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RELIABILITY MEASURES OF A COMPUTER SYSTEM WITH SOFTWARE REDUNDANCY SUBJECT TO MAXIMUM REPAIR TIME

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ABSTRACT

In this paper, the authors are concentrated on the reliability measures of a computer system with software redundancy by introducing the concepts of maximum repair time. The system fails independently from normal mode. All the repair activities such as hardware repair, software up-gradation and hardware replacement are carried out by a single server immediately on need basis. The hardware component is replaced after a pre-specific time‘t’ (called maximum repair time) by new one when server fails to get its repair. All random variables are statistically independent. The negative exponential distribution is taken for the failure time of the component while the distributions of repair time, up-gradation time and replacement time are assumed arbitrary with different probability density functions. Semi-Markov process and regenerative point technique are used for obtaining the values of various performance measures. The behaviour of some important performance measure has been examined for different parameters and costs. The profit comparison of the present model has also been made with that of the model analyzed by Munday and Malik (2015).

KEYWORDS: Computer System, Software Redundancy, Up-gradation, Replacement, Maximum Repair Times and Reliability Measures.

1. INTRODUCTION

In the age of modern technology, a computer system is demanded with high reliable hardware and software components. When the industrialists and engineers uses a computer system for analysing the data of any company, firm and organization then the necessity and have to on computer increases and the possibility of their failures also increases. Generally, a computer system exhibits two types of failures - hardware and software. And, the impact of these failures ranges from inconvenience to economic damage and may also lead to loss of life. Therefore, it becomes necessary to handle such systems with very care and of high reliability. The remarkable progress in the field of computer technology has resulted in the widespread usage of computer applications in most of all academic, business and industrial sectors. A major challenge to the industrialists now a day is to provide reliable hardware and software components. Most of the academicians are also trying to explore new techniques for reliability improvement of the computer systems. In spite of these efforts, a little work has been dedicated to the reliability modelling of computer systems. And, most of the research work carried out so far in the subject of hardware and software reliability has been limited to the consideration of either hardware or software subsystem alone. Osaki and Nishio (1979) and Lai et al. (2002) evaluated the availability analysis of distributed hardware/software systems. And, Malik and Anand (2010) discussed on a reliability model of a computer system with independent hardware and software failures considering different repair policies. Recently, reliability models of two-unit cold standby computer systems having independent hardware and software failures have been suggested by some more researchers including Anand and Malik (2011) and Kumar and Malik (2013). Also, Malik and Sureria (2012) and Malik and Munday (2014) studied a cold standby computer system with hardware repair and software up-gradation by a server who visits the system immediately whenever needed. And, Munday et al. (2015) discussed a computer system model with hardware redundancy using the concept of maximum repair time. In view of the practical importance of computer systems in our daily lives, a stochastic model of a computer system is developed in which initially system is operative with one software component kept as spare in cold standby. Every system comprises hardware and software components which have independent failure via normal mode. A single server visits the system immediately as and when needed. The hardware component under goes for repair at its failure and replaced by new one in case it is not repaired up to a maximum repair time. However, software component is up-graded at its failure. The failure time distribution of the components follow negative exponential whereas the distributions of up-gradation time, repair time and replacement time are taken as arbitrary with different probability density functions. Various reliability and economic measures of the system model such as transition probabilities, mean sojourn times, mean time to system failure (MTSF), availability, busy period of the server due to hardware repair and replacement, busy period of the server due to software up-gradation, expected number of hardware repairs, expected number of software up-gradations, expected number of hardware replacements by the server and profit function have been obtained using semi-Markov process and regenerative point technique. The graphical study has also been made to depict the behavior and profit comparison of the system for different values of parameters and costs with that of Munday and Malik (2015).

2. Some Important Notations

O: Computer system is operative

Scs: Software is in cold standby

a/b: Probability that the system has hardware / software failure

λ_1/ λ_2: Hardware/Software failure rate

α_0: The rate by which failed component undergoes for replacement by new one when its repair is not possible by the server in a given pre specific time (called maximum repair time)

HFUr /HFWr: The hardware is failed and under/waiting for repair

SFUg/SFWUg: The software is failed and under/waiting for up-gradation

HFURp /HFWRp: The hardware is failed and under/waiting for replacement after the elapsed of maximum repair time t

HFUR/HFWR: The hardware is failed and continuously under/ waiting for repair from previous state

SFUG/SFWUG: The software is failed and continuously under /waiting for up- gradation from previous state

HFURP/HFWRP: The hardware is failed and under/ waiting for replacement continuously from previous state

G(t)/G(t): pdf/cdf of hardware repair time

F(t)/F(t): pdf/cdf of software up-gradation time

R(t)/R(t): pdf/cdf of hardware replacement time

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

$q_{ij.k}$ (t)/$Q_{ij.k}(t)$: pdf/cdf of direct transition time from regenerative state S_i to a regenerative state S_j or to a failed state S_j visiting state S_k 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 via 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

$$\mu_i = \sum_j m_{ij} \;\; and \; m_{ij} = \int_0^{\infty} t dQ_{ij}(t) = -q_{ij}^{*'}(0)$$

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

*/**: Symbol for Laplace Transformation (LT)/Laplace Stieltjes Transformation (LST)

P: Profit of the present model

P1:Profit of the system model Munday and Malik (2015)

3. Analysis of System Model

The state transition diagram is shown in the following figure:

State Transition Diagram

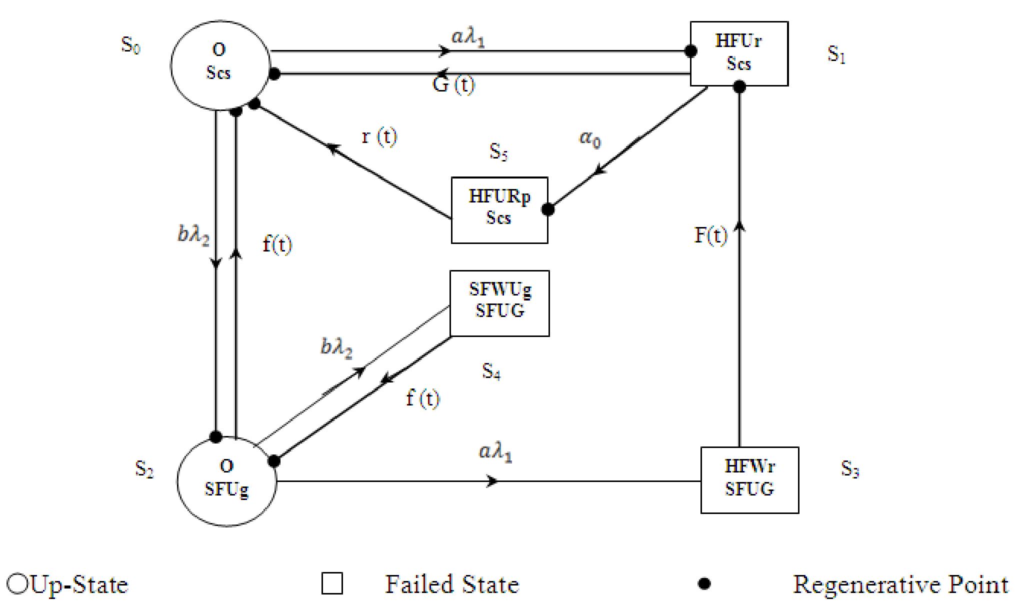

Fig. 1

3.1 Transition Probabilities and Mean Sojourn Times

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

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

$p_{01} = \frac{a\lambda_1}{a\lambda_1+b\lambda_2}$, $p_{02} = \frac{b\lambda_2}{a\lambda_1+b\lambda_2}$, $p_{10} = g^*(\alpha_0)$, $p_{15} = 1 - g^*(\alpha_0)$, $p_{20} = f^*(a\lambda_1 + b\lambda_2)$

$p_{23} = \frac{a\lambda_1}{a\lambda_1+b\lambda_2}\{1 - f^*(a\lambda_1 + b\lambda_2)\}$, $p_{24} = \frac{b\lambda_2}{a\lambda_1+b\lambda_2}\{1 - f^*(a\lambda_1 + b\lambda_2)\}$,

$p_{31} = p_{42} = f^*(0)$

$p_{51} = r^*(0)$, $p_{21.3} = \frac{a\lambda_1}{a\lambda_1+b\lambda_2}\{1 - f^*(a\lambda_1 + b\lambda_2)\}f^*(0)$,

$p_{22.4} = \frac{b\lambda_2}{a\lambda_1+b\lambda_2}\{1 - f^*(a\lambda_1 + b\lambda_2)\}f^*(0)$

If $g(t) = \alpha e^{-\alpha t}$, $f(t) = \theta e^{-\theta t}$ and $r(t) = \beta e^{-\beta t}$, then

We have, $r^*(0) = f^*(0) = g^*(0) = 1$ and $p + q = 1$

It can be easily verified that

$p_{01} + p_{02} = p_{10} + p_{15} = p_{20} + p_{23} + p_{24} = p_{31} = p_{42} = p_{20} + p_{21.3} + p_{22.4} = p_{50} = 1$

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

$\mu_0 = \frac{1}{a\lambda_1+b\lambda_2}$, $\mu_1 = \frac{1}{\alpha+\alpha_0}$, $\mu_2 = \frac{1}{a\lambda_1+b\lambda_2+\theta}$, $\mu_2' = \frac{1}{\theta}$, $\mu_5 = \frac{1}{\beta_0}$

Also, $m_{01} + m_{02} = \mu_0$, $m_{10} + m_{15} = \mu_1$, $m_{20} + m_{23} + m_{24} = \mu_2$, $m_{51} = \mu_5$ and

$m_{20} + m_{21.3} + m_{22.4} = \mu_2'$

3.2 Reliability and Mean Time to System Failure (MTSF)

Let $\phi_i(t)$ be the cdf of first passage time from regenerative state S_i to a failed state. Regarding the failed state as absorbing state, we have the following recursive relations for $\phi_i(t)$,

$\phi_0(t) = Q_{02}(t) \,\&\, \phi_2(t) + Q_{01}(t)$

$\phi_2(t) = Q_{20}(t) \,\&\, \phi_0(t) + Q_{23}(t) + Q_{24}(t)$ (1)

Taking LST of above relations (1) and solving for $\phi_0^{**}(s)$

We have

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

The reliability of the system model can be obtained by taking Laplace inverse transform of the above equation.

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

$$MTSF = \lim_{s\to 0} \frac{1-\phi_0^{**}(s)}{s} = \frac{N_1}{D_1} \quad (2)$$

Where

$$N_1 = \mu_0 + p_{02}\mu_2 \; and \; D_1 = 1 - p_{02}p_{20} \quad (3)$$

3.3 Steady State Availability

Let $A_i(t)$ be the probability that the system is in up-state at an instant‘t’ given that the system entered regenerative state $S_i \; at \; t = 0$. The recursive relations for $A_i(t)$ are given as:

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

$$A_1(t) = q_{10}(t)©A_0(t)+ q_{15}(t)©A_5(t)$$

$$A_2(t) = M_2(t) + q_{20}(t)©A_0(t) + q_{21.3}(t)© A_1(t) + q_{22.4}(t)© A_2(t)$$

$$A_5(t) = q_{50}(t)©A_0(t) \quad (4)$$

Where

$$M_0(t) = e^{-(a\lambda_1+b\lambda_2)t} \; and \; M_2(t) = e^{-(a\lambda_1+b\lambda_2)t}\,\overline{F(t)}$$

Taking LT of relations (4) and solving for $A_0^*(s)$, the steady state availability is given by

$$A_0(\infty) = \lim_{s\to 0} s\, A_0^*(s) = \frac{N_2}{D_2} \quad (5)$$

Where

$$N_2 = (1 - p_{22.4})\mu_0 + p_{02}\mu_2$$

$$D_2 = (1 - p_{22.4})\mu_0 + p_{02}\mu_2' + (p_{20}p_{01} + p_{21.3})(\mu_1 + p_{15}\mu_5) \quad (6)$$

3.4 Busy Period of the 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 $S_i \; at \; t = 0$. The recursive relations for $B_i^H(t)$ are as follows:

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

$$B_1^H(t) = W_1^H(t) + q_{10}(t)©B_0^H(t) + q_{15}(t)©B_5^H(t)$$

$$B_2^H(t) = q_{20}(t)©B_0^H(t) + q_{21.3}(t)©B_1^H(t) + q_{22.4}(t)©B_2^H(t)$$

$B_5^H(t) = q_{50}(t)©B_0^H(t)$ (7)

Where

$W_1^H(t) = e^{-\alpha_0 t}\,\overline{G(t)} + (\alpha_0 e^{-\alpha_0 t}©1)\overline{G(t)}\,dt$

(b). Due to software Up-gradation

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 $S_i\ at\ t = 0$. We have the following recursive relations for $B_i^S(t)$:

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

$B_1^S(t) = q_{10}(t)©B_0^S(t) + q_{15}(t)©B_5^S(t)$

$B_2^S(t) = W_2^S(t) + q_{20}(t)©B_0^S(t) + q_{21.3}(t)©B_1^S(t) + q_{22.4}(t)©B_2^S(t)$

$B_5^S(t) = q_{50}(t)©B_0^S(t)$ (8)

Where

$W_2^S(t) = e^{-(a\lambda_1+b\lambda_2)t}\,\overline{F(t)} + \left(a\lambda_1 e^{-(a\lambda_1+b\lambda_2)t}©1\right)\overline{F(t)} + \left(b\lambda_2 e^{-(a\lambda_1+b\lambda_2)t}©1\right)\overline{F(t)}$

(c). Due to Hardware Replacement

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

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

$B_1^{Rp}(t) = q_{10}(t)©B_0^{Rp}(t) + q_{15}(t)©B_5^{Rp}(t)$

$B_2^{Rp}(t) = q_{20}(t)©B_0^{Rp}(t) + q_{21.3}(t)©B_1^{Rp}(t) + q_{22.4}(t)©B_2^{Rp}(t)$

$B_5^{Rp}(t) = W_5^{Rp}(t) + q_{50}(t)©B_0^{Rp}(t)$ (9)

Where

$W_5^{Rp}(t) = \overline{R(t)}$

Taking LT of relations (7), (8) & (9), solving for $B_0^{H^*}(t), B_0^{S^*}(t)\ and\ B_0^{Rp^*}(t)$. The time for which server is busy due to repair, up-gradations and replacement respectively are given by

$B_0^H(t) = \lim_{s\to 0} s\,B_0^{H^*}(t) = \frac{N_3^H}{D_2}$ (10)

$B_0^S(t) = \lim_{s\to 0} s\, B_0^{S^*}(t) = \frac{N_3^S}{D_2}$ (11)

$B_0^{Rp}(t) = \lim_{s\to 0} s\, B_0^{Rp^*}(t) = \frac{N_3^{Rp}}{D_2}$ (12)

Where

$N_3^H = p_{02}p_{21.3}W_1^{H^*}(0) + p_{01}(1-p_{22.4})W_1^{H^*}(0)$

$N_3^S = p_{02}W_2^{S^*}(0)$

$N_3^{Rp} = p_{15}W_5^{Rp^*}(0)(p_{01}(1-p_{22.4}) + p_{02}p_{21.3}) and\ D_2\ is\ already\ mentioned.$ (13)

3.5 Expected Number of Hardware Repairs

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

$NHR_0(t) = Q_{01}(t)\ \&\ [1 + NHR_1(t)] + Q_{02}(t)\ \&\ NHR_2(t)$

$NHR_1(t) = Q_{10}(t)\ \&\ NHR_0(t) + Q_{15}(t)\ \&\ NHR_5(t)$

$NHR_2(t) = Q_{20}(t)\ \&\ NHR_0(t) + Q_{21.3}(t)\ \&\ NHR_1(t) + Q_{22.4}(t)\ \&\ NHR_2(t)$

$NHR_5(t) = Q_{50}(t)\ \&\ NHR_0(t)$ (14)

Taking LST of relations (14) and solving for $NHR_0^{**}(s)$. The expected number of hardware repair is given by

$NHR_0 = \lim_{s\to 0} sNHR_0^{**}(s) = \frac{N_4}{D_2}$ (15)

Where $N_4 = p_{01}(1-p_{22.4}) and\ D_2\ is\ already\ mentioned.$ (16)

3.6 Expected Number of Software Up-gradations

Let $NSU_i(t)$ be the expected number of software up-gradations in (0, t] given that the system entered the regenerative state $S_i\ at\ t = 0$. The recursive relations for $NSU_i(t)$ are given as follows:

$NSU_0(t) = Q_{01}(t)\ \&\ NSU_1(t) + Q_{02}(t)\ \&\ [1 + NSU_2(t)]$

$NSU_1(t) = Q_{10}(t)\ \&\ NSU_0(t) + Q_{15}(t)\ \&\ NSU_0(t)$

$NSU_2(t) = Q_{20}(t)\ \&\ NSU_0(t) + Q_{21.3}(t)\ \&\ NSU_1(t) + Q_{22.4}(t)\ \&\ NSU_2(t)$

$NSU_5(t) = Q_{50}(t)\ \&\ NSU_0(t)$ (17)

Taking LST of relations (17) and solving for $NSU_0^{**}(s)$. The expected numbers of software up-gradation are given by

$$NSU_0(\infty) = \lim_{s\to 0} sNSU_0^{**}(s) = \frac{N_5}{D_2} \quad (18)$$

Where$N_5 = p_{02}(1-p_{22.4})$ *and* D_2 *is already mentioned*. (19)

3.7 Expected Number of Hardware Replacement

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

$$NHRp_0(t) = Q_{01}(t) \,\&\, NHRp_1(t) + Q_{02}(t) \,\&\, NHRp_2(t)$$

$$NHRp_1(t) = Q_{10}(t) \,\&\, NHRp_0(t) + Q_{15}(t) \,\&\, [1 + NHRp_5(t)]$$

$$NHRp_2(t) = Q_{20}(t) \,\&\, NHRp_0(t) + Q_{21.3}(t) \,\&\, NHRp_1(t) + Q_{22.4}(t) \,\&\, NHRp_2(t)$$

$$NHRp_5(t) = Q_{50}(t) \,\&\, NHRp_0(t) \quad (20)$$

Taking LST of relations (20) and solving for $NHRp_0^{**}(s)$. The expected number of hardware repair is given by

$$NHRp_0 = \lim_{s\to 0} sNHRp_0^{**}(s) = \frac{N_6}{D_2} \quad (21)$$

Where $N_6 = p_{01}p_{15}(1-p_{22.4}) + p_{02}p_{15}p_{21.3}$ *and* D_2 *is already mentioned*. (22)

4. Profit Analysis

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

$$P = K_0A_0 - K_1B_0^H - K_2B_0^S - K_3NHR_0 - K_4NSU_0 - K_5B_0^{Rp} - K_6NHRp_0 \quad (23)$$

Where

$K_0 = Revenue\ per\ unit\ up - time\ of\ the\ system$

$K_1 = Cost\ per\ unit\ time\ for\ which\ server\ is\ busy\ due\ to\ hardware\ repair$

$K_2 = Cost\ per\ unit\ time\ for\ which\ server\ is\ busy\ due\ to\ software\ up - gradation$

$K_3 = Cost\ per\ unit\ repair\ of\ the\ failed\ hardware$

$K_4 = Cost\ per\ unit\ up - gradation\ of\ the\ failed\ software$

$K_5 = Cost\ per\ unit\ time\ for\ which\ server\ is\ busy\ due\ to\ hardware\ replacement$

$K_6 = Cost\ per\ unit\ replacement\ of\ the\ failed\ hardware$

and $A_0, B_0^H, B_0^S, NHR_0, NSU_0, B_0^{Rp}, NHRp_0$ *are already defined.*

5. Particular Cases

Suppose $g(t) = \alpha e^{-\alpha t}, f(t) = \theta e^{-\theta t}$ and $r(t) = \alpha_0 e^{-\alpha_0 t}$

We can obtain the following results:

$$MTSF(T_0) = \frac{N_1}{D_1}$$

$$Availability(A_0) = \frac{N_2}{D_2}$$

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

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

$$Busy\ Period\ due\ to\ hardware\ replacement\ (B_0^{Rp}) = \frac{N_3^{Rp}}{D_2}$$

$$Expected\ number\ of\ repair\ at\ hardware\ failure\ (NHR_0) = \frac{N_4}{D_2}$$

$$Expected\ number\ of\ up-gradation\ at\ software\ failure\ (NSU_0) = \frac{N_5}{D_2}$$

$$Expected\ number\ of\ replacement\ at\ hardware\ failure\ (NHRp_0) = \frac{N_6}{D_2}$$

Where

$$N_1 = \frac{a\lambda_1 + 2b\lambda_2 + \theta}{(a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta)} \qquad D_1 = \frac{(a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta) - \theta b\lambda_2}{(a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta)}$$

$$N_2 = \frac{1}{a\lambda_1 + b\lambda_2} \qquad D_2 = \frac{\theta(a\lambda_1 + \theta)(a + a_0) + (a\lambda_1 + b\lambda_2 + \theta)(b\lambda_2(a + a_0) + a\lambda_1(\theta + a_0))}{\theta(a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta)(a + a_0)}$$

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

$$N_3^{Rp} = \frac{a\lambda_1 a_0}{\beta_0(a\lambda_1 + b\lambda_2)(a + a_0)} \qquad N_4 = \frac{a\lambda_1(a\lambda_1 + \theta)}{(a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta)}$$

$$N_5 = \frac{b\lambda_2(a\lambda_1 + \theta)}{(a\lambda_1 + b\lambda_2)(a\lambda_1 + b\lambda_2 + \theta)} \qquad N_6 = \frac{a\lambda_1 a_0}{(a\lambda_1 + b\lambda_2)(a + a_0)}$$

6. CONCLUSION

The effect of various parameters on reliability measures of a computer system has been observed by considering exponential distribution for the random variables associated with repair, up-gradation and replacement times as shown in figures 2 to 4. It is analyzed that mean time to system failure (MTSF), availability and profit function go on decreasing with the increase of failure rates (λ_1 and λ_2) and their values increase with the increase of hardware repair rate (α), software up-gradation rate (θ) and hardware replacement rate (β). It is also concluded that there is no effect of α_0 on MTSF whereas availability and profit become more with the increase of the rate α_0 irrespective of any constraint on the values of a and b.

7. Graphical Presentation of Reliability Measures for the System Model

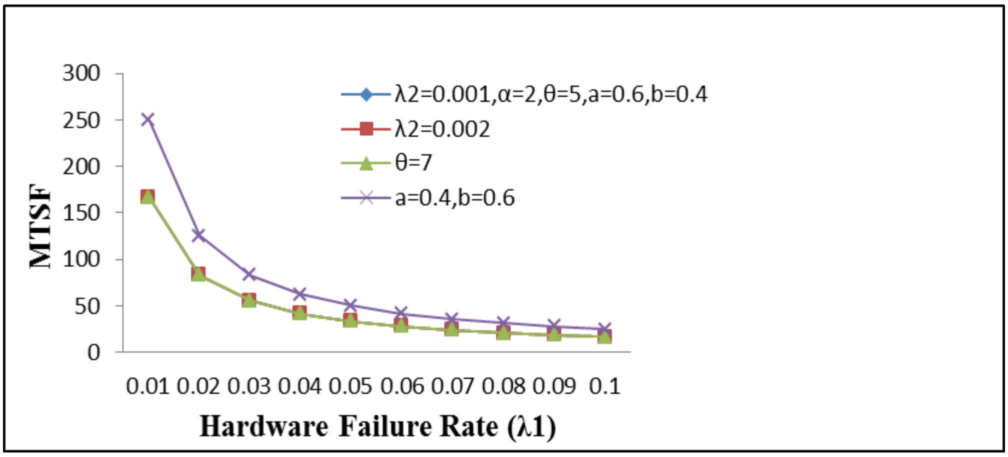

Fig. 2: MTSF Vs Hardware Failure Rate (λ1).

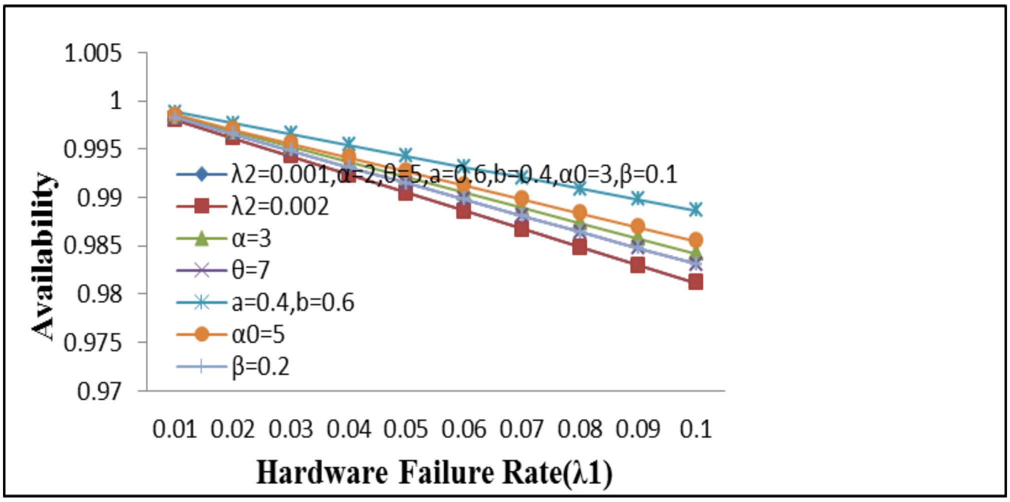

Fig. 3: Availability Vs Hardware Failure Rate (λ1)

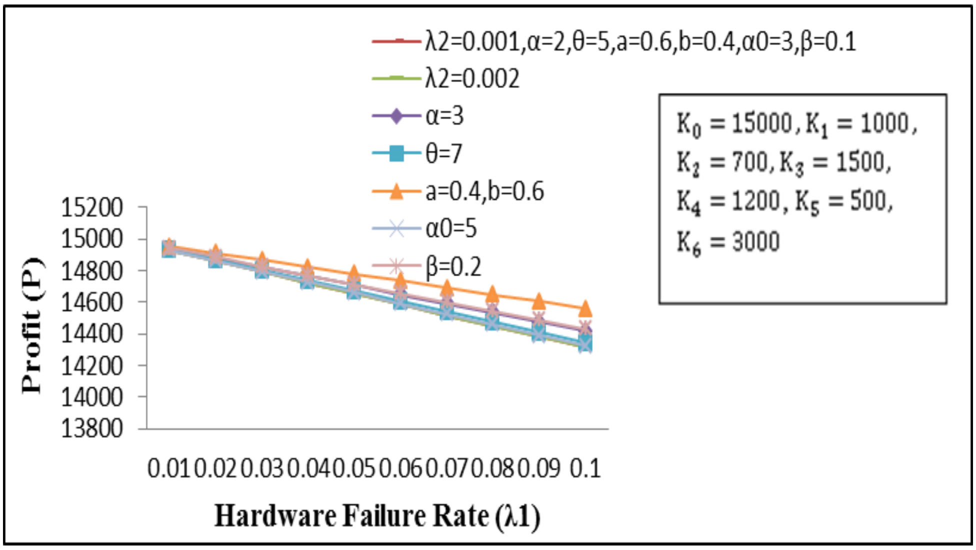

Fig. 4: Profit (P) Vs Hardware Failure Rate (λ1).

8. Comparative Study of Profit of System Models

The profit of the present model has been compared with that of the model discussed in the research paper Munday and Malik (2015). It is analyzed that the present model is less profitable. Thus, the concept of maximum repair time to hardware is not much useful in making the system more profitable if software redundancy in cold standby is provided to the computer system.

9. Graphical Presentation of Profit Difference

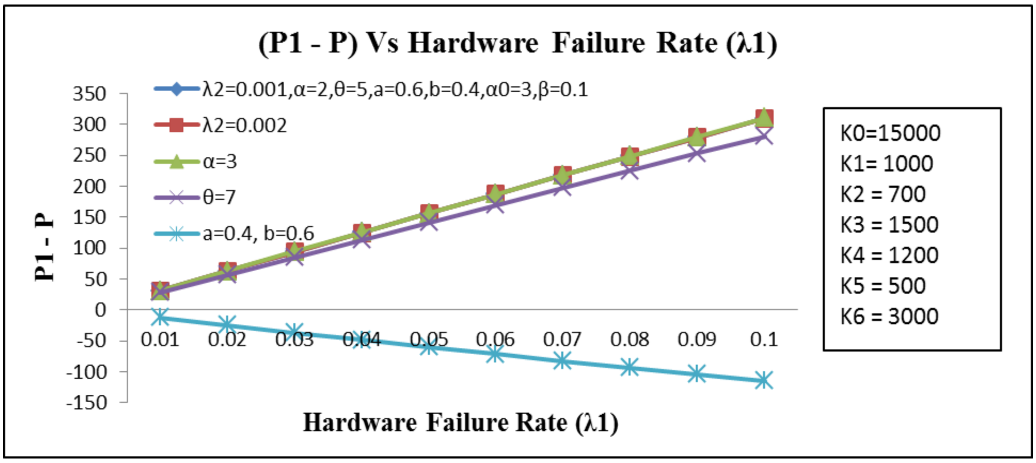

Fig. 5: Profit Difference (P1 – P) Vs Hardware Failure Rate (λ1)

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