Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 5 (2023)

Profit Analysis Of An Electronic System With Human Failure And Hardware Repair Before Human Treatment

[1]Komal, [2*]S. Malik, [3]N. Kadian

[1][2] Department of Mathematics, Baba Mastnath University, Rohtak
[3] Department of Applied Science, Sat Kabir Institute of Technology and Management, Jhajjar

E-mail: [1]komalpgt@gmail.com, [2]sangeetastat@gmail.com
[3] naveenkadian78@gmail.com

Abstract: The aim of this paper is to analyze a probabilistic model by considering the human failure and repair time less than human treatment. Here, one unit is taken as electronic system comprises of h/w and s/w and another unit as human being which will give service after failure of electronic system. There are two severs in which one for h/w repair or s/w up-gradation and other for human treatment. The repair time of hardware component is assumed less than human treatment. The hardware repair rate, software up-gradation rate and human treatment rate follow the arbitrary distributions. The various reliability measures are determined in steady state by using semi-Markov process and regenerative point technique. The graphical presentations of important measures have been shown for arbitrary values of parameter.
Keywords: Electronic System, Human Failure, Hardware, Software, Reliability Measures, Profit Analysis.

I. Introduction

In the era of modern technological world, the use of electronic systems has increased exponentially in almost all branches of sciences, engineering and public administration in order to complete the assignments in time and with perfectness. And, therefore it has become very difficult to ignore completely the usage of electronic systems while fulfilling the job's requirements. The electronic systems having these characteristics have possibility of the failures - hardware and software. These failures can cause a major setback to the owners in terms of financial loss, goodwill and loss of life. As a result of which the system becomes less reliable to the users. To deal with such situations the researchers have suggested several performance improvement techniques and thus reliability of these systems. Over the years a good number of research papers have also been reported by the scholars on reliability modeling of redundant systems with different repair policies. The cold standby redundancy has been used frequently by the researchers by considering one or more unit.

There are many research papers on reliability measures of system in which the concept of redundancy has been used. The expected profit has been evaluated by taking repair man appearance and disappearance in a stochastic model developed for a two-unit cold standby system [1]. For the combined hardware/software systems, the authors Friedman & Tran [2] gave the overview of the developed reliability techniques. Gupta et al. [3] analyzed two-unit standby system with fixed allowed down time and truncated exponential life time distributions. For analyzing the two-unit cold standby redundant system, two types of repairmen (regular and expert) have been used [4].

The system availability has been determined for distributed hardware/software system [5]. A two-unit cold standby system has been described by Meng et al. [6] with switch failure and equipment maintenance. Malik and Anand [7] determined economic analysis of a computer system with independent hardware and software failures. A two-unit cold standby system with arrival time of the server subject to MOT has been analyzed by Barak et al. [8]. Deswal and Malik [9] calculated reliability measures of a system of two non-identical units with priority subject to weather conditions.

Upma and Malik [10] analyzed the system of non-identical units under preventive maintenance and replacement. Kumar et al. [11] determined cost of an engineering system involving subsystems in series configuration. A two non-identical unit parallel system has been analyzed stochastically with incorporating waiting time and preventive maintenance by Youssef and Assed [12]. Kaur et al. [13] analyzed two non-identical units standby system with switching device and proviso of rest. Shekhar et al. [14] discussed a load sharing redundant repairable system. Malik and Yadav [15] determined reliability analysis of a computer system with unit wise cold standby redundancy subject to failure of service facility during software up-gradation. Kumar and Nandal [16] discussed a system of two non-identical units with priority for operation and repair to main unit subject to conditional failure of repairman. Malik and Yadav [17] described a computer system with unit wise cold standby redundancy and priority to hardware repair subject to failure of service facility. A repairable system of non-identical units with priority and conditional failure of repairman has been analyzed stochastically by Kumar et al. [18]. In the above literature the idea of human redundancy in cold standby has not been introduced reliability modeling of electronic system.

The aim of this paper is to analyze a probabilistic model by considering the human failure and repair time less than human treatment. Here, one unit is taken as electronic system comprises of h/w and s/w and another unit as human being which will give service after failure of electronic system. There are two severs in which one for h/w repair or s/w up-gradation and other for human treatment. The repair time of hardware component is assumed less than human treatment. The hardware repair rate, software up-gradation rate and human treatment rate follow the arbitrary distributions. The various reliability measures are determined in steady state by using semi-Markov process and regenerative point technique. The graphical presentations of important measures have been shown for arbitrary values of parameter.

II. Abbreviations and Notations

MTSF	Mean Time to System Failure
SMP	Semi-Markov Process
RPT	Regenerative Point Technique
MST	Mean Sojourn Time
O	The unit is operative
Hm O	Human is operative
Hm Cs	Human is in cold standby
a/b	Probability of hardware/software failure
x_1/x_2/ μ	Hardware/software/ human failure rates
α/β/γ	Hardware repair/software up-gradation/human treatment rates
HFUr	The failed hardware is under repair
HFUR	The failed hardware is continuously under repair from prior state
SFUg	The failed software is under up-gradation
SFUG	The failed software is continuously under up-gradation from prior state
Hm Ut	The injured human is under treatment
Hm UT	The injured human is continuously under treatment from prior state
f(t)/F(t)	pdf/cdf of hardware repair time
g(t)/G(t)	pdf/cdf of software repair time
s(t)/S(t)	pdf/cdf of human treatment time
pdf/cdf	Probability density function/Cumulative density function
$q_{ij}(t)/Q_{ij}(t)$	pdf/cdf of 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 $(0, t]$
$q_{ij.kr}(t)/Q_{ij.kr}(t)$	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 states S_k and S_r once in $(0, t]$
$p_{ij}/p_{ij.kr}$	Steady state probability of transition from state S_i to state S_j directly/via states S_k and S_r once
μ_i	MST in state S_i which is given by $\mu_i = E(T_i) = \int_0^\infty P(T_i > t)dt$ where T_i denotes the sojourn time in state S_i.

m_{ij}	Contribution to MST(μ_i) in state S_i when system transits directly to state S_j so that $\mu_i = \sum_j m_{ij}$ and $m_{ij} = \int tdQ_{ij}(t) = -q_{ij}^{*'}(0)$
$\emptyset_i(t)$	cdf of first passage time from regenerative state S_i to a failed state
$A_i(t)$	Probability that the system is in up-state at instant 't' given that the system entered in regenerative state S_i at $t = 0$
$M_i(t)$	Probability that the system up initially in regenerative state S_i is up at time t without visiting any other state
$R_i(t)$	Expected number of hardware repairs in the interval $(0, t]$ given that the system entered in regenerative state S_i at $t = 0$.
$U_i(t)$	Expected number of software up-gradations in the interval $(0, t]$ given that the system entered in regenerative state S_i at $t = 0$.
$T_i(t)$	Expected number of treatments given to the human in the interval $(0, t]$ given that the system entered in regenerative state S_i at $t = 0$.
Ⓢ/©	Standard notation for Laplace-Stieltjes convolution/Laplace convolution
*/**	Symbol for Laplace Transform (LT)/Laplace Stieltjes Transform (LST)
P	Profit function of system
Z_0	System revenue per unit up-time
Z_1/Z_2	Repair/up-gradation cost per unit time due to hardware failure/software failure
Z_3	Treatment cost of the human per unit time

III. Assumptions and State Descriptions

To describe the system the following assumptions are made:

a) There is an electronic system (hardware + software) in which components function independently.
b) Two non-identical units are taken up in which one unit (electronic system) is in operation mode and the other unit (human) is in spare.
c) There are separate servers for repairing or upgrading the components of electronic system and human.
d) The h/w repairs, s/w up-gradation and treatments are perfect.
e) The failure rates of components (hardware and software) and human are assumed to be constant.
f)The distributions for repair, up-gradation and treatment rates are considered as arbitrary.

The possible states of the model are described as follows:

S_0: (O, Hm Cs) S_1: (HFUr, Hm O) S_2: (SFUg, Hm O) S_3: (HFUR, Hm Ut)
S_4: (SFUG, Hm Ut) S_5: (O, Hm UT) S_6: (SFUG, Hm O) S_7: (HFUr, Hm UT)
S_8: (SFUg, Hm UT)

These states are shown in the Figure 1 in which S_0, S_1, S_2, S_5, S_6 are up-states and S_3, S_4, S_7, S_8 are failed states.

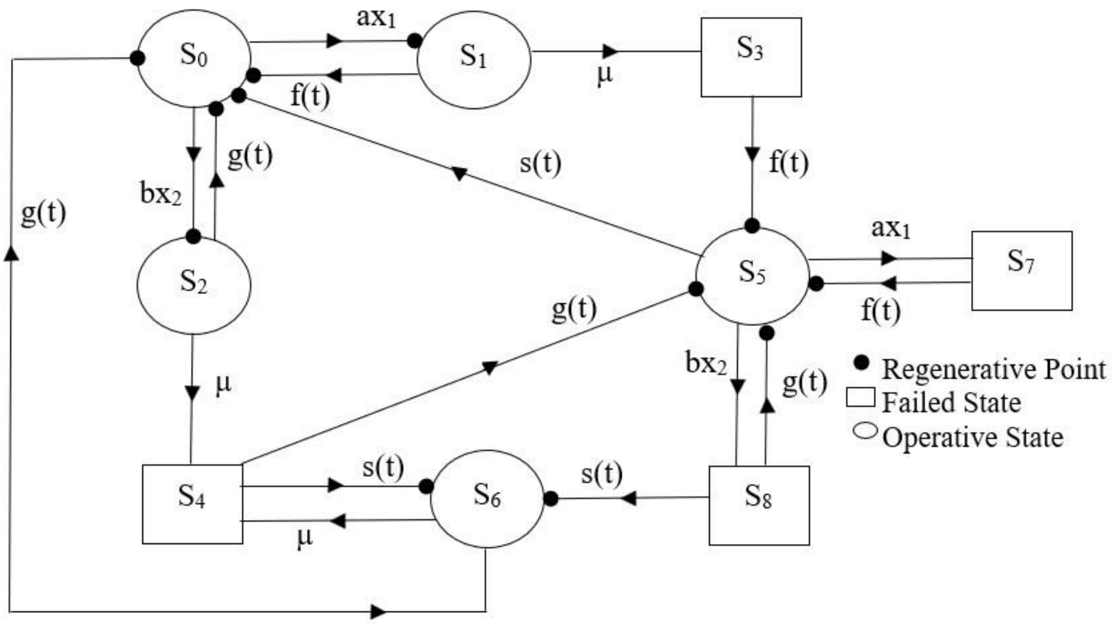

Figure 1: State transition Diagram

IV. Performance Measures

a) Transition Probabilities

The arbitrary distributions are considered as: $f(t) = \alpha e^{-\alpha t}$, $g(t) = \beta e^{-\beta t}$ and $s(t) = \gamma e^{-\gamma t}$.
Then the differential transition probabilities for state S_0 are given by
$dQ_{01}(t) = ax_1 e^{-(ax_1+bx_2)t}dt$, $dQ_{02}(t) = bx_2 e^{-(ax_1+bx_2)t}dt$
Taking LST of above equations and using the following results
$p_{ij} = \lim_{s\to 0} \emptyset_{ij}^{**}(s) = \emptyset_{ij}^{**}(0) = \int_0^\infty \mathrm{d}Q_{ij}(t) = \int_0^\infty q_{ij}(t)\mathrm{d}t$, we get
$p_{01} = \int_0^\infty ax_1 e^{-(ax_1+bx_2)t}\, dt = \frac{ax_1}{ax_1+bx_2}$, $p_{02} = \int_0^\infty bx_2 e^{-(ax_1+bx_2)t}\, dt = \frac{bx_2}{ax_1+bx_2}$

Similarly, the other transition probabilities for remaining states are given by

$p_{10} = \frac{\alpha}{\alpha+\mu}$	$p_{13} = \frac{\mu}{\alpha+\mu}$	$p_{20} = p_{60} = \frac{\beta}{\beta+\mu}$	$p_{24} = p_{64} = \frac{\mu}{\beta+\mu}$
$p_{35} = p_{75} = 1$	$p_{45} = p_{85} = \frac{\beta}{\beta+\gamma}$	$p_{46} = p_{86} = \frac{\gamma}{\beta+\gamma}$	$p_{50} = \frac{\gamma}{ax_1+bx_2+\gamma}$
$p_{57} = \frac{ax_1}{ax_1+bx_2+\gamma}$	$p_{58} = \frac{bx_2}{ax_1+bx_2+\gamma}$	$p_{15.3} = p_{13}p_{35}$	$p_{25.4} = p_{65.4} = p_{24}p_{45}$
$p_{26.4} = p_{66.4} = p_{24}p_{46}$	$p_{55.7} = p_{57}p_{75}$	$p_{55.8} = p_{58}p_{85}$	$p_{56.8} = p_{58}p_{86}$

From the above transition probabilities, the following relations are obtained as follows:
$p_{01} + p_{02} = p_{10} + p_{13} = p_{20} + p_{24} = p_{35} = p_{45} + p_{46} = p_{50} + p_{57} + p_{58} = p_{75} = 1$
$p_{60} + p_{64} = p_{85} + p_{86} = p_{10} + p_{15.3} = p_{50} + p_{55.8} + p_{55.7} + p_{56.8} = p_{60} + p_{65.4} + p_{66.4} = 1$

b) Mean Sojourn Times (MST)

The MST (μ_i) in state S_i are calculated by the following relations
$m_{ij} = \left|-\frac{d}{ds}Q_{ij}^{**}(s)\right|_{s=0} = -Q_{ij}^{**\prime}(0)$ and $\mu_i = \sum_j m_{ij}$ where $Q_{ij}^{**}(s) = \int_0^\infty \mathrm{e}^{-\mathrm{st}}\mathrm{d}Q_{ij}(t)$. Thus, we have
$\mu_0 = \frac{1}{ax_1+bx_2}$, $\mu_1 = \frac{1}{\alpha+\mu}$, $\mu_2 = \frac{1}{\beta+\mu} = \mu_6$, $\mu_3 = \frac{1}{\alpha} = \mu_7$, $\mu_4 = \frac{1}{\beta+\gamma} = \mu_8$, $\mu_5 = \frac{1}{ax_1+bx_2+\gamma}$

$\mu_1' = \frac{1}{\alpha}$, $\mu_2' = \frac{\beta+\mu+\gamma}{(\beta+\mu)(\beta+\gamma)} = \mu_6'$, $\mu_5' = \frac{bx_2+\beta+\gamma}{(ax_1+bx_2+\gamma)(\beta+\gamma)}$

c) Reliability and Mean Time to System Failure (MTSF)

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

$\emptyset_i(t) = \sum_j Q_{ij}(t)Ⓢ\emptyset_j(t) + \sum_k Q_{ik}(t)$

where S_j is an un-failed regenerative state to which the given regenerative state S_i can transit and S_k is a failed state to which the state S_i can transit directly. Thus, the following equations are obtained as:

$\emptyset_0(t) = Q_{01}(t)Ⓢ\emptyset_1(t) + Q_{02}(t)Ⓢ\emptyset_2(t)$

$\emptyset_1(t) = Q_{10}(t)Ⓢ\emptyset_0(t) + Q_{13}(t)$

$\emptyset_2(t) = Q_{20}(t)Ⓢ\emptyset_0(t) + Q_{24}(t)$

Taking Laplace Stieltjes Transform of above equations, we get

$\emptyset_0^{**}(s) = Q_{01}^{**}(s)\emptyset_1^{**}(s) + Q_{02}^{**}(s)\emptyset_2^{**}(s)$

$\emptyset_1^{**}(s) = Q_{10}^{**}(s)\emptyset_0^{**}(s) + Q_{13}^{**}(s)$

$\emptyset_2^{**}(s) = Q_{20}^{**}(s)\emptyset_0^{**}(s) + Q_{24}^{**}(s)$

Solving for $\emptyset_0^{**}(s)$ by Cramer Rule, we have

$\emptyset_0^{**}(s) = \frac{\Delta_1}{\Delta}$

Where $\Delta = \begin{vmatrix} 1 & -Q_{01}^{**}(s) & -Q_{02}^{**}(s) \\ -Q_{10}^{**}(s) & 1 & 0 \\ -Q_{20}^{**}(s) & 0 & 1 \end{vmatrix}$ and

$\Delta_1 = \begin{vmatrix} 0 & -Q_{01}^{**}(s) & -Q_{02}^{**}(s) \\ Q_{13}^{**}(s) & 1 & 0 \\ Q_{24}^{**}(s) & 0 & 1 \end{vmatrix}$

Now, we have $R^*(s) = \frac{1-\emptyset_0^{**}(s)}{s}$

The reliability of the system model can be obtained by

$$R(t) = L^{-1}[R^*(s)]$$

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

$MTSF = \lim_{s\to 0} R^*(s) = R^*(0) = \frac{N_1}{D_1}$, where $N_1 = \mu_0 + p_{01}\mu_1 + p_{02}\mu_2$ and

$D_1 = p_{01}p_{13} + p_{02}p_{24}$

d) Availability

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

$A_i(t) = M_i(t) + \sum_j q_{ij}^{(n)}(t)©A_j(t)$

where S_j is any successive regenerative state to which the regenerative state S_i can transit through n transitions. Thus, the following equations are obtained as:

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

$A_1(t) = M_1(t) + q_{10}(t)©A_0(t) + q_{15.3}(t)©A_5(t)$

$A_2(t) = M_2(t) + q_{20}(t)©A_0(t) + q_{25.4}(t)©A_5(t) + q_{27.4}(t)©A_7(t) + q_{26.4}(t)©A_6(t)$

$A_5(t) = M_5(t) + q_{50}(t)©A_0(t) + [q_{55.8}(t) + q_{55.7}(t)]©A_5(t) + q_{56.8}(t)©A_6(t)$

$A_6(t) = M_6(t) + q_{60}(t)©A_0(t) + q_{65.4}(t)©A_5(t) + q_{66.4}(t)©A_6(t)$

where $M_0(t) = e^{-(ax_1+bx_2)t}$, $M_1(t) = e^{-\mu t}\bar{F}(t)$, $M_2(t) = M_6(t) = e^{-\mu t}\bar{G}(t)$ and

$M_5(t) = e^{-(ax_1+bx_2)t}\bar{S}(t)$

Thus, applying the same procedure as in section 4.3, the steady state availability is calculated by

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

where

$N_2 = (p_{01}\mu_1 + \mu_0)[p_{50}(1-p_{26.4}) + p_{20}p_{56.8}] + \mu_5[p_{01}p_{13}(1-p_{26.4}) + p_{02}p_{25.4}] + \mu_2[p_{01}p_{13}p_{56.8} + p_{02}(p_{50} + p_{56.8})]$,

$D_2 = (p_{01}\mu_1' + \mu_0 + p_{02}\mu_2')[p_{50}(1-p_{26.4}) + p_{20}p_{56.8}] + p_{01}p_{13}[\mu_5'(1-p_{26.4}) + \mu_2'p_{56.8}] + p_{02}p_{24}[\mu_5'p_{45} + \mu_2'p_{46}(p_{50} + p_{58})]$,

and $\mu_i = M_i^*(0), i = 0,1,2,5$

e) Expected Number of Hardware Repairs

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

$$R_0(\infty) = \lim_{s\to 0} sR_0^{**}(s)$$

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

$R_i(t) = \sum_j Q_{ij}^{(n)}(t)Ⓢ[\delta_j + R_j(t)]$

Where S_j is any regenerative state to which the regenerative state S_i can transit through n transitions and $\delta_j = 1$, if S_j is the regenerative state where server does job afresh, otherwise $\delta_j = 0$. Thus, the following equations are obtained as:

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

$R_1(t) = Q_{10}(t)Ⓢ[1 + R_0(t)] + Q_{15.3}(t)Ⓢ[1 + R_5(t)]$

$R_2(t) = Q_{20}(t)ⓈR_0(t) + Q_{25.4}(t)ⓈR_5(t) + Q_{26.4}(t)ⓈR_6(t)$

$R_5(t) = Q_{50}(t)ⓈR_0(t) + Q_{55.7}(t)Ⓢ[1 + R_5(t)] + Q_{55.8}(t)ⓈR_5(t) + Q_{56.8}(t)ⓈR_6(t)$

$R_6(t) = Q_{60}(t)ⓈR_0(t) + Q_{65.4}(t)ⓈR_5(t) + Q_{66.4}(t)ⓈR_6(t)$

Thus, applying the same procedure as in section 4.3, the expected number of the hardware repairs are given by

$$R_0(\infty) = \lim_{s\to 0} sR_0^{**}(s) = \frac{N_3}{D_2}$$

where

$N_3 = p_{01}[p_{50} + p_{56.8} + p_{13}p_{57}] + p_{57}p_{02}p_{25.4}$ and

$D_2 = (p_{01}\mu_1' + \mu_0 + p_{02}\mu_2')[p_{50}(1-p_{26.4}) + p_{20}p_{56.8}] + p_{01}p_{13}[\mu_5'(1-p_{26.4}) + \mu_2'p_{56.8}] + p_{02}p_{24}[\mu_5'p_{45} + \mu_2'p_{46}(p_{50} + p_{58})]$

f) Expected Number of Software Up-gradations

Let $U_i(t)$ be the expected number of the software up-gradations by the server in the interval $(0, t]$ given that the system entered regenerative state S_i at $t = 0$. The expected number of the software up-gradations is given by

$$U_0(\infty) = \lim_{s\to 0} sU_0^{**}(s)$$

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

$U_i(t) = \sum_j Q_{ij}^{(n)}(t)Ⓢ[\delta_j + U_j(t)]$

Where S_j is any regenerative state to which the regenerative state S_i can transit through n transitions and $\delta_j = 1$, if S_j is the regenerative state where server does job afresh, otherwise $\delta_j = 0$. Thus, the following equations are obtained as:

$U_0(t) = Q_{01}(t)ⓈU_1(t) + Q_{02}(t)ⓈU_2(t)$

$U_1(t) = Q_{10}(t)ⓈU_0(t) + Q_{15.3}(t)ⓈU_5(t)$

$U_2(t) = Q_{20}(t)Ⓢ[1 + U_0(t)] + Q_{25.4}(t)Ⓢ[1 + U_5(t)] + Q_{26.4}(t)ⓈU_6(t)$

$U_5(t) = Q_{50}(t)ⓈU_0(t) + Q_{55.7}(t)ⓈU_5(t) + Q_{55.8}(t)Ⓢ[1 + U_5(t)] + Q_{56.8}(t)ⓈU_6(t)$

$U_6(t) = Q_{60}(t)Ⓢ[1 + U_0(t)] + Q_{65.4}(t)Ⓢ[1 + U_5(t)] + Q_{66.4}(t)ⓈU_6(t)$

Thus, applying the same procedure as in section 4.3, the expected number of the software up-gradations are given by

$$U_0(\infty) = \lim_{s\to 0} sU_0^{**}(s) = \frac{N_4}{D_2}$$

where

$N_4 = p_{01}[p_{02}p_{50} + p_{58}p_{01}p_{13}] + p_{58}p_{02}[p_{25.4} + p_{46}p_{20}]$ and

$D_2 = (p_{01}\mu_1' + \mu_0 + p_{02}\mu_2')[p_{50}(1 - p_{26.4}) + p_{20}p_{56.8}] + p_{01}p_{13}[\mu_5'(1 - p_{26.4}) + \mu_2' p_{56.8}] + p_{02}p_{24}[\mu_5' p_{45} + \mu_2' p_{46}(p_{50} + p_{58})]$

g) Expected Number of Treatments given to Human

Let $T_i(t)$ be the expected number of the treatments given to human by the server in the interval $(0, t]$ given that the system entered regenerative state S_i at $t = 0$. The expected number of the treatments given to human is given by

$$T_0(\infty) = \lim_{s\to 0} sT_0^{**}(s)$$

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

$T_i(t) = \sum_j Q_{ij}^{(n)}(t)Ⓢ[\delta_j + T_j(t)]$

Where S_j is any regenerative state to which the regenerative state S_i can transit through n transitions and $\delta_j = 1$, if S_j is the regenerative state where server does job afresh, otherwise $\delta_j = 0$. Thus, the following equations are obtained as:

$T_0(t) = Q_{01}(t)ⓈT_1(t) + Q_{02}(t)ⓈT_2(t)$

$T_1(t) = Q_{10}(t)ⓈT_0(t) + Q_{15.3}(t)ⓈT_5(t)$

$T_2(t) = Q_{20}(t)ⓈT_0(t) + Q_{25.4}(t)ⓈT_5(t) + Q_{26.4}(t)Ⓢ[1 + T_6(t)]$

$T_5(t) = Q_{50}(t)Ⓢ[1 + T_0(t)] + [Q_{55.8}(t) + Q_{55.7}(t)]ⓈT_5(t) + Q_{56.8}(t)Ⓢ[1 + T_6(t)]$

$T_6(t) = Q_{60}(t)ⓈT_0(t) + Q_{65.4}(t)ⓈT_5(t) + Q_{66.4}(t)Ⓢ[1 + T_6(t)]$

Thus, applying the same procedure as in section 4.3, the expected number of the treatments given to human are given by

$$T_0(\infty) = \lim_{s\to 0} sT_0^{**}(s) = \frac{N_5}{D_2}$$

where

$N_5 = p_{50}[p_{02}p_{25.4} + p_{01}p_{13}(1 - p_{26.4})] + p_{01}p_{13}p_{56.8} + p_{02}p_{26.4}(p_{50} + p_{58})$ and

$D_2 = (p_{01}\mu_1' + \mu_0 + p_{02}\mu_2')[p_{50}(1 - p_{26.4}) + p_{20}p_{56.8}] + p_{01}p_{13}[\mu_5'(1 - p_{26.4}) + \mu_2' p_{56.8}] + p_{02}p_{24}[\mu_5' p_{45} + \mu_2' p_{46}(p_{50} + p_{58})]$

V. Profit Analysis

The profit function in the time t is given by

P(t) = Expected revenue in (0, t] – expected total cost in (0, t]

In steady state, the profit of the system model can be obtained by the following formula:

$P = Z_0 A_0(\infty) - Z_1 R_0(\infty) - Z_2 U_0(\infty) - Z_3 T_0(\infty)$

VI. Graphical Study of Performance Measures

The graphical study of reliability measures such as MTSF, availability and profit function are shown in figures: Figure 2, Figure 3 and Figure 4 respectively.

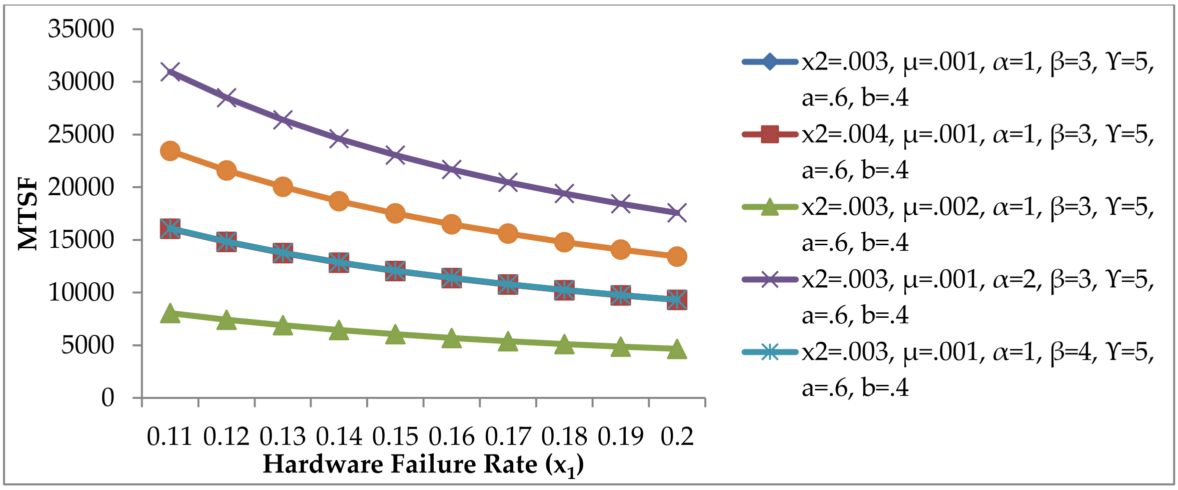

Figure 2: MTSF Vs Hardware Failure Rate (x_1)

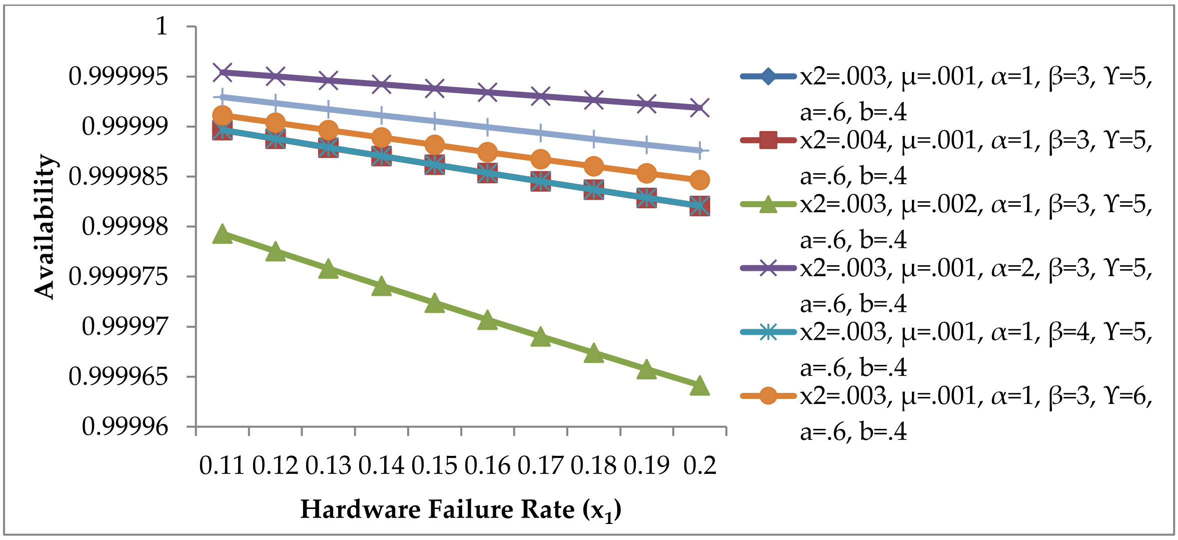

Figure 3: Availability Vs Hardware Failure Rate (x_1)

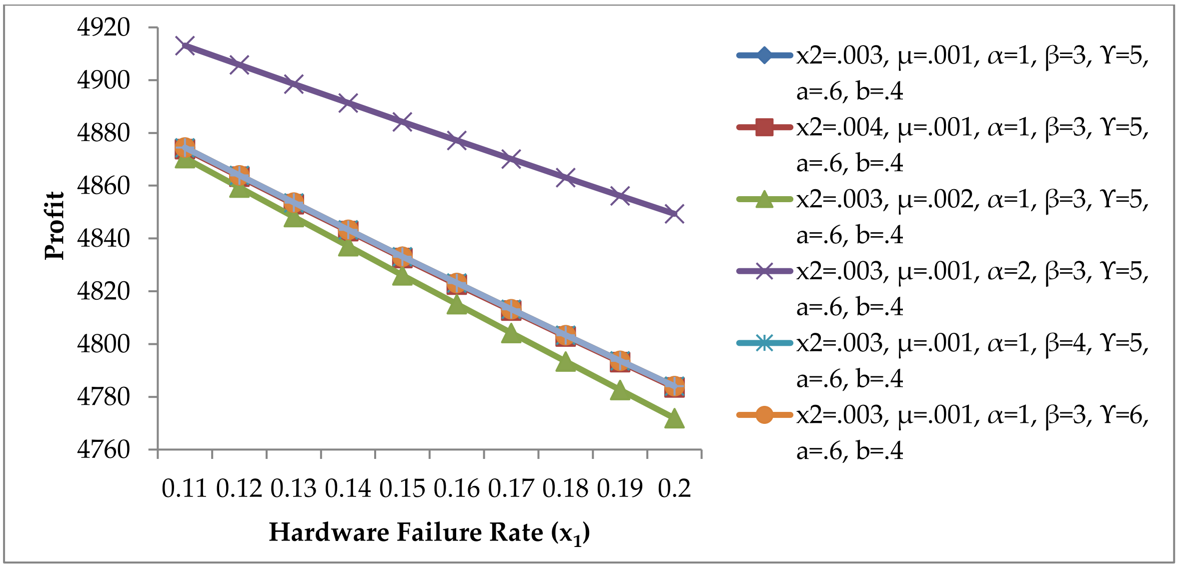

Figure 4: Profit Vs Hardware Failure Rate (x_1)

VII. Conclusion

The present study mainly focuses on MTSF, availability and profit analysis of an electronic system with human redundancy in cold standby. The graphical behavior of MTSF, availability and profit function are studied w.r.t hardware failure rate. From the Figure 2, MTSF declines by increasing the values of failure rates of components and human and increases with rise in repair rates of components and treatment rate given to human. Figure 3 reveals that availability declines sharply by increasing human failure rate and the increased value of α makes the system more available. The Figure 4 clears that profit of the system has same trend as the availability.

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