Research Article

Reliability and performance analysis of a base transceiver system considering software based hardware and common cause failures

Rajeev Kumar*, Sunny Kapoor**

Department of Mathematics, M.D. University, Rohtak, Haryana, INDIA.
Email: drrajeevmdu@gmail.com, sunnykapoor323@gmail.com

Abstract

In this paper a stochastic model for a Base Transceiver System (BTS) is proposed that taking into account that a Base transceiver station (BTS) is the most important networking component of mobile communication system from which all signals are sent and received having both hardware and software components. The hardware and software components may have various types of major and minor faults. The aspect of hardware software interaction failure in the system is also considered. On failure, the repair team first inspects whether there is hardware or software and hardware software interaction failure, then recovery of the relevant component is done. In case of occurrence of major fault, there is complete failure of system whereas in case of minor fault system performance and capacity may decrease The possibility of occurrence of traffic Congestion in the system is also incorporated, wherein traffic congestion is automatic removed by the system. Using Markov processes and regenerative point technique various measures of system performance are obtained. Various conclusions about reliability, performance and profit of the system are made on the basis of the graphical studies. The comparative analysis of the proposed model with the existing model is also incorporated.
Keywords: Base Transceiver System (BTS), hardware software interaction failures, common cause failure, Mean time to system failure, expected uptime, expected degradation time, expected congestion time, Profit, Markov process and regenerative point technique.

****Address for Correspondence:**
Dr. Sunny Kapoor, Department of Mathematics, M.D. University, Rohtak, Haryana, INDIA.
Email: sunnykapoor323@gmail.com
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INTRODUCTION

Mobile communication systems have become part and partial of our day to day lives and are developing regularly to ease life. There is not a single area left, where technology has not transformed life of individuals but on the other part more dependence on systems have raised certain concerns related to their performance and reliability. A Base transceiver station (BTS) is the most important networking component of mobile communication system from which all signals are sent and received having both hardware and software components. A BTS may fails due to software based hardware fault apart from other reasons as discussed in Kumar and Kapoor (2013). Here hardware based software faults are those software faults which occur due to improper functioning or failure of hardware components, like fault in optical fiber component leads to improper working of DTMU. Software based hardware faults are hardware faults related to software

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like if a DTRU card hangs then it is reset from BSC, but if there is need of cyclic reset and time interval between these successive resets goes on decreasing then quality of the card degraded and finally we have to replace it. Common cause failures are due to power failure, storms, floods, earthquakes etc. the network may not provide its service continuously to its subscribers. In case of occurrence of major fault, there is complete failure of system whereas in case of minor fault system performance and capacity may decrease. Moreover when there is saturation or traffic congestion in BTS then the services for some subscribers of network is reduced or calls are unattended. Then system operation is such will be restored automatically from congestion. In the field of reliability modeling several researchers Tuteja et al (1991), Rizwan and Taneja (2000), Taneja et al (2004), Kumar and Bhatia (2011), Kumar and Batra(2013) analyzed a large number of systems considering various aspects. For hardware-software systems, Welke et al (1995), Teng et al (2006), Tumar and Smidts (2011), Kumar and Kumar (2012) analysed hardware-software system considering hardware based software interaction failures and different types of recovery. Bothwell et al (1996), Purohit and Tokekar(2008), Ever et al(2009) and Ashan et al (2010) analyses the reliability and performability of different mobile communication system. Recently Kumar and Kapoor (2013) carried out the economic and performance evaluation of stochastic model on a base transceiver system considering hardware based software faults. However none of the researcher has carried out the analysis of BTS considering both the hardware based software and software based hardware failure. Using Markov processes and regenerative point technique various measures of system performance are obtained. Various conclusions about reliability, performance and profit of the system are made on the basis of the graphical studies. In the present paper, a comparative analysis between this proposed model (say model I), and the model discussed in Kumar and Kapoor (2013) (say model II) is carried out to judge for a base transceiver system which model is better in what situation in terms of reliability and expected uptimes, expected degradation times, expected congestion times and profits. Other assumptions are same as in Kumar and Kapoor (2013).

STATES OF THE SYSTEM

O / O_c	Operative/Congestion state
O_i / F_i	Degraded/Failed state under inspection
$O_{h_r} / O_{s_r} / O_{hs_r}$	Degraded state due to hardware/software/hardware based software fault under repair
$F_{h_r} / F_{s_r} / F_{hs_r}$	Failed state due to hardware/software/hardware based software fault under repair
$O_{sh_{rp}} / F_{sh_{rp}}$	Degraded state/failed state due to software based minor/major hardware fault under replacement
F_{cf_r}	Failed state due to common cause failure under repair

NOTATIONS

λ_1 / λ_2	Rate of occurrence of major/minor faults
λ_3 / λ_4	Rate of occurrence of software based major/minor hardware faults
λ_5 / λ_6	Rate of occurrence of hardware based major/minor software faults
η	Rate of traffic congestion
δ_1	Rate of automatic restoration after traffic congestion
a_1 / a_2	Probability that a major/minor hardware fault occurs in the system

b_1 / b_2	Probability that a major/minor software fault occurs in the system
c_1 / c_2	Probability that a hardware based major/minor software fault occurs in the system
d_1	Probability that a common cause failure occurs in the system
$q_{ij}(t) / Q_{ij}(t)$	P.d.f/C.d.f of first passage time from state 'i' to state 'j'
$g_{h_1}(t) / g_{h_2}(t)$	P.d.f. of repair time of major/minor hardware fault
$g_{s_1}(t) / g_{s_2}(t)$	P.d.f. of repair time of major/minor software fault
$g_{h_3}(t) / g_{h_4}(t)$	P.d.f. of repair time of hardware based major/minor software fault
$g_{c_f}(t) / G_{c_f}(t)$	P.d.f./C.d.f of repair time of common cause failure
$i_1(t) / i_2(t)$	P.d.f. of inspection time of major/minor fault
$I_1(t) / I_2(t)$	C.d.f. of inspection time of major/minor fault
$G_{h_1}(t) / G_{h_2}(t)$	C.d.f. of repair time of major/minor hardware fault
$G_{s_1}(t) / G_{s_2}(t)$	C.d.f. of repair time of major/minor software fault
$G_{h_3}(t) / G_{h_4}(t)$ $h_{h_3}(t) / h_{h_4}(t)$	C.d.f. of repair time of hardware based major/minor software fault P.d.f. of replacement time of software based major/minor hardware fault
$H_{h_3}(t) / H_{h_4}(t)$	C.d.f. of replacement time of software based major/minor hardware fault

THE PROPOSED MODEL

A transition diagram showing the various states of transition is shown as **Figure 1**. The epochs of entry in to state 0,1,2,3,4,5,6,7,8,9,10,11,12 are regenerative points, i.e. all the states are regenerative states.

The non-zero elements $p_{ij} = \lim_{s \to 0} q_{ij}^*(s)$

$p_{01} = \dfrac{\lambda_1}{\lambda_1 + \lambda_2 + \eta}$ $\quad p_{02} = \dfrac{\lambda_2}{\lambda_1 + \lambda_2 + \eta}$ $\quad p_{03} = \dfrac{\eta}{\lambda_1 + \lambda_2 + \eta}$ $\quad p_{14} = a_1 i_1^*(0)$

$p_{15} = c_1 i_1^*(0)$ $\quad p_{16} = b_1 i_1^*(0)$

$p_{17} = d_1 i_1^*(0)$ $\quad p_{28} = a_2 i_2^*(0)$

$p_{29} = c_2 i_2^*(0)$ $\quad p_{210} = b_2 i_2^*(0)$

$p_{30} = 1$ $\quad p_{40} = g_{h_1}^*(\lambda_5)$

$p_{45} = 1 - g_{h_1}^*(\lambda_5)$ $\quad p_{56} = g_{h_3}^*(0)$

$p_{60} = g^*_{s_1}(\lambda_3)$ $p_{70} = g^*_{c_f}(0)$

$p_{80} = g^*_{h_2}(\lambda_6)$ $p_{89} = 1 - g^*_{h_2}(\lambda_6)$

$p_{910} = g^*_{h_4}(0)$ $p_{100} = g^*_{s_2}(\lambda_4)$

$p_{1012} = 1 - g^*_{s_2}(\lambda_4)$ $p_{110} = h^*_{h_3}(0)$

$p_{120} = h^*_{h_4}(0)$

By these transition probabilities, it can be verified that

$p_{01}+p_{02}+p_{03}= p_{14}+p_{15+} p_{16} + p_{17} = p_{28}+p_{29} + p_{210}= p_{40}+p_{45} = p_{60}+p_{611}= p_{80}+p_{89}= 1$

$p_{100}+p_{1012} = p_{30}= p_{56} = p_{70} = p_{910} = p_{110} = p_{120} = 1$

The mean sojourn time (μ_i) in the regenerative state i is defined as the time of stay in that state before transition to any other state. If T denotes the sojourn time in regenerative state i, then

$\mu_0 = \frac{1}{\lambda_1 + \lambda_2 + \eta}$ $\mu_1 = -i_1^{*'}(0)$

$\mu_2 = -i_2^{*'}(0)$ $\mu_3 = \frac{1}{\delta_1}$

$\mu_4 = \frac{1}{\lambda_5}(1 - g^*_{h_1}(\lambda_5))$ $\mu_5 = -g^{*'}_{h_3}(0)$ $\mu_6 = \frac{1}{\lambda_3}(1 - g^*_{s_1}(\lambda_3))$ $\mu_7 = -g^{*'}_{c_f}(0)$ $\mu_8 = \frac{1}{\lambda_6}(1 - g^*_{h_2}(\lambda_6))$ $\mu_9 = -g^{*'}_{h_4}(0)$

$\mu_{10} = \frac{1}{\lambda_4}(1 - g^*_{s_2}(\lambda_4))$ $\mu_{11} = -h^{*'}_{h_3}(0)$

$\mu_{12} = -h^{*'}_{h_4}(0)$

Thus,

$m_{01} + m_{02} + m_{03} = \mu_0$

$m_{14} + m_{15} + m_{16} + m_{17} = \mu_1$

$m_{28} + m_{29} + m_{210} = \mu_2$

$m_{30} = \mu_3$ $m_{40} + m_{45} = \mu_4$

$m_{56} = \mu_5$ $m_{60} + m_{611} = \mu_6$

$m_{70} = \mu_7$ $m_{80} + m_{89} = \mu_8$

$m_{910} = \mu_9$

$m_{100} + m_{1012} = \mu_{10}$

$m_{110} = \mu_{11}$

$m_{120} = \mu_{12}$

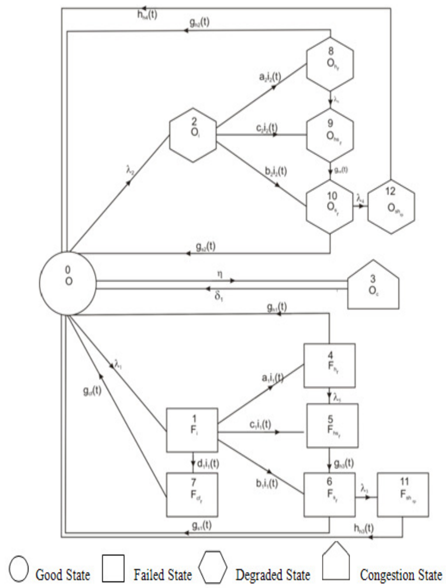

Figure 1: State Transition Diagram

MEASURES OF SYSTEM PERFORMANCE

Using probabilistic arguments for regenerative processes, various recursive relations are obtained and are solved to derive measures of the system performance. In steady state the important measures of system performance obtained are:

These are as given below:

Mean Time to System Failure (T_1)=N_1/D_1

Expected Uptime of the system (UT_1) = N_{11}/ D_{11}

Expected Degradation Time of the System (DT_1)=N_{21}/ D_{11}

Expected Congestion Time of the System (CT_1) = N_{31}/ D_{11}

Busy Period of Repairman (inspection time only) (BI_1) = N_{41}/ D_{11}

Busy period of Repairman (repair time only) (BR_1) =
N_{51}/ D_{11}

Busy Period of Repairman (replacement time only) (BRP_1) = N_{61}/ D_{11}

where

$N_1= \mu_0 + p_{02}\,\mu_2 + p_{03}\,\mu_3 + p_{02}\,p_{28}\,\mu_8 + (p_{02}\,p_{28}\,p_{89} + p_{02}\,p_{29})\,\mu_9 + (p_{02}\,p_{28}\,p_{89} + p_{02}\,p_{29}+ p_{02}\,p_{210})\,\mu_{10}+ (p_{02}\,p_{28}\,p_{89}\,p_{1012} + p_{02}\,p_{29}\,p_{1012} + p_{02}\,p_{210}\,p_{1012})\,\mu_{12}$

$D_1= p_{01},$

$N_{11} =\mu_0$,

$N_{21} = p_{02}\mu_2 + p_{02}\,p_{28}\,\mu_8 + p_{02}\,(p_{28}\,p_{89} + p_{29})\,\mu_9 + p_{02}\,(p_{28}\,p_{89} + p_{29} + p_{210})\,\mu_{10}+ p_{02}\,(p_{28}\,p_{89}\,p_{1012} + p_{29}\,p_{1012} + p_{210}\,p_{1012})\,\mu$

$N_{31} = p_{03}\,\mu_3,$

$N_{41}= p_{01}\mu_1+ p_{02}\mu_2,$

$N_{51}= p_{01}p_{14}\,\mu_4 + (p_{01}\,p_{14}\,p_{45} + p_{01}\,p_{15})\,\mu_5 + (p_{01}\,p_{14}\,p_{45} + p_{01}\,p_{15} + p_{01}\,p_{16})\,\mu_6 + p_{01}\,p_{17}\,\mu_7 + p_{02}\,p_{28}\,\mu_8\,(p_{02}\,p_{28}\,p_{89} + p_{02}\,p_{29})\,\mu_9 + (p_{02}\,p_{28}\,p_{89} + p_{02}\,p_{29} + p_{02}\,p_{210})\,\mu_{10},$

$N_{61}= p_{01}\,(p_{14}\,p_{45}\,p_{611} +p_{15}\,p_{611} +p_{16}\,p_{611})\,\mu_{11}+ p_{02}\,(p_{28}\,p_{89}\,p_{1012} + p_{29}\,p_{1012} + p_{210}\,p_{1012})\,\mu_{12}$,

$D_{11} = \mu_0 + p_{01}\,\mu_1 + p_{02}\,\mu_2 + p_{03}\,\mu_3 + p_{01}\,p_{14}\,\mu_4 + p_{01}\,(p_{14}\,p_{45} + p_{15})\,\mu_5 + p_{01}\,(p_{14}\,p_{45} + p_{15} + p_{16})\,\mu_6+p_{01}\,p_{17}\mu_7 + p_{02}\,p_{28}\,\mu_8 + p_{02}\,(p_{28}\,p_{89} + p_{29})\,\mu_9 + p_{02}\,(p_{28}\,p_{89} + p_{29} + p_{210})\,\mu_{10} + p_{01}\,(p_{14}\,p_{45}\,p_{611} + p_{15}\,p_{611}+ p_{16}\,p_{611})\,\mu_{11} + p_{02}\,(p_{28}\,p_{89}\,p_{1012} + p_{29}\,p_{1012} + p_{210}\,p_{1012})\,\mu_{12}$

PROFIT ANALYSIS

The expected profit incurred of the system is in steady state given by

$P_1 = C_0\,UT_1 + C_1DT_1 + C_2\,CT_1 - C_3\,BI_1 - C_4$

BR_1 - C_5 BRP_1 - C
where
C_0 = revenue per unit uptime of the system
C_1= revenue per unit degradation time of the system
C_2 = revenue per unit congestion time of the system
C_3 = cost per unit time of inspection
C_4 = cost per unit time of repair
C_5 = cost per unit time of replacement
C = cost of installation of the system

GRAPHICAL INTERPRETATION

For graphical analysis purposes, following particular cases are considered:

$$g_{h_1}(t) = \beta_{h_1} e^{-\beta_{h_1} t}; \qquad g_{h_2}(t) = \beta_{h_2} e^{-\beta_{h_2} t};$$

$$g_{s_1}(t) = \beta_{s_1} e^{-\beta_{s_1} t}; \qquad g_{s_2}(t) = \beta_{s_2} e^{-\beta_{s_2} t};\ g_{h_3}(t) = \beta_{h_3} e^{-\beta_{h_3} t}; \qquad g_{h_4}(t) = \beta_{h_4} e^{-\beta_{h_4} t};$$

$$h_{h_3}(t) = \gamma_{h_3} e^{-\gamma_{h_3} t}; \qquad h_{h_4}(t) = \gamma_{h_4} e^{-\gamma_{h_4} t};$$

$$g_{c_f}(t) = \beta_{c_f} e^{-\beta_{c_f} t}; \qquad i_1(t) = \alpha_1 e^{-\alpha_1 t};\ i_2(t) = \alpha_2 e^{-\alpha_2 t}$$

Various graphs for measures of system performances viz.MTSF, expected uptime, expected degradation time, expected congestion time and profit are plotted for different values of rates of occurrence of faults $(\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6)$, probabilities of occurrence of hardware/software/ hardware based software/common cause failure (a_1,a_2,b_1,b_2,c_1,c_2,d_1) inspection rates (α_1, α_2), hardware/ software/ hardware based software / common cause failure repair rates ($\beta_{h_1}, \beta_{h_2}, \beta_{s_1}, \beta_{s_2}, \beta_{h_3}\ \beta_{h_4}, \beta_{c_f}$), software based hardware replacement rates $(\gamma_{h_3}, \gamma_{h_4})$, traffic congestion and system automatic restoration rates (η, δ_1).

Figure 2 gives the graph between MTSF(T_1) and rate of occurrence of software based minor hardware faults (λ_4) for different values of rate of occurence of hardware based minor software faults(λ_6). The graph reveals that MTSF decreases with increase in the values of the rate of occurrence of software based minor hardware faults and has lower values for higher values of rate of hardware based minor software faults.

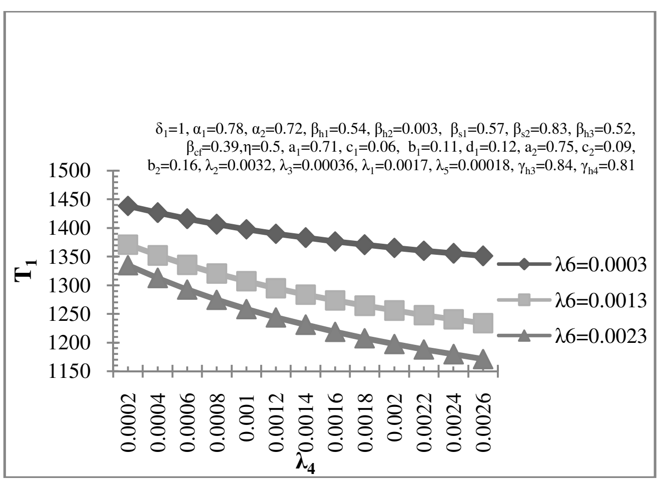

Figure 2: MTSF V/S Rate of software based minor hardware faults for different values of rate of hardware based minor software faults

The curve in **Figure 3** depicts the pattern between MTSF(T_1) and rate of occurrence of major faults (λ_1) for different values of probability of occurence of minor hardware faults(a_2). It reveals that MTSF decreases with increase in the values of the rate of occurrence of major faults and has lower for higher values of probability of minor hardware faults.

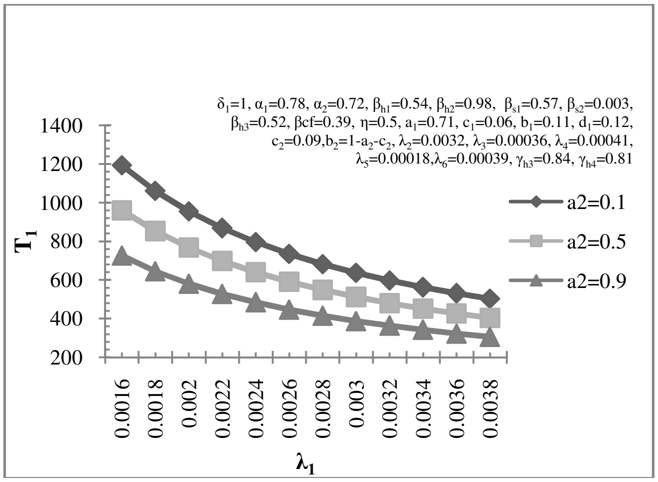

Figure 3: MTSF V/S Rate of major fault for different values of probability of minor hardware fault

Figure 4 shows the graph between expected uptime of the system (UT_1) and rate of occurrence of software based minor hardware faults (λ_4) for different values of rate of occurrence of minor faults (λ_2). It is concluded from the graph that expected uptime of the system decreases with increase in the values of rate of occurrence of software based minor hardware faults and has smaller values for higher values of rate of occurrence of minor faults.

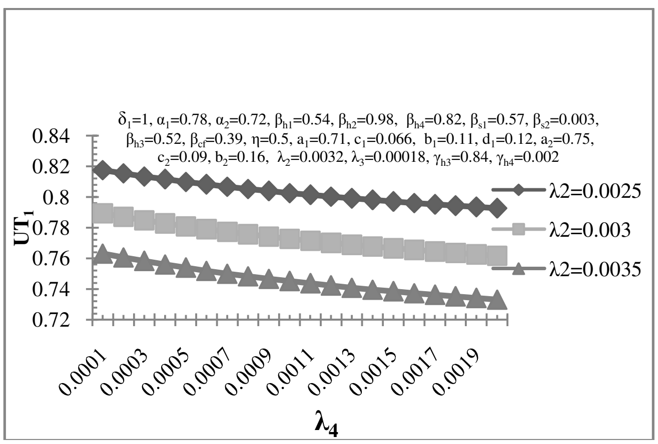

Figure 4: Expected uptime v/s Rate of software based minor hardware faults for different values of rate of minor faults

In **Figure 5,** the curves represent pattern of expected uptime of the system (UT_1) and rate of occurrence of hardware based major software faults (λ_5) for different values of rate of occurrence of major faults (λ_1). It shows that the expected uptime of the system decreases with increase in the values of rate of occurrence of hardware based major software faults and has smaller values for higher values of rate of occurrence of major faults.

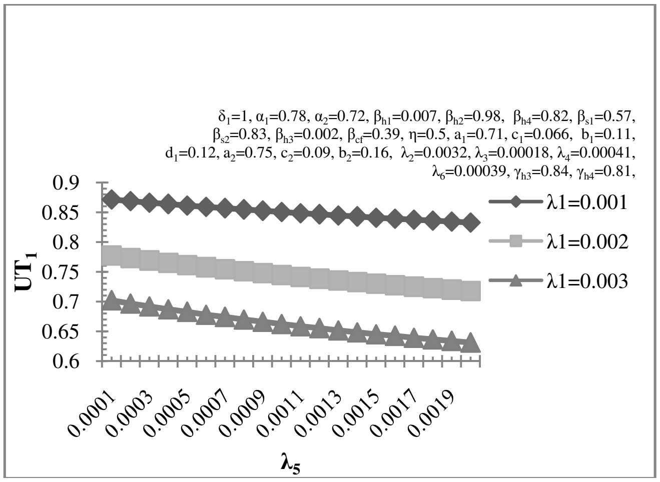

Figure 5: Expected uptime v/s Rate of hardware based major software faults for different values of rate of major faults

Figure 6 gives the graph between expected congestion time (CT_1) of the system and rate of traffic congestion for different values of automatic restoration rate (δ_1) .The graph indicates that expected congestion time increases with increase in the values of rate of traffic congestion and has lower values for higher values of automatic restoration rate.

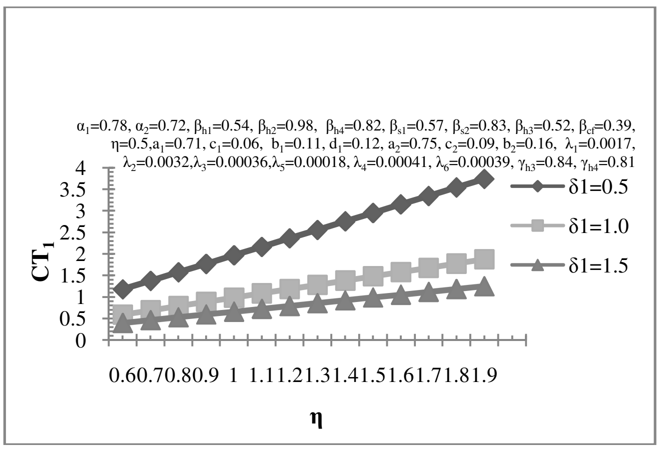

Figure 6: Expected congestion time v/s Rate of traffic congestion for different values of rate of automatic restoration

The graph in **Figure 7** shows the pattern of profit (P_1) with respect to the rate of occurrence of major faults (λ_1) for different values of rate of hardware based major software faults (λ_5). The curve in the graph reveals that the profit of the system decreases with the increase in the values of the rates of occurrence of major faults as well as with the values of rate of hardware based major software faults. Further from the graph it may also be noticed that for λ_5 =0.0001, the profit is > or = or < 0 according as λ_1 is < or = or > 0.0048. Hence the system is profitable to the company whenever $\lambda_1 \leq$ 0.0048. Similarly, for λ_5 = 0.0011 and λ_5 = 0.0021, the profit is > or = or < 0 according as λ_1 is < or = or > 0.0043 and 0.0041, respectively. Hence in these cases the system is profitable to the company whenever $\lambda_1 \leq$ 0.0043 and 0.0041 respectively.

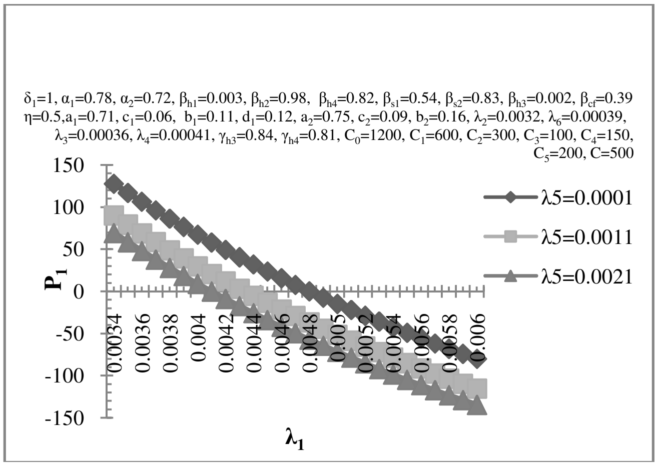

Figure 7: Profit v/s Rate of major faults for different values of rate of hardware based major software faults

The curves in **Figure 8** shows the pattern of profit (P_1) with respect to the rate of occurrence of hardware based minor software faults (λ_6) for different values of rate of software based minor hardware faults (λ_4). The curve in the graph indicates that the profit of the system decreases with the increase in the values of the rates of occurrence of hardware based minor software faults and has smaller values for higher value of rate of software based minor hardware faults. Further from the graph it may also be noticed that for λ_4 =0.0011, the profit is > or = or < 0 according as λ_6 is < or = or > 0.0025. Hence the system is profitable to the company whenever $\lambda_6 \leq 0.0025$. Similarly, for λ_4 = 0.0021 and λ_4 = 0.0031, the profit is > or = or < 0 according as λ_6 is < or = or > 0.0018 and 0.0015, respectively. Hence in these cases the system is profitable to the company whenever $\lambda_6 \leq 0.0018$ and 0.0015 respectively.

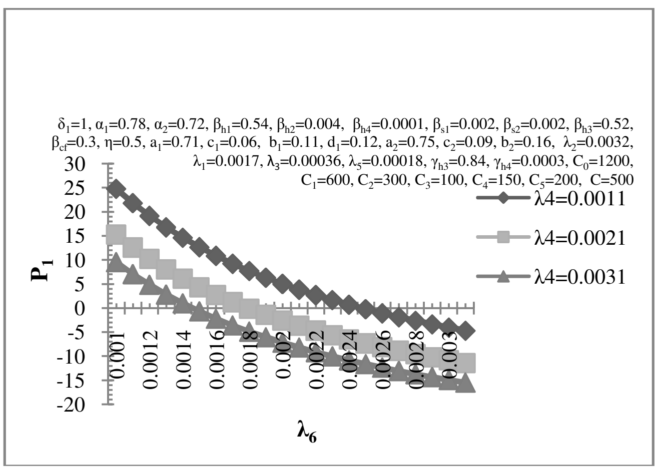

Figure 8: Profit v/s Rate of hardware based minor software faults for different values of rate of software based minor hardware faults

Figure 9 shows the pattern of profit (P_1) with respect to the revenue per unit uptime of the system (C_0) for different values of rate of software based major hardware faults (λ_3). It is observed that the profit of the system increases with the increase in the values of the revenue per unit uptime of the system but decreases with increase in the values of rate of software based major hardware faults. Further from the graph it may also be noticed that for λ_3 =0.0001, the profit is < or = or > 0 according as C_0 is < or = or > 479.30. Hence in this case the system is profitable to the company whenever $C_0 \geq 479.30$. Similarly, for λ_3 =0.0009 and λ_3 =0.0017, the profit is < or = or > 0 according as C_0 is < or = or > 637.38 and 727.10, respectively. Hence in these cases the system is profitable to the company whenever $C_0 \geq 637.38$ and 727.10 respectively.

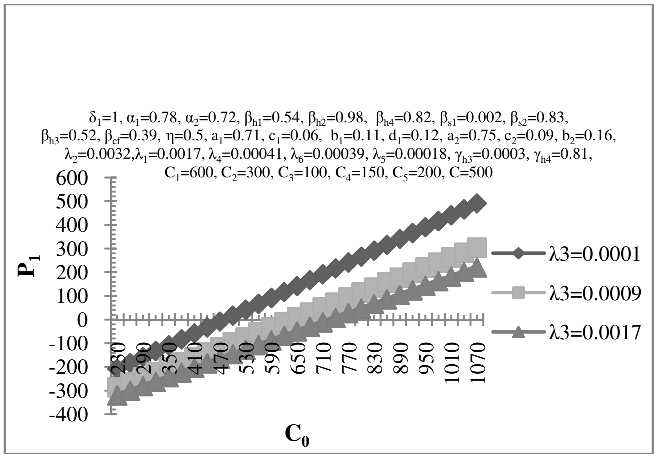

Figure 9: Profit v/s Revenue per unit uptime of the system for different values of rate of software based major hardware faults

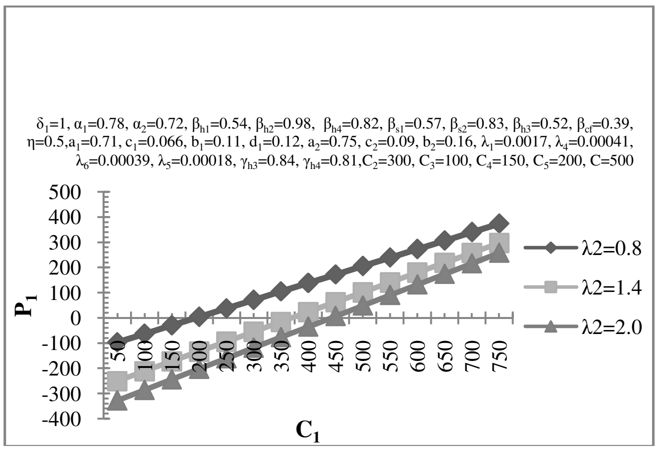

Figure 10: Profit v/s Revenue per unit degradation time of the system for different values of rate of minor faults

Figure 10 shows the graph of profit (P_1) with respect to the revenue per unit degraded time of the system (C_1) for different values of rate of occurrence of minor faults (λ_2). It is concluded from the graph that the profit of the system increases with the increase in the values of the revenue per unit degradation time of the system and has smaller values for higher values of rate of occurrence of minor faults. Further from the graph it may also be noticed that for $\lambda_2 = 0.8$, the profit is < or = or > 0 according as C_1 is < or = or > 193.36. Hence in this case the system is profitable to the company whenever $C_1 \geq 193.36$. Similarly, for $\lambda_2 = 1.4$ and $\lambda_2 = 2.0$, the profit is < or = or > 0 according as C_1 is < or = or > 370.35 and 441.18, respectively. Hence in these cases the system is profitable to the company whenever $C_1 \geq 370.35$ and 441.18 respectively.

COMPARATIVE ANALYSIS

The proposed model say model I is compared to the model given in Kumar and Kapoor (2013) say model II for the above mentioned particular cases with respect to various measures of system performance and profits.

The various measures of system performance obtained in Kumar and Kapoor (2013) are as under:

Mean Time to System Failure (T_2) = N_2/D_1

Expected Uptime of the System (UT_2) = N_{11}/ D_{12}

Expected Degradation Time of the System (DT_2) = N_{22}/ D_{12}

Expected Congestion Time of the System (CT_2) = N_{31}/ D_{12}

Busy Period of Repairman (inspection time only) (BI_2) =
N_{41}/ D_{12}

Busy Period of Repairman (repair time only) (BR_2) =
N_{51}/ D_{12}

where

$N_2 = \mu_0 + p_{02}\,\mu_2 + p_{03}\,\mu_3 + p_{02}\,p_{28}\,\mu_8 + (p_{02}\,p_{28}\,p_{89} + p_{02}\,p_{29})\,\mu_9 + (p_{02}\,p_{28}\,p_{89} + p_{02}\,p_{29} + p_{02}\,p_{210})\,\mu_{10}$,

$N_{22} = p_{02}\mu_2 + p_{02}\,p_{28}\mu_8 + p_{02}\,(p_{28}\,p_{89} + p_{29})\,\mu_9 + p_{02}\,(p_{28}\,p_{89} + p_{29} + p_{210})\,\mu_{10}$,

$D_{12} = \mu_0 + p_{01}\mu_1 + p_{02}\mu_2 + p_{03}\mu_3 + p_{01}p_{14}\mu_4 + p_{01}\,(p_{14}\,p_{45} + p_{15})\,\mu_5 + p_{01}\,(p_{14}\,p_{45} + p_{15} + p_{16})\,\mu_6 + p_{01}\,p_{17}\mu_7 + p_{02}p_{28}\,\mu_8 + p_{02}\,(p_{28}p_{89} + p_{29})\,\mu_9 + p_{02}\,(p_{28}\,p_{89} + p_{29} + p_{210})\,\mu_{10}$

D_1, N_{11}, N_{31}, N_{41}, N_{51} are already specified in model I.

Also the expected profit incurred from the system using the model II is given by

$P_1 = C_0\,UT_2 + C_1DT_2 + C_2\,CT_2 - C_3\,BI_2 - C_4$
$BR_2 - C$

where

C_0, C_1, C_2, C_3, C_4, C are the costs as specified in model I.

Figure 11 shows the behavior of difference between the mean times to system failure of the model I and model II, i.e. T_1-T_2 with respect to the rate of occurrence of software based minor hardware faults (λ_4) for different values rate of occurrence of hardware based minor software faults (λ_6). The graph reveals that the difference of mean times to system failure of the two models decreases with increase in the values of rate of occurrence of software based minor hardware faults and has smaller values for higher values of rate of occurrence of hardware based minor faults. It may also be observed from the graph that the **model II** has more reliability than **model I** for a fixed value of hardware based minor software fault.

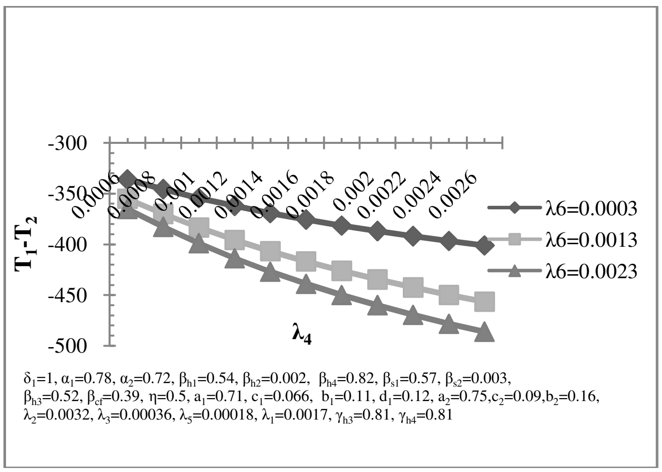

Figure 11: Difference of mean times to system failure v/s rate of software based minor hardware faults for different values of rate of hardware based minor software faults

The curve in the **Figure 12** shows the behavior of the difference of expected uptimes (UT_1-UT_2) of the models with respect to the rate of occurrence of software based major hardware faults (λ_3) for different values of rate of occurrence of major faults (λ_1). It is evident from the graph that difference of expected uptimes decreases with the increase in the values of rate of occurrence of software based major hardware faults and has lower values for upper values of the rate of major faults. From the **Figure 12** it may also be observed that for λ_1= 0.003, the difference of expected uptimes is > or = or < 0 according as is λ_3 < or = or > 0.001. Hence the **model I** is better or equally good or worse than **model II** whenever λ_3 < or = or > 0.001. Similarly, for λ_1 = 0.004 and λ_1 =0.005, the difference of profits is > or = or < 0 according as is λ_3 < or = or > and 0.00067 and 0.00051 respectively. Thus, in these cases, **model I** is better or equally good or worse than **model II** whenever λ_3 < or = or > 0.00067 and λ_3 < or = or >0.00051.

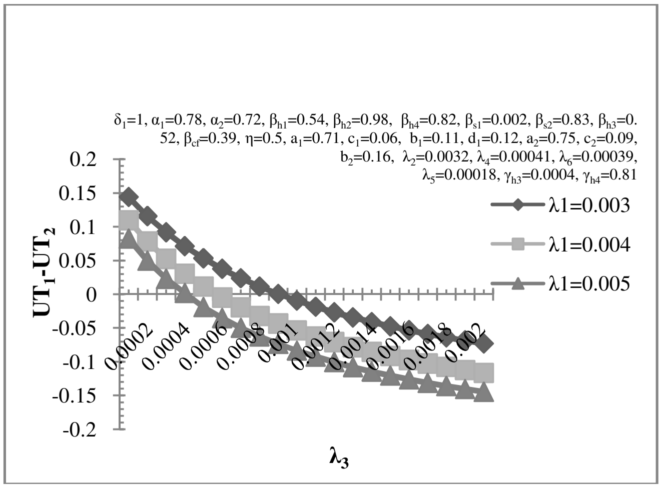

Figure 12: Difference of expected uptimes v/s rate of software based major hardware faults for different values of rate of major faults

The curves in the **Figure 13** shows the behavior of the difference of expected uptimes(UT_1-UT_2) of the two models with respect to the rate of occurrence of software based minor hardware faults(λ_4) for different values of rate of occurrence of hardware based minor software faults(λ_6). It is concluded from the graph that the difference of expected uptimes decreases with the increase in the values of rate of occurrence of software based minor hardware faults and has smaller values for higher values of the rate of hardware based minor software faults. From the **Figure 13** it may also be observed that for λ_6= 0.0005, the difference of expected uptimes is > or = or < 0 according as is λ_4 < or = or > 0.00124. Hence the **model I** is better or equally good or worse than **model II** whenever λ_4 < or = or > 0.00124. Similarly, for λ_6 = 0.0009 and λ_6 =0.0013, the difference of expected uptimes is > or = or < 0 according as is λ_4 < or = or > and 0.00096 and 0.00082 respectively. Thus, in these cases, **model I** is better or equally good or worse than **model II** whenever λ_4 < or = or > 0.00096 and λ_4 < or = or >0.00082 respectively.

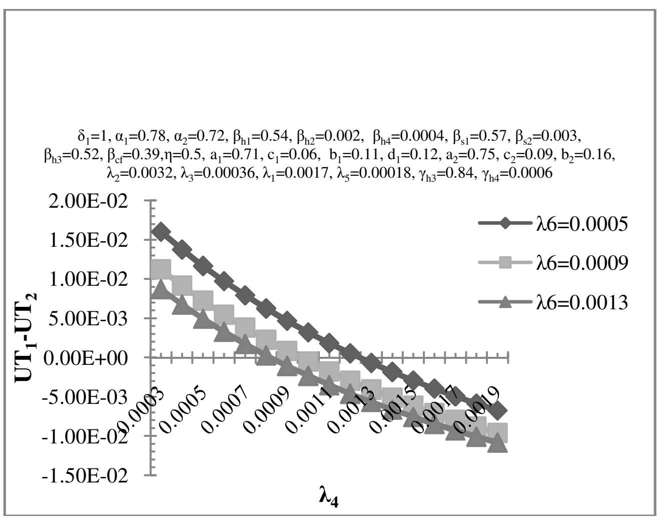

Figure 13: Difference of expected uptimes v/s rate of software based minor hardware faults for different values of rate of hardware based minor software faults

The curves in the **Figure 14** shows the behavior of the difference of profits (P_1-P_2) of the models with respect to the rate of occurrence of software based minor hardware faults (λ_4) for different values of rate of occurrence of minor faults (λ_2). It is evident from the graph that difference of profits decreases with the increase in the values of rate of occurrence of software based minor hardware faults and has lower values for higher values of the rate of minor faults. From the **Figure 14** it may also be observed that for λ_2= 0.005, the difference of profits is > or = or < 0 according as is λ_4 < or = or > 0.00310. Hence the **model I** is better or equally good or worse than **model II** whenever λ_4 < or = or > 0.00310. Similarly, for λ_2 = 0.0065 and λ_2 =0.008, the difference of profits is > or = or < 0 according as is λ_4 < or = or >

and 0.00244 and 0.00214 respectively. Thus, in these cases, **model I** is better or equally good or worse than **model II** whenever λ_4 < or = or > 0.00244 and λ_4 < or = or 0.00214 respectively.

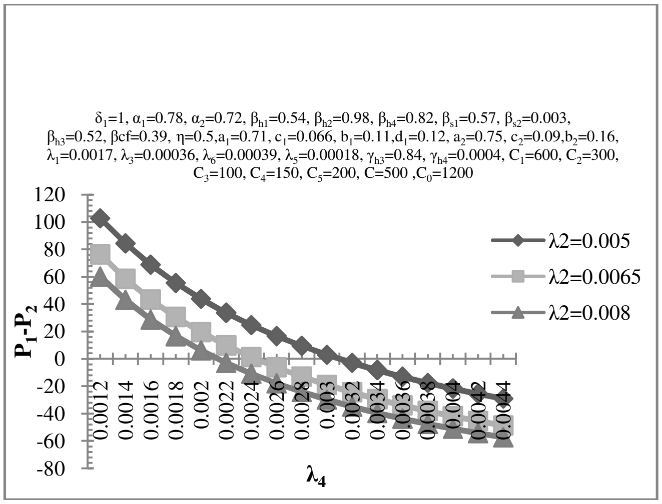

Figure 14: Difference of profits v/s rate of software based major hardware faults for different values of rate of minor faults

The curves in the **Figure 15** shows the behavior of the difference of profits (P_1-P_2) of the models with respect to the rate of occurrence of software based major hardware faults(λ_3) for different values of revenue per unit uptime of the system(C_0). It is observed from the graph that difference of profits decreases with the increase in the values of rate of occurrence of software based major hardware faults and has higher values for higher values of the revenue per unit uptime of the system. From the **Figure 15** it may also be observed that for C_0=200, the difference of profits is > or = or < 0 according as is λ_3 < or = or > 0.00081. Hence the **model I** is better or equally good or worse than **model II** whenever λ_3 < or = or > 0.00081. Similarly, for C_0 = 450 and C_0 =700, the difference of profits is > or = or < 0 according as is λ_3 < or = or > and 0.00117 and 0.00142 respectively. Thus, in these cases, **model I** is better or equally good or worse than **model II** whenever λ_3 < or = or > 0.00117 and λ_3 < or = or > 0.00142 respectively.

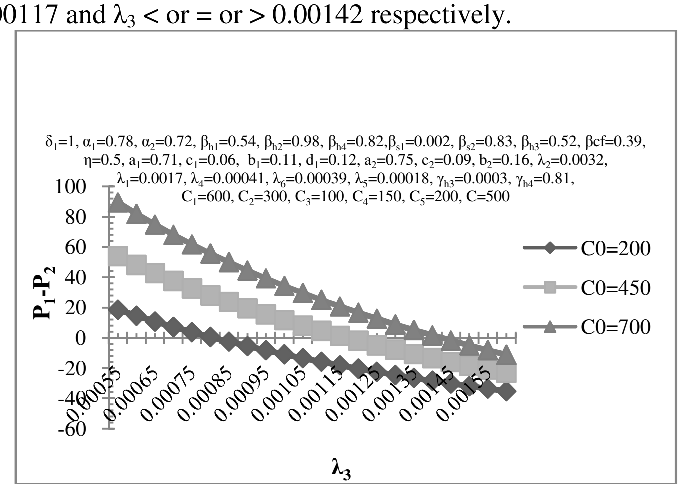

Figure 15: Difference of profits v/s rate of software based major hardware faults for different values of revenue per unit uptime of the system

The curves in the **Figure 16** shows the behavior of the difference of profits (P_1-P_2) with respect to the cost per unit replacement time of the system (C_5) for different values of cost per unit repair time of the system (C_4). It is evident from the graph that difference of profits decreases with the increase in the values of cost per unit replacement time of the system (C_5) and has larger values for larger values of the cost per unit repair of the system. From the **Figure 16** it may also be observed that for C_4=100, the difference of profits is > or = or < 0 according as is C_5 < or = or > 1831.84. Hence the **model I** is better or equally good or worse than **model II** whenever C_5 < or = or > 1831.84. Similarly, for C_4 = 250 and C_4 =400, the difference of profits is > or = or < 0 according as is C_5 < or = or > 1954.49 and 2077.13 respectively.

Thus, in these cases, **model I** is better or equally good or worse than **model II** whenever C_5 < or = or >1954.49 and C_5 < or = or 2077.13 respectively.

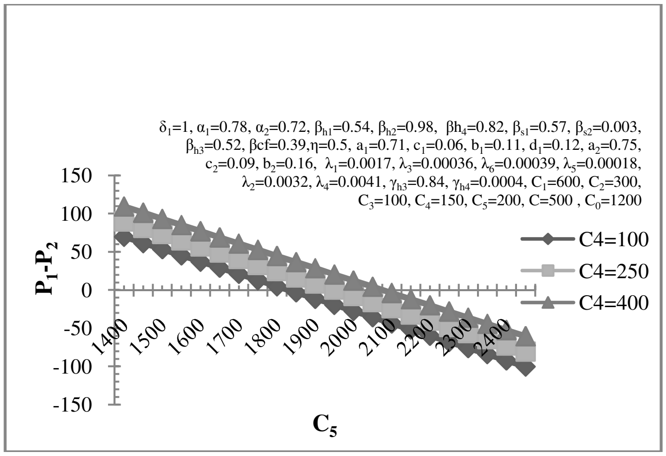

Figure 16: Difference of profits v/s cost per unit replacement time of the system for different values of cost per unit repair time of the system

CONCLUSION

From the graphical analysis, it may be concluded for the proposed model that the mean time to system failure (MTSF) decreases with increase in the values of probability of minor hardware faults. It is also observed that MTSF and expected uptime of the BTS decreases with the increase in the values of the rates of occurrence of major as well minor faults. Further it is observed that the MTSF and expected uptime decreases with the increase in the values of rates of occurrence of hardware based software/software based hardware faults whereas expected degradation time of the system increases with the increase in values of rates of hardware based software/software based hardware faults. The expected congestion time of the system increases with the increase in values of the traffic congestion rate and decreases with the increase in the values of rate of automatic restoration. The profit of the system increases with the increase in the values of revenues per unit up time, degradation time and congestion time of the system but decreases with increase in the values of rates of occurrence of major and minor hardware/software faults and also decreases with rate of occurrence of hardware based software/software based hardware faults. Various cutoff points for revenue per unit uptime/degradation time, rate of hardware based software/software based hardware faults can be obtained. From the comparative analysis between the proposed model and the existing model it can be concluded that the difference of MTSF of the models decreases with increase in the rate of occurrence of minor faults as well as with rate of occurrence of software based minor hardware faults. It is also concluded that the model II is better than model I in terms of mean times to system failures for the considered values of the parameters. It is also observed that the difference of the expected uptimes decreases with increase in the values of occurrence of rate of major/minor faults as well as with rate of software based hardware and hardware based software faults. Further for fixed values of rate of major and minor faults, cutoff points for rate of occurrence of software based major/minor faults and revenue per unit uptime of the system can be obtained. For fixed values of cost per unit repair time of the system, cutoff points for cost per unit replacement time of the system can also be obtained.

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