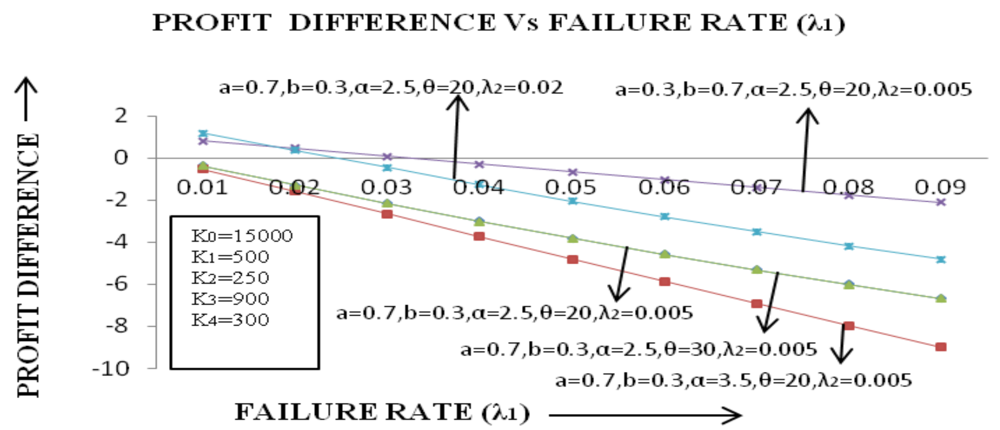

Fig. 6