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Analysis of a Cold Standby Computer System with Arrival Time of the Server at S/w Failure and Priority for S/w Up-Gradation over H/w Repair

Joginder Kumar

Department of Statistics, Sri Venkateswara College, University of Delhi, Delhi

ABSTRACT

The purpose of this paper is to examine the behaviour of some important performance measures of a computer system with the concepts of cold standby redundancy, arrival time of the server and priority for s/w up-gradation. A reliability model is developed in which two identical units of a computer system are taken up- one unit is initially operative and the other is kept as spare in cold standby. In each unit h/w and s/w work together and may fail independently from normal mode. There is a single server who visits the system immediately at h/w failure while some arrival time is given to him at s/w failure. Server repairs the unit at h/w failure; whereas s/w is upgraded from time to time when it fails to execute the programs properly. Priority to s/w up-gradation is given over h/w repair in case one unit is under repair due to h/w failure and other unit fails due to s/w. All random variables are assumed as statistically independent. The time to h/w and s/w failures follows negative exponential while the distributions of h/w repair time, s/w up-gradation time and arrival time of the server are taken as arbitrary with different probability density functions. The expressions for various performance measures are derived in steady state using semi-Markov process and regenerative point technique. Graphs are drawn to depict the behaviour of some performance measures such as MTSF, availability and profit function giving particular values to several parameters and costs.

Keywords: Computer System, H/w Repair, S/w up-gradation, Arrival Time and Priority.

1.Introduction

In modern society, computer systems are being used in most of the day-to-day activities because of their ability to finish the jobs in time with full efficiency. Therefore, industrialists are focusing on the development of such computer systems which suit the society in all respects. But suitability of a system depends purely on the reliability and quality of the system. Reliability is a design engineering discipline that assures a system (or product) will perform its intended function for the required duration under stated conditions. This includes not only the ability to maintain, test, and support the product throughout its total life cycle but to make the right decision when selecting the system architecture, materials, processes, and components -both software and hardware. Furthermore, reliability includes hardware, software and even human factors. System reliability estimation via simulation, simulation-based algorithms and other techniques take importance. It is proved that the performance and reliability of operating systems can be improved by taking spare unit(s) in standby.

Recently, reliability models of computer systems with cold standby redundancy have been suggested by some researchers including Malik and Anand [2010, 11, and 2012] and Malik and Kumar [2011]. Also, Malik and Sureria [2012] studied a cold standby computer system with h/w repair and s/w replacement by a server who visits the system immediately whenever needed. But, sometimes, it becomes very difficult for a server to reach at the system immediately may because of his pre-occupations. And, in such a situation, the server may take some time to arrive at the system (called arrival time of the server) with the condition that he has to attend the serious technical hitches occurred in the system immediately.

While considering the above observations and facts in mind, here the behaviour of some important performance measures of a computer system has been examined with the concepts of redundancy in cold standby, arrival time of the server and priority for s/w up gradation. A reliability model is developed in which two identical units of a computer system are taken up- one unit is initially operative and the other is kept as spare in cold standby. In each unit h/w and s/w work together and may fail independently from normal mode. There is a single server who visits the system immediately at h/w failure while some arrival time is given to him at s/w failure. Server repairs the unit at h/w failure whereas s/w is upgraded from time to time when it fails to execute the programs properly. Priority to s/w up gradation is given over h/w repair in case one unit is under repair due to h/w failure and other unit fails due to s/w. All random variables are assumed as statistically independent. The time to h/w and s/w failures follows negative exponential while the distributions of h/w repair, s/w up gradation and arrival times are taken as arbitrary with different probability density functions. The switch devices are perfect. The h/w and s/w works as new after repair and up-gradation. The expressions for various performance measures such as mean sojourn times, mean time to system failure (MTSF), availability, busy period of the server due to hardware and software failures, expected number of up-gradations of the software, expected number of visits by the server and profit are derived in steady state using semi-Markov process and regenerative point technique. The behaviour of some performance measures such as MTSF, availability and profit functions has been shown graphically giving arbitrary values to several parameters and costs.

Notations

E : The set of regenerative states
O : The unit is operative and in normal mode
Cs : The unit is cold standby
a/b : Probability that the system has hardware / software failure
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 up-gradation/under up-gradation continuously from previous state
FSWRp/FSWRP : The unit is failed due to the software and is waiting for up-gradation / waiting for up gradation continuously from previous state
w(t) / W(t) : pdf / cdf of waiting time of server due to software up gradation
f(t) / F(t) : pdf / cdf of up-gradation 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 transits directly to state S_j so that

$$\mu_i = \sum_j m_{ij} \quad \text{and} \quad m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*\prime}(0)$$

Ⓢ/© : Symbol for Laplace-Stieltjes convolution/Laplace convolution
~ / * : Symbol for Laplace Steiltjes Transform (LST) / LaplaceTransform (LT)

The following are the possible transition states of the system:

S_0= (O, Cs), S_1= (O, FHUr), S_2= (O, FSWRp), S_3= (O, FSURp),
S_4= (FHWr, FSURP), S_5= (FSWRP, FSWRp), S_6= (FHUr, FSWRP),
S_7 = (FHWr, FSURp), S_8 = (FHUR, FHWr), S_9= (FSURp, FSWRP),
S_{10}= (FSURP, FSWRp)

The state S_0–S_3 and S_7 are regenerative states while the states S_4–S_6 and S_8–S_{10} are non-regenerative as shown in figure 1.

Transition Probabilities and Mean Sojourn Times

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

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

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

$$p_{10} = g^*(a\lambda_1 + b\lambda_2), \qquad p_{17} = \frac{b\lambda_2}{a\lambda_1 + b\lambda_2}\left[1 - g^*(a\lambda_1 + b\lambda_2)\right],$$

$$p_{18}=\frac{a\lambda_1}{a\lambda_1+b\lambda_2}\left[1-g^*\left(a\lambda_1+b\lambda_2\right)\right],\quad p_{23}=w^*\left(a\lambda_1+b\lambda_2\right),$$

$$p_{25}=\frac{b\lambda_2}{a\lambda_1+b\lambda_2}\left[1-w^*\left(a\lambda_1+b\lambda_2\right)\right],\quad p_{26}=\frac{a\lambda_1}{a\lambda_1+b\lambda_2}\left[1-w^*\left(a\lambda_1+b\lambda_2\right)\right],$$

$$p_{30}=f^*\left(a\lambda_1+b\lambda_2\right),\quad p_{34}=\frac{a\lambda_1}{a\lambda_1+b\lambda_2}\left[1-f^*\left(a\lambda_1+b\lambda_2\right)\right],$$

$$p_{3,10}=\frac{b\lambda_2}{a\lambda_1+b\lambda_2}\left[1-f^*\left(a\lambda_1+b\lambda_2\right)\right] \tag{1}$$

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

$$p_{17}=\frac{b\lambda_2}{a\lambda_1+b\lambda_2+\alpha},\quad p_{11.8}=\frac{a\lambda_1}{a\lambda_1+b\lambda_2+\alpha},\quad p_{23.59}=\frac{b\lambda_2}{a\lambda_1+b\lambda_2+\beta},$$

$$p_{23.6}=\frac{a\lambda_1}{a\lambda_1+b\lambda_2+\beta},\ p_{31.4}=\frac{a\lambda_1}{a\lambda_1+b\lambda_2+\theta},\ p_{33.10}=\frac{b\lambda_2}{a\lambda_1+b\lambda_2+\theta} \tag{2}$$

It can be easily verified that $p_{01}+p_{02}=p_{10}+p_{17}+p_{18}=p_{23}+p_{25}+p_{26}=p_{30}+p_{34}+p_{3,10}=p_{10}+p_{11.8}+p_{17}=p_{23}+p_{23.59}+p_{23.6}=p_{30}+p_{31.4}+p_{33.10}=1$ (3)

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

$$\mu_0=\frac{1}{a\lambda_1+b\lambda_2},\ \mu_1=\frac{1}{a\lambda_1+b\lambda_2+\alpha},\ \mu_2=\frac{1}{a\lambda_1+b\lambda_2+\beta},\ \mu_3=\frac{1}{a\lambda_1+b\lambda_2+\theta} \tag{4}$$

also

$$m_{01}+m_{02}=\mu_0,\ m_{10}+m_{17}+m_{18}=\mu_1,\ m_{23}+m_{25}+m_{26}=\mu_2,\ m_{30}+m_{34}+m_{3,10}=\mu_3 \tag{5}$$

and

$$m_{10}+m_{11.8}+m_{13.7}=\mu_1',\ m_{20}+m_{23.6}+m_{23.56}=\mu_2',\ m_{30}+m_{31.4}+m_{33.10}=\mu_3'\text{(say)} \tag{6}$$

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

we have $$\mu_1'=\frac{\alpha+a\lambda_1}{\alpha(a\lambda_1+b\lambda_2+\alpha)},\ \mu_2'=\frac{(\alpha+a\lambda_1)\theta\beta+b\lambda_2\alpha(\beta+\theta)}{\alpha\theta\beta(a\lambda_1+b\lambda_2+\beta)},\ \mu_3^1=\frac{1}{\theta} \tag{7}$$

Reliability and Mean Time to System Failure (MTSF)

Let $\phi_i(t)$ 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):

$$\phi_i(t)=\sum_j Q_{i,j}(t)(S)\phi_j(t)+\sum_k Q_{i,k}(t) \tag{8}$$

where *j* is an un-failed regenerative state to which the given regenerative state *i* can transit and *k* is a failed state to which the state *i* can transit directly. Taking LST of above relations (8) and solving for $\tilde{\phi}_0(s)$

We have

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

The reliability of the system model can be obtained by taking Inverse Laplace Transform of (9). The mean time to system failure (MTSF) is given by

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

Where

$N_1 = \mu_0 + p_{01}\mu_1 + p_{02}\mu_2 + p_{02}p_{23}\mu_3$ and $D_1 = 1 - p_{01}p_{10} - p_{02}p_{23}p_{30}$

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

$$A_i(t) = M_i(t) + \sum_j q_{i,j}^{(n)}(t) © A_j(t) \qquad (11)$$

where *j* is any successive regenerative state to which the regenerative state *i* can transit through n≥1 transitions and $M_i(t)$ 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

$$M_0(t) = e^{-(a\lambda_1+b\lambda_2)t}, M_1(t) = e^{-(a\lambda_1+b\lambda_2)t}\bar{G}(t), M_2(t) = e^{-(a\lambda_1+b\lambda_2)t}\overline{W}(t), M_3(t) = e^{-(a\lambda_1+b\lambda_2)t}\bar{F}(t) \qquad (12)$$

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

$$A_0(\infty) = \lim_{s\to 0} sA_0^*(s) = \frac{N_2}{D_2} \qquad (13)$$

where

$N_2 = p_{30}(1-p_{33.10})\,\mu_0 + [p_{31.4} + p_{01}p_{30}]\,\mu_1 + p_{02}p_{10}(1-p_{33.10})\,\mu_2 + p_{02}p_{10}\,\mu_3$ and

$D_2 = p_{30}(1-p_{33.10})\,\mu_0 + [p_{31.4} + p_{01}p_{30}]\,\mu_1' + p_{02}p_{10}(1-p_{33.10})\,\mu_2' + p_{02}p_{10}\,\mu_3' + p_{17}[p_{31.4} + p_{01}p_{30}]\,\mu_7'$

BUSY PERIOD ANALYSIS FOR SERVER

(a) Due to Hardware Repair

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:

$$B_i^H(t) = W_i^H(t) + \sum_j q_{i,j}^{(n)}(t) © B_j^H(t) \qquad (14)$$

where *j* is any successive regenerative state to which the regenerative state *i* can transit through n transitions and $W_i^H(t)$ 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

$$W_1^H(t) = e^{-(a\lambda_1+b\lambda_2)t}\bar{G}(t) + \left[a\lambda_1 e^{-(a\lambda_1+b\lambda_2)} © 1\right]\bar{G}(t) + \left[b\lambda_2 e^{-(a\lambda_1+b\lambda_2)t} © 1\right]\bar{G}(t) \qquad (15)$$

(b) Due to Up-gradation of the Software

Let $B_i^S(t)$ be the probability that the server is busy due to up-gradation 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 $B_i^S(t)$:

$$B_i^S(t) = W_i^S(t) + \sum_j q_{i,j}^{(n)}(t) © B_j^S(t) \qquad (16)$$

where *j* is any successive regenerative state to which the regenerative state *i* can transit through n transitions and $W_i^S(t)$ be the probability that the server is busy in state S_i due to up-gradation 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

$$W_3^S(t) = e^{-(a\lambda_1+b\lambda_2)t}\overline{F}(t) + (a\lambda_1 e^{-(a\lambda_1+b\lambda_2)t} © 1)\overline{F}(t) + (b\lambda_2 e^{-(a\lambda_1+b\lambda_2)t} © 1)\overline{F}(t) \text{ and } W_7^S(t) = \overline{F}(t) \qquad (17)$$

Taking LT of above relations (14) & (16) and solving for $B_0^{*H}(s)$ and $B_0^{*S}(s)$, the time for which server is busy due to repair and up-gradation respectively is given by

$$B_0^H = \lim_{s\to 0} sB_0^{*H}(s) = \frac{N_3^H}{D_2} \qquad (18)$$

$$B_0^S = \lim_{s\to 0} sB_0^{*S}(s) = \frac{N_3^S}{D_2} \qquad (19)$$

where

$$N_3^H = [p_{01}(1-p_{33.10}) + p_{02}p_{31.4}]\tilde{W}_1^H(0)\ ,\ N_3^S = p_{01}p_{02}\tilde{W}_3^S(0) + p_{17}[p_{01}(1-p_{33.10}) + p_{02}p_{31.4}]\tilde{W}_7^S(0)$$

and D_2 is already mentioned.

Expected Number of Up-gradations of the Software

Let $R_i^S(t)$ be the expected number of up-gradations 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 $R_i(t)$ are given as

$$R_i^S(t) = \sum_j Q_{i,j}^{(n)}(t)(S)\left[\delta_j + R_j^S(t)\right] \quad (20)$$

Where j is any regenerative state to which the given regenerative state *i* transits and δj=1, if *j* is the regenerative state where the server does job afresh, otherwise δj= 0. Taking LST of relations (20) and solving for $\tilde{R}_0(s)$, the expected number of up-gradations per unit time to the software failures is given by

$$R_0(\infty) = \lim_{s\to 0} s\tilde{R}_0^S(s) = \frac{N_4}{D_2} \quad (21)$$

where

$N_4 = p_{01}p_{02} + p_{17}[p_{01}(1-p_{33.10}) + p_{02}p_{31.4}]$ and D_2 is already mentioned.

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

$$N_i(t) = \sum_j Q_{i,j}^{(n)}(t)(S)\left[\delta_j + N_j(t)\right] \quad (22)$$

where j is any regenerative state to which the given regenerative state *i* transits and δj =1, if *j* is the regenerative state where the server does job afresh, otherwise δj =0. Taking LST of relation (22) and solving for $\tilde{N}_0(s)$. The expected numbers of visits per unit time by the server are given by

$$N_0(\infty) = \lim_{s\to 0} s\tilde{N}_0(s) = \frac{N_5}{D_2} \quad (23)$$

where

$N_5 = p_{10}(1-p_{33.10})$ and D_2 is already specified.

Profit Analysis

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

$$P = K_0A_0 - K_1B_0^H - K_2B_0^S - K_3R_0 - K_4N_0 \quad (24)$$

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 repair
K_2 = Cost per unit time for which server is busy due to software up-gradation
K_3 = Cost per unit up gradation of the failed software
K_4 = Cost per unit visit by the server and $A_0, B_0^H, B_0^S, R_0, N_0$ are already defined.

Particular Case

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

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 repair $\left(B_0^H\right) = \frac{N_3^H}{D_2}$

Busy period due to software up-gradation $\left(B_0^S\right)=\dfrac{N_3^S}{D_2}$

Expected number of up-gradation at software failure $\left(R_0\right)=\dfrac{N_4}{D_2}$

Expected number of visits by the server $\left(N_0\right)=\dfrac{N_5}{D_2}$ (25)

Where

$$N_1=\frac{\begin{array}{c}(a\lambda_1+b\lambda_2+\beta)(a\lambda_1+b\lambda_2+\theta)(a\lambda_1+b\lambda_2+\alpha)+a\lambda_1(a\lambda_1+b\lambda_2+\theta)(a\lambda_1+b\lambda_2+\beta)\\+b\lambda_2(a\lambda_1+b\lambda_2+\alpha)(a\lambda_1+b\lambda_2+\theta)+b\lambda_2\beta(a\lambda_1+b\lambda_2+\beta)\end{array}}{R_1}$$

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

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

$$D_2=\frac{\begin{array}{c}\theta\alpha^2\beta(a\lambda_1+b\lambda_2+\beta)(\theta+a\lambda_1)+(a\lambda_1+b\lambda_2+\beta)(a\lambda_1+b\lambda_2+\theta)\beta\\(\alpha b\lambda_2+\theta a\lambda_1)(\alpha+a\lambda_1)+b\lambda_2\alpha(\theta+a\lambda_1)[\beta\theta(\alpha+a\lambda_1)+(\beta+\theta)\alpha b\lambda_2]\end{array}}{\alpha\beta\theta R_1}$$

$$N_2=\frac{(2a\lambda_1+2b\lambda_2+\beta+\theta)\alpha b\lambda_2+(a\lambda_1+\theta)\alpha(a\lambda_1+b\lambda_2+\beta)+a\lambda_1(a\lambda_1+b\lambda_2+\theta)(a\lambda_1+b\lambda_2+\beta)}{R_1}$$

$$N_3^H=a\lambda_1/\alpha(a\lambda_1+b\lambda_2)\ \ N_3^S=(\alpha+a\lambda_1)b\lambda_2/\theta(a\lambda_1+b\lambda_2)(\alpha+a\lambda_1+b\lambda_2),$$

$$N_4=(\alpha+a\lambda_1)b\lambda_2/(a\lambda_1+b\lambda_2)(\alpha+a\lambda_1+b\lambda_2)\ \ N_5=\alpha(\theta+a\lambda_1)/(a\lambda_1+b\lambda_2+\theta)(a\lambda_1+b\lambda_2+\alpha)$$

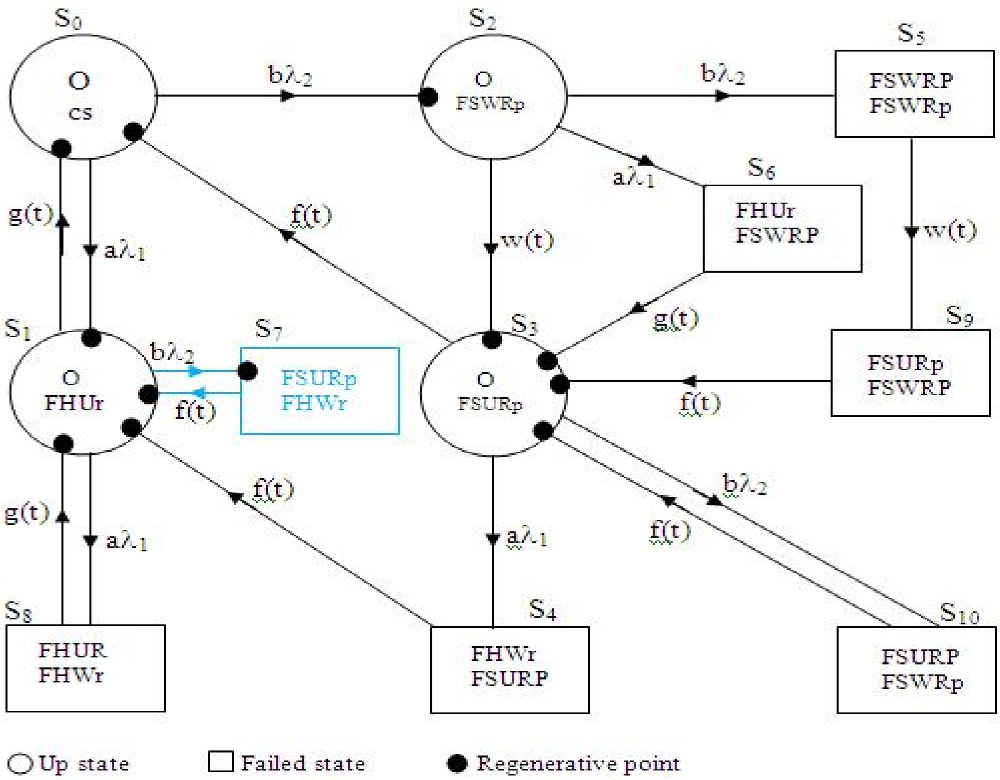

Fig:-1 State Transition Diagram

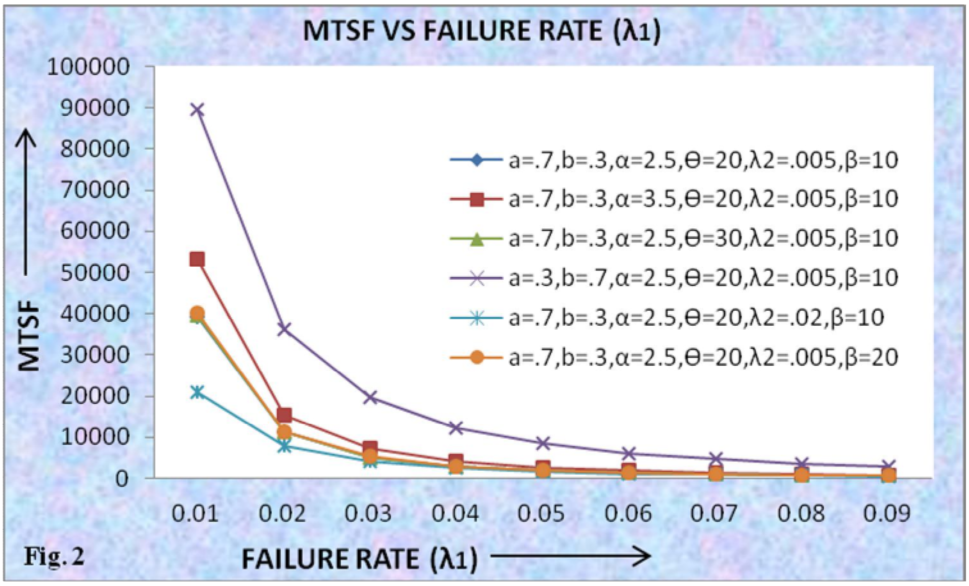

Fig. 2

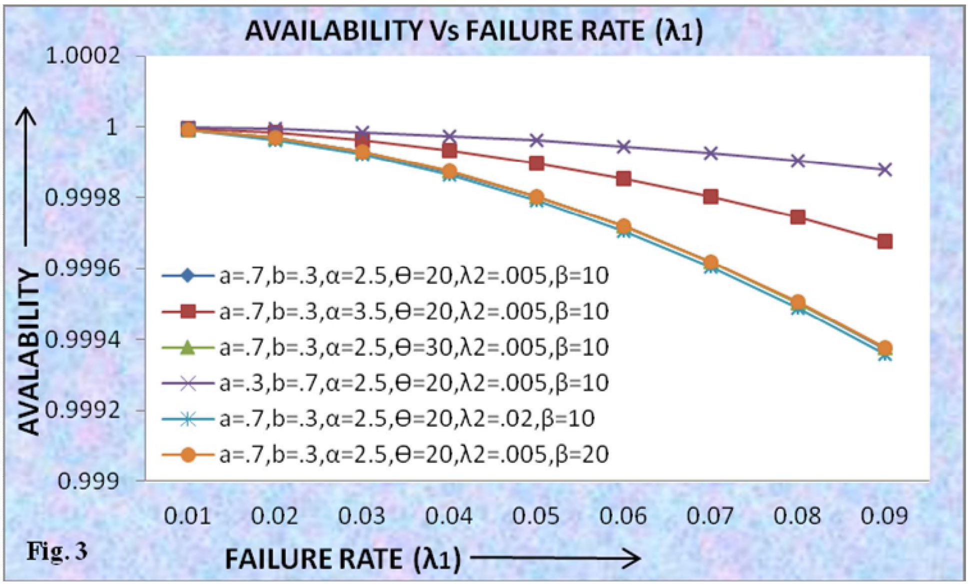

Fig. 3

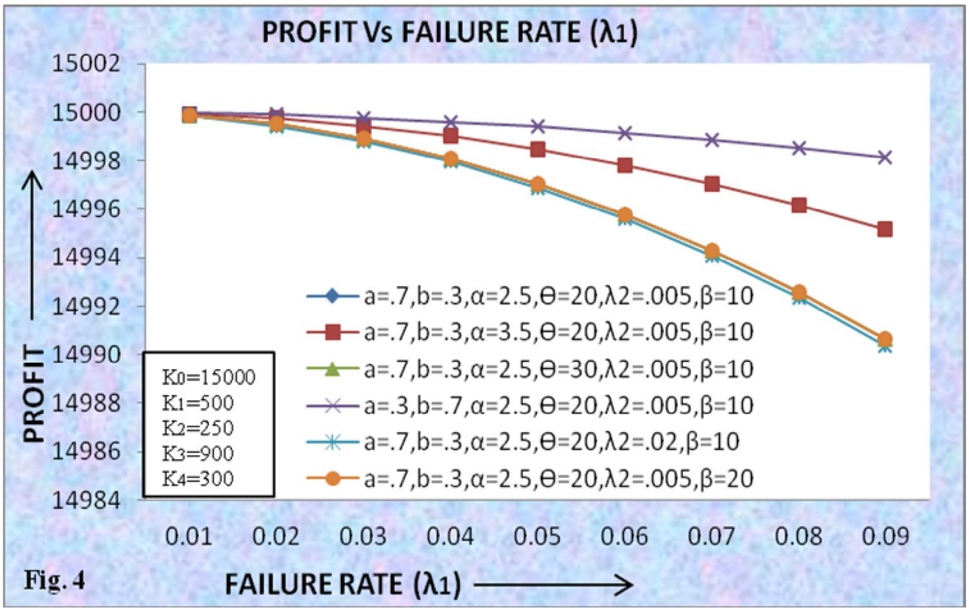

Fig. 4

2.Conclusion

Giving particular values to various parameters and costs, it is observed that MTSF, availability and profit of the system model go on decreasing with the increase of h/w and s/w failure rates (λ_1 and λ_2) for fixed values of other parameters including a=.7 and b=.3 as shown in figures 2, 3 and 4 respectively. However, their values increase with the increase of h/w repair rate (α), s/w up-gradation rate (□) and arrival rate of the server (β).

Thus, it is concluded that, a computer system in which priority is given to s/w up-gradation over h/w repair can be made more profitable by increasing the arrival rate of the server at s/w failure.

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