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Comparative cost-benefit analysis of two reliability models for one unit base transceiver system considering hardware based software faults

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Abstract
This paper deals with comparative analysis of two stochastic models for a base transceiver system given in [5] and [6] to judge which and when one model is better than the other in terms of different measures of system performance and costs. A base transceiver system may fail or may not work satisfactorily on occurrence of some major or minor faults, common cause failures or network traffic congestion. When major/minor fault occurs the repair team first inspects whether there is hardware or software or hardware based software fault then recovery of the relevant component is done. In the first model given in [5], only hardware and software failures are taken whereas in the model given in [6], hardware based software failures and common cause failures are taken apart from considering occurrence of some minor or major faults in hardware/ software components and traffic congestion. In these models it is assumed that the minor fault leads to partial failure or degradation state whereas a major fault and common cause failure leads to complete failure of the system. On the basis of computed measures of system performance, comparison of the models with respect to their mean times to failures, expected uptimes/degradation times and profits is made using graphs for some particular case and conclusions are drawn.

Keywords: Base Transceiver System (BTS), common cause failure, traffic congestion, hardware based software faults, mean time to system failure, expected up/degradation/congestion times, profit, Markov process, regenerative point technique

Introduction

In the field of reliability, several researchers Arora [1], garg and Kumar [2], Goel *et al*. [3] and Gupta and Kumar [4] analyzed a large number of systems considering various aspects such as different failure modes, repairs, replacements, inspections and different operational stages. Murari and Goyal [10] studied reliability system with two types of repair facility. Gopalan *et al*. [3] did cost analysis of a system subject to on-line preventive maintenance and repair. Kumar and Mor [8] have given a probabilistic analysis of a sophisticated system with some warranted components considering two types of service facility and delay in warranty claims. Beside these a few researchers like Teng *et al*. [11], Tumer and Smidts [12], Welke *et al*. [13], Kumar and Kumar [9], Kumar and Kapoor [7] etc. discussed various types of hardware/software failures with different recovery policies while analyzing systems having both hardware and software components. Kumar and Kapoor [8] did the comparative analysis of stochastic models for a base transceiver system considering software based hardware failure and congestion of calls.

Recently, Kumar and Kapoor [5] analysed a model on a base transceiver system onsidering hardware faults, software faults and congestion of calls. Thereafter, for the system Kumar and Kapoor [6] discussed a model considering hardware based software faults and catastrophic failures. It is pertinent to mentioned that the model developed for a system cannot be good for all its operational conditions/situations. However stakeholders are interested to judge which and when one model is better for the system with respect to different measures of system performance. Keeping this fact in view, in the present paper a comparative analysis has been done between the models for a base transceiver system given in [5] and [6] to investigate which and when a model is better for the system, respectively, in terms of their reliability, expected uptime/degradation times/congestion time and profit.

A base transceiver system may fail or may not work satisfactorily on occurrence of some major or minor faults, common cause failures or network traffic congestion. When major/minor fault occurs the repair team first inspects whether there is hardware or software or hardware based software fault then recovery of the relevant component is done. In the first model given in [5], only hardware faults, software faults and network traffic congestion are taken whereas in the model given in [6], hardware based software failures and common cause failures are taken apart from considering occurrence of some minor or major faults in hardware/ software components and traffic congestion. In these models it is assumed that the minor fault leads to partial failure or degradation state whereas a major fault and common cause failure leads to complete failure of the system. On the basis of computed measures of system performance, comparison of the models with respect to their mean times to system failures, expected uptimes/degradation times and profits is made using graphs for some particular case and conclusions are drawn.

States of The system

O/O_c	Operative/Congestion state
O_i/F_i	Degradation state/Failed state under inspection
O_{h_r}/F_{h_r}	Degradation/Failed state due to hardware fault under repair
O_{s_r}/F_{s_r}	Degradation/Failed state due to software fault under repair
O_{hs_r}/F_{hs_r}	Degradation/Failed state due to hardware based software fault under repair
F_{cf_r}	Failed state due to common cause failure under repair

Notations

λ_1/λ_2	Rate of major/minor faults
λ_3/λ_4	Rate of major/minor hardware based software faults
λ_5/λ_6	Rate of major/minor software based hardware faults
a_1/a_2	Probability that major/minor hardware fault occurs
b_1/b_2	Probability that major/minor software fault occurs
c_1/c_2	Probability of the major/minor hardware based software fault
d_1	Probability that the common cause failure occurs
η	Network traffic congestion rate
δ_1	Automatic network restoration rate
$i_1(t)/I_1(t)$	P.d.f./C.d.f. of inspection time for major fault
$i_2(t)/I_2(t)$	P.d.f./C.d.f. of inspection time for minor fault
$g_{h_1}(t)/G_{h_1}(t)$	P.d.f./C.d.f. of repair time of major hardware fault
$g_{h_2}(t)/G_{h_2}(t)$	P.d.f./C.d.f. of repair time of minor hardware fault
$g_{s_1}(t)/G_{s_1}(t)$	P.d.f./C.d.f. of repair time of major software fault
$g_{s_2}(t)/G_{s_2}(t)$	P.d.f./C.d.f. of repair time of minor software fault
$g_{h_3}(t)/G_{h_3}(t)$	P.d.f./C.d.f. of repair time of major hardware based software fault
$g_{h_4}(t)/G_{h_4}(t)$	P.d.f./C.d.f. of repair time of minor hardware basedsoftware fault
$g_{c_f}(t)/G_{c_f}(t)$	P.d.f./C.d.f of repair time of common cause failure

State Transition Diagram

For the model-I, a diagram presenting various states of transition of the system is shown in fig. 1 whereas for the model-II, various states are given in fig. 2. In both the diagrams the epochs of entry in to various states are regenerative points and hence all the states are regenerative states.

Transition probabilities and mean sojourn times

Various transition probabilities and mean sojourn times respectively for the Model-I and Model-II as given in [5] and [6] are as under.

Model-I

$$p_{01} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \eta} \qquad p_{02} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \eta} \qquad p_{03} = \frac{\eta}{\lambda_1 + \lambda_2 + \eta}$$

$$p_{14} = a_1 i_1^*(0) \qquad p_{15} = b_1 i_1^*(0) \qquad p_{26} = a_2 i_2^*(0)$$

$$p_{27} = b_2 i_2^*(0) \qquad p_{30} = 1 \qquad p_{40} = g_{h_1}^*(0)$$

$$p_{50} = g_{s_1}^*(0) \qquad p_{60} = g_{h_2}^*(0) \qquad p_{70} = g_{s_2}^*(0)$$

By these transition probabilities, it can be verified that

$p_{01} + p_{02} + p_{03} = p_{14} + p_{15} = p_{26} + p_{27} = 1$; $\quad p_{30} = p_{40} = p_{50} = p_{60} = p_{70} = 1$

Model-I

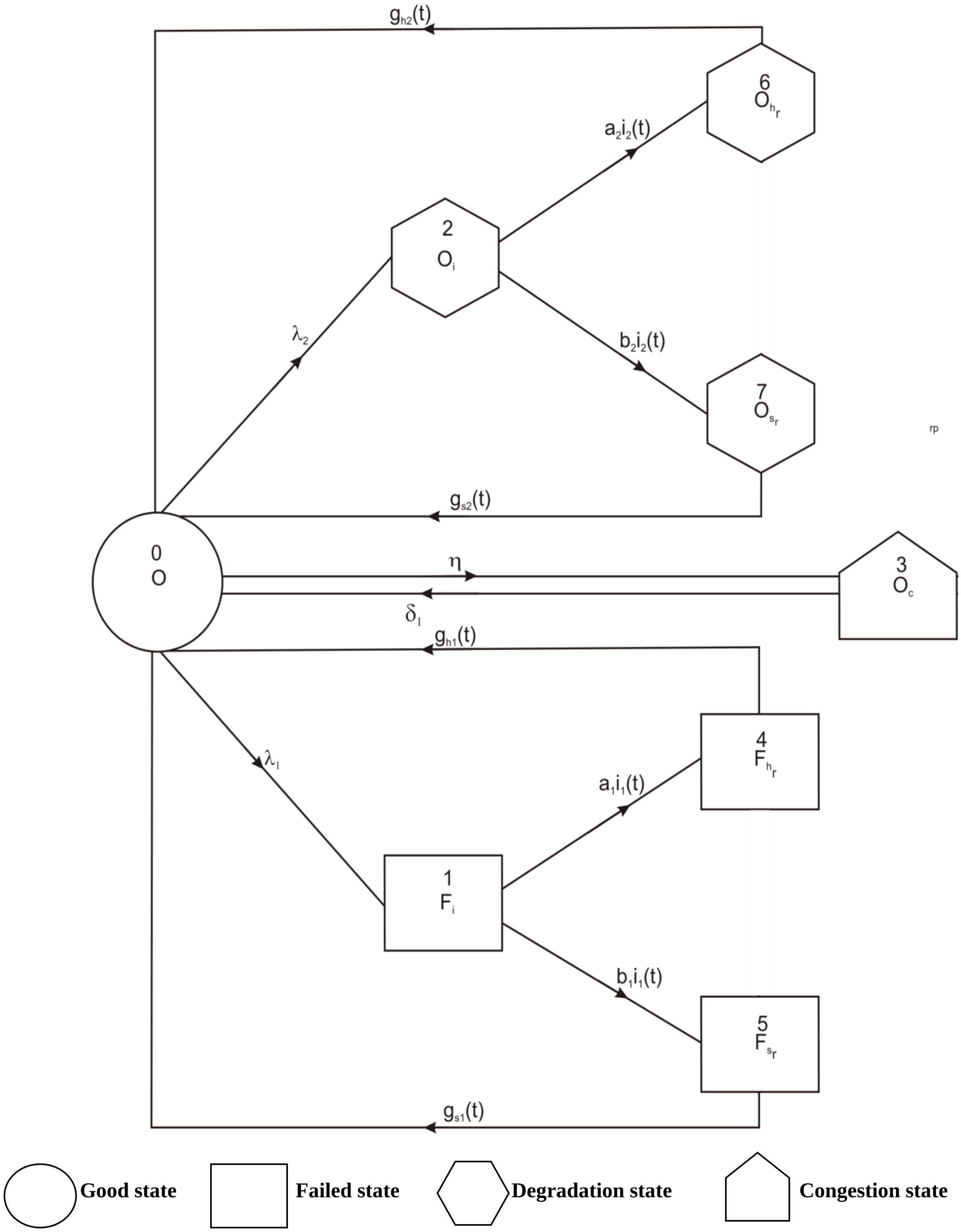

Fig 1

Model-II

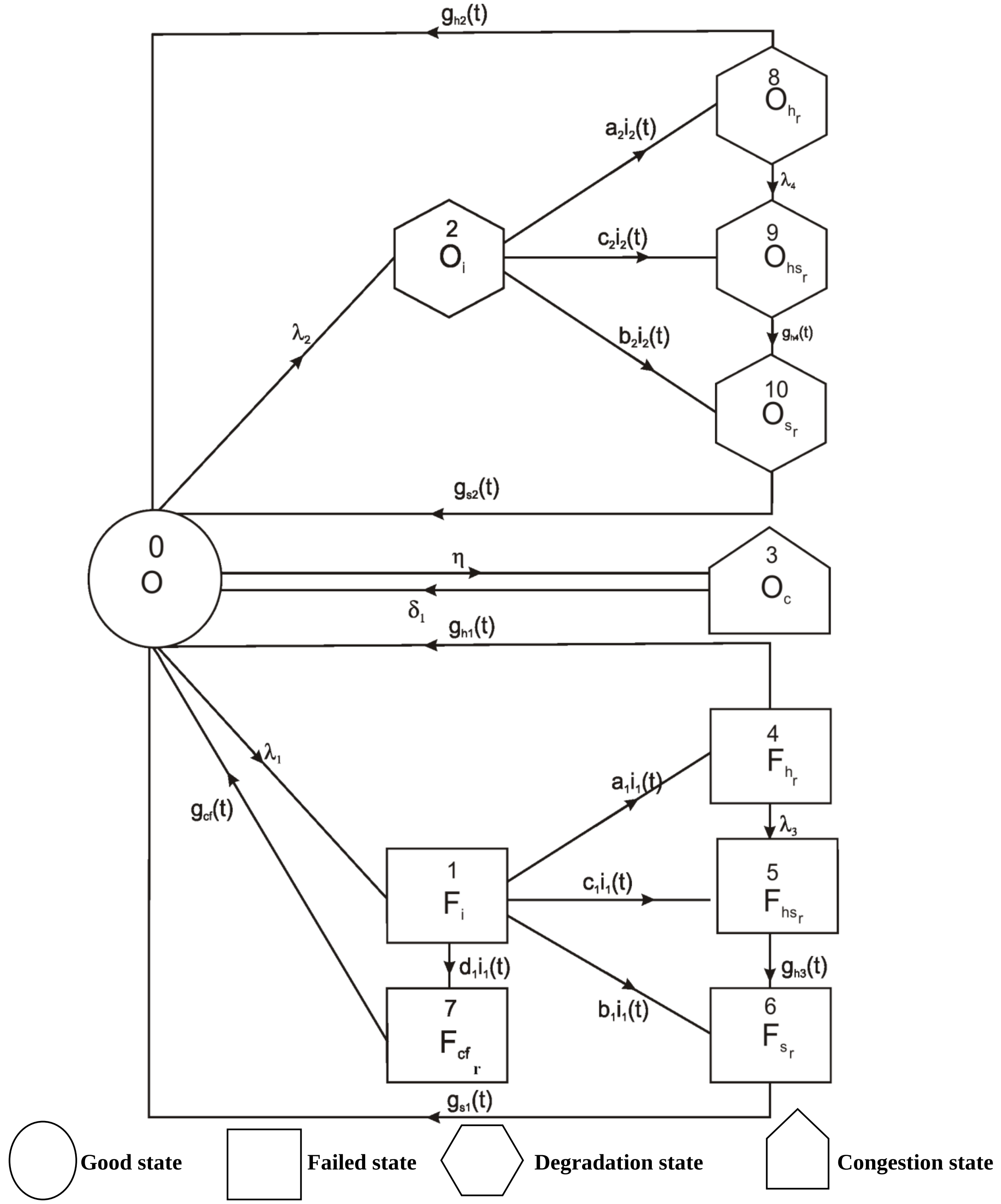

Fig 2

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

$$\mu_0 = \frac{1}{\lambda_1+\lambda_2+\eta} \quad \mu_1 = -i_1^{*'}(0) \quad \mu_2 = -i_2^{*'}(0) \quad \mu_3 = \frac{1}{\delta_1}$$

$$\mu_4 = -g_{h_1}^{*'}(0) \quad \mu_5 = -g_{s_1}^{*'}(0) \quad \mu_6 = -g_{h_2}^{*'}(0) \quad \mu_7 = -g_{s_2}^{*'}(0)$$

The unconditional mean time taken by the system to transit for any regenerative state j, when it is counted from epoch of entrance into that state i, is mathematically stated as

$m_{ij} = \int t\, q_{ij}(t)\, dt$

Thus,

$m_{01} + m_{02} + m_{03} = \mu_0$ $\quad m_{14} + m_{15} = \mu_1$ $\quad m_{26} + m_{27} = \mu_2$

$m_{30} = \mu_3$ $\quad m_{40} = \mu_4$ $\quad m_{50} = \mu_5$

$m_{60} = \mu_6$ $\quad m_{70} = \mu_7$

Model-II

$$p_{01} = \frac{\lambda_1}{\lambda_1+\lambda_2+\eta} \qquad p_{02} = \frac{\lambda_2}{\lambda_1+\lambda_2+\eta} \qquad p_{03} = \frac{\eta}{\lambda_1+\lambda_2+\eta}$$

$$p_{14} = a_1 i_1^*(0) \qquad p_{15} = c_1 i_1^*(0) \qquad p_{16} = b_1 i_1^*(0)$$

$$p_{17} = d_1 i_1^*(0) \qquad p_{28} = a_2 i_2^*(0) \qquad p_{29} = c_2 i_2^*(0)$$

$$p_{2,10} = b_2 i_2^*(0) \qquad p_{30} = 1 \qquad p_{40} = g_{h_1}^*(\lambda_3)$$

$$p_{45} = 1 - g_{h_1}^*(\lambda_3) \qquad p_{56} = g_{h_3}^*(0) \qquad p_{60} = g_{s_1}^*(0)$$

$$p_{70} = g_{c_f}^*(0) \qquad p_{80} = g_{h_2}^*(\lambda_4) \qquad p_{89} = 1 - g_{h_2}^*(\lambda_4)$$

$$p_{9,10} = g_{h_4}^*(0) \qquad p_{10,0} = g_{s_2}^*(0)$$

By these transition probabilities, it can be verified that

$p_{01} + p_{02} + p_{03} = p_{14} + p_{15} + p_{16} + p_{17} = p_{28} + p_{29} + p_{2,10} = p_{40} + p_{45} = p_{80} + p_{89} = 1$

$p_{30} = p_{56} = p_{60} = p_{70} = p_{9,10} = p_{10,0} = 1$

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

$$\mu_1 = -i_1^{*'}(0) \qquad \mu_2 = -i_2^{*'}(0) \qquad \mu_3 = \frac{1}{\delta_1}$$

$$\mu_4 = \frac{1}{\lambda_3}(1 - g_{h_1}^*(\lambda_3)) \qquad \mu_5 = -g_{h_3}^{*'}(0) \qquad \mu_6 = -g_{s_1}^{*'}(0)$$

$$\mu_7 = -g_{c_f}^{*'}(0) \qquad \mu_8 = \frac{1}{\lambda_4}(1 - g_{h_2}^*(\lambda_4)) \qquad \mu_9 = -g_{h_4}^{*'}(0)$$

$$\mu_{10} = -g_{s_2}^{*'}(0)$$

Thus,

$m_{01} + m_{02} + m_{03} = \mu_0$	$m_{14} + m_{15} + m_{16} + m_{17} = \mu_1$
$m_{28} + m_{29} + m_{2,10} = \mu_2$	$m_{30} = \mu_3$
$m_{40} + m_{45} = \mu_4$	$m_{56} = \mu_5$
$m_{60} = \mu_6$	$m_{70} = \mu_7$
$m_{80} + m_{89} = \mu_8$	$m_{9,10} = \mu_9$
$m_{10,0} = \mu_{10}$	

Measures of System Performance

For the purpose of comparison between the models following values of measures of performance of the system are taken from [5] and [6]:

For Model-I

Mean time to system failure (T_1)	$= N_1/D_1$
Expected up time 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 the repairman (BI_1) (Inspection time only)	$= N_{41}/D_{11}$
Busy period of the repairman (BR_1) (Repair time only)	$= N_{51}/D_{11}$

For Model-II

Mean time to system failure (T_2)	$= N_2/D_1$
Expected up time 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 the repairman (BI_2) (Inspection time only)	$= N_{41}/D_{12}$
Busy period of the repairman (BR_2) (Repair time only)	$= N_{52}/D_{12}$

where

$N_1 = \mu_0 + p_{02}\,\mu_2 + p_{03}\,\mu_3 + p_{02}\,(p_{26}\,\mu_6 + \mu_8 p_{28} + p_{27}\mu_7)$

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

$p_{210}) \mu_{10}$

$N_{11}= \mu_0$ $N_{21}= p_{02}\mu_2+p_{02} p_{26}\mu_6+p_{02} p_{27}\mu_7$

$N_{31} = p_{03}\mu_3$ $N_{41}= p_{01}\mu_1+p_{02}\mu_2$,

$N_{51}= p_{01} p_{14}\mu_4 + p_{01}p_{15}\mu_5 + p_{02}p_{26}\mu_6 + p_{02}p_{27}\mu_7$,

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

$N_{52}= p_{01}p_{14}\mu_4 + (p_{01}p_{14} p_{45}+ p_{01}p_{15}) \mu_5+ (p_{01}p_{14}p_{45} + p_{01}p_{15} +p_{01}p_{16}) \mu_6 + p_{01}p_{17}\mu_7 + p_{02}p_{28}\mu_8 + (p_{02}p_{28}p_{89} + p_{02}p_{29})\mu_9 + (p_{02}p_{28}p_{89} + p_{02}p_{29} + p_{02}p_{210}) \mu_{10}$

$D_1 = p_{01}$

$D_{11}= \mu_0+ p_{01}\mu_1+ p_{02}\mu_2 + p_{03} \mu_3+ p_{01}p_{14}\mu_4 + p_{01}p_{15}\mu_5+ p_{02} p_{26}\mu_6 + p_{02} p_{27} \mu_7$

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

Profit analysis

The expected profits of the system corresponding to model-I and model-II are:

$P_1= C_0 UT_1 + C_1DT_1 + C_2 CT_1 – C_3 BI_1 –C_4BR_1--C$

$P_2 = C_0 UT_2 + C_1DT_2 + C_2 CT_2 – C_3 BI_2 –C_4BR_2-C$

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 = cost of installation of the system

Graphical analysis

For graphical analysis the following particular case is considered:

$i_1(t)=\alpha_1 e^{-\alpha_1 t}$; $i_2(t)=\alpha_2 e^{-\alpha_2 t}$; $g_{h_1}(t)=\beta_{h_1} e^{-\beta_{h_1} t}$;

$g_{h_2}(t)=\beta_{h_2} e^{-\beta_{h_2} t}$; $g_{s_1}(t)=\beta_{s_1} e^{-\beta_{s_1} t}$; $g_{s_2}(t)=\beta_{s_2} e^{-\beta_{s_2} t}$;

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

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 faults ($\lambda_1, \lambda_2, \lambda_3, \lambda_4$), probabilities of hardware/ software/ hardware based software/common cause failures ($a_1,a_2,b_1,b_2,c_1,c_2,d_1$), inspection rates ($\alpha_1, \alpha_2$), hardware/ software/ hardware based software repair rates ($\beta_{h_1}, \beta_{h_2}, \beta_{s_1}, \beta_{s_2}, \beta_{h_3}, \beta_{h_4}$), common cause repair rate (β_{c_f}), network traffic congestion and automatic network restoration rates (η, δ_1).

Fig. 3 shows the behavior of difference of mean times to system failure of the system i.e. T_2-T_1 with respect to the rate of occurrence of major faults (λ_1) for different values rate of occurrence of minor hardware based software faults (λ_4). The graph reveals that the difference of mean times to system failure of two models decreases with increase in the values of rate of occurrence of major faults and has lower values for higher values of the rate of minor hardware based software faults. This also concludes that that model II has more reliability than model I.

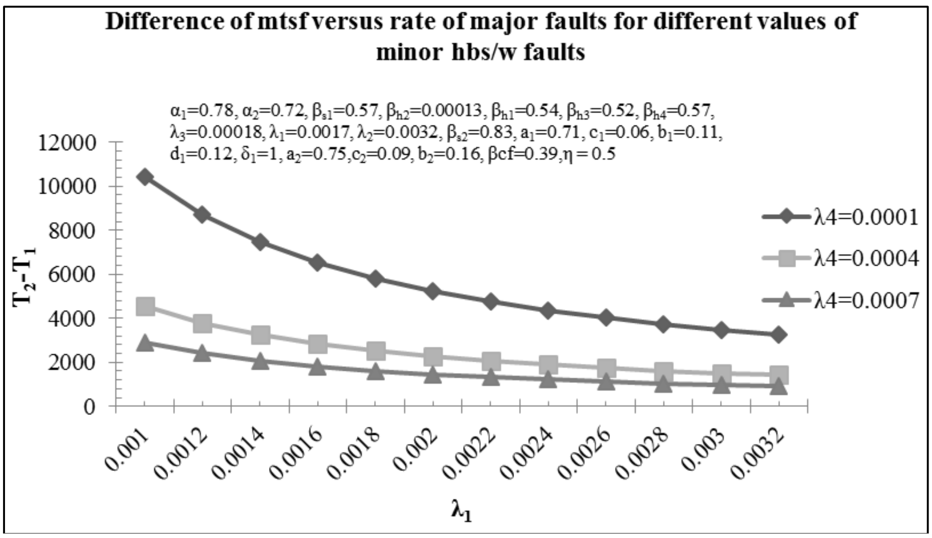

Fig 3

The curves in the fig.4 shows the behavior of difference of the expected uptimes (UT_2-UT_1) with respect to the rate of occurrence of major fault of the system (λ_1) for the different values of rate of occurrence of major hardware based software faults (λ_3). It is evident from the graph that difference of expected uptimes increases with the increase in the values of rate of occurrence of major fault and has lower values for higher values of rate of occurrence of major hardware based software fault (λ_3). From the fig.4 it may also be observed that for λ_3= 0.0001, difference of the expected uptime is < or = or > 0 according as λ_1 is < or = or > 0.00223. Hence the Model I is better or equally good or worse than Model II whenever λ_1 is < or = > 0.00223.Similarly, for λ_3= 0.0016 and λ_3=0.0031, difference of the expected uptimes is < or = or > 0 according as s λ_1 is < or = or > 0.00252 and 0.00289 respectively. Thus, in these cases, Model I is better or equally good or worse than Model II whenever λ_1 < or = or > 0.00252 and λ_1 < or = or > 0.00289.

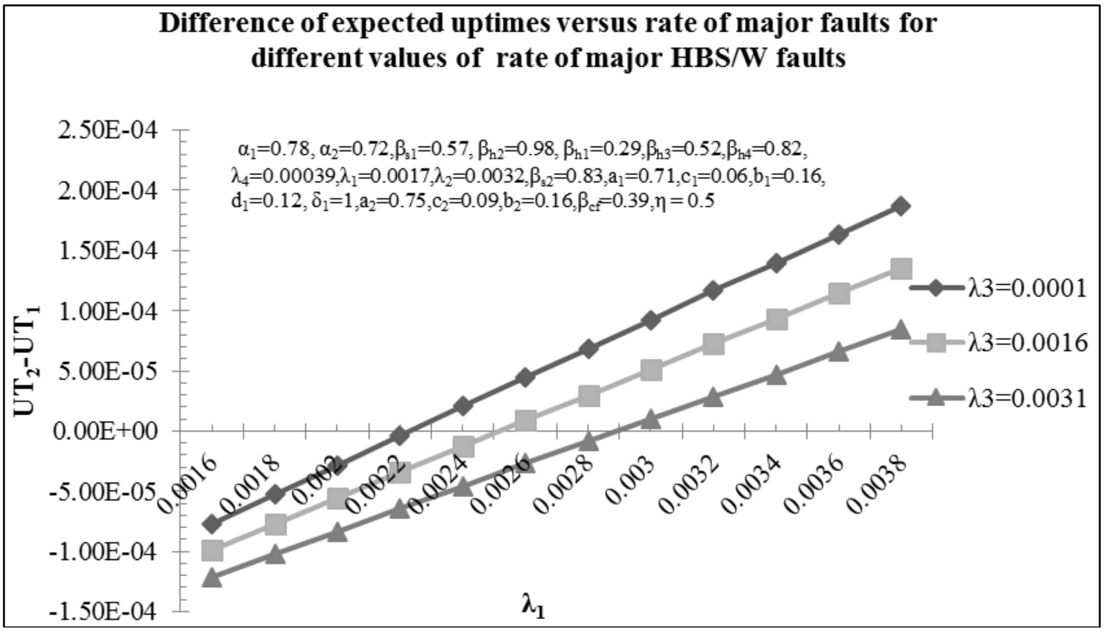

Fig 4

Fig. 5 shows the behavior of difference of the expected degradation times of the system i.e. DT_2-DT_1 on the basis of two models with respect to the rate of occurrence of minor faults (λ_2) for different values of rate of occurrence of minor hardware based software faults (λ_4). The graph reveals that the difference of expected degradation times of the two models increases with increase in the values of rate of occurrence of minor faults and has higher values for higher values of rate of occurrence of minor hardware based software faults. This shows that model II has more expected degradation time than model I.

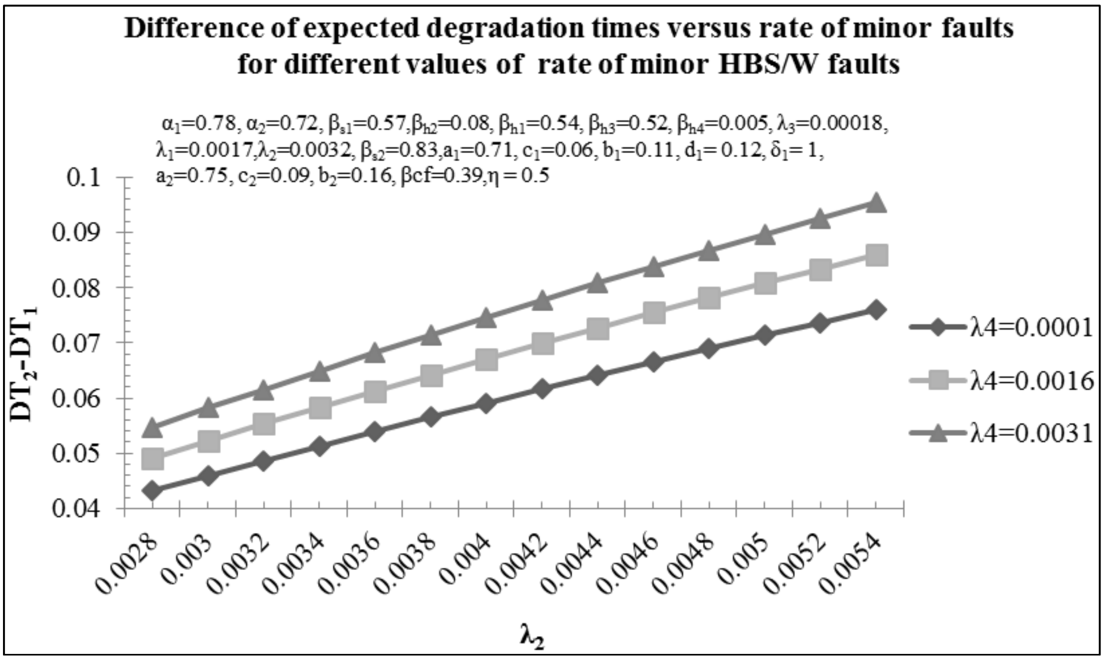

Fig 5

Fig. 6 gives the graph difference of expected congestion times (CT_0) of the system and traffic congestion rate (η) for different values of network restoration rate (δ_1). The graph indicates that difference of expected congestion times decreases with increase in the values of rate of traffic congestion and has higher values for higher values of automatic network restoration rate on traffic congestion. The graph also reveals that model I has more expected congestion time than model II for considered values of parameters.

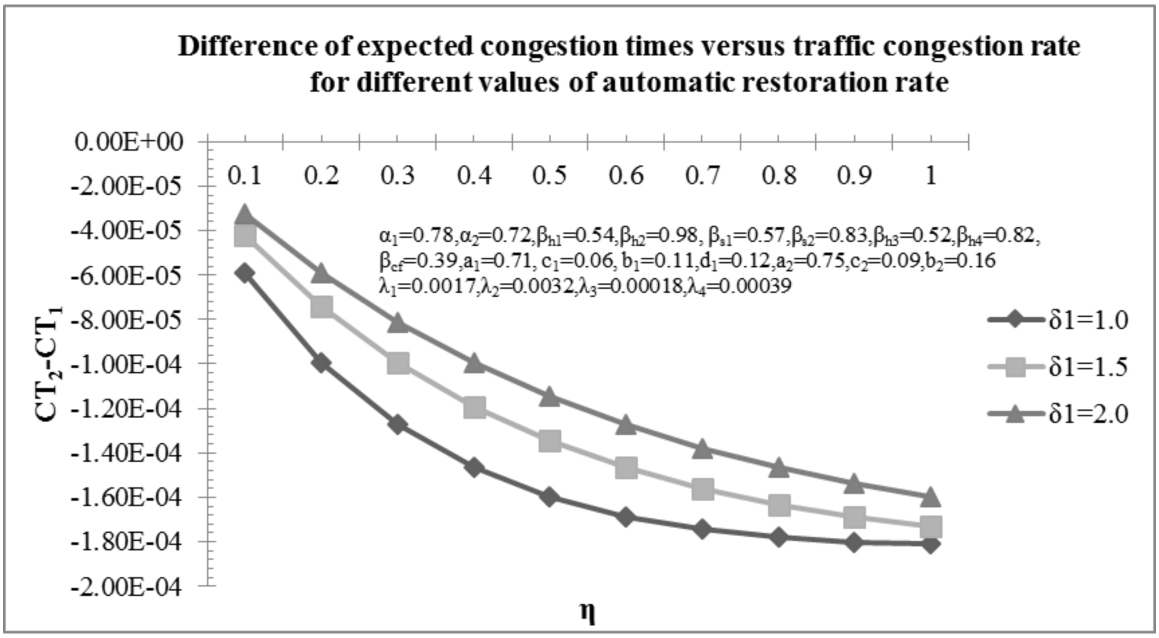

Fig 6

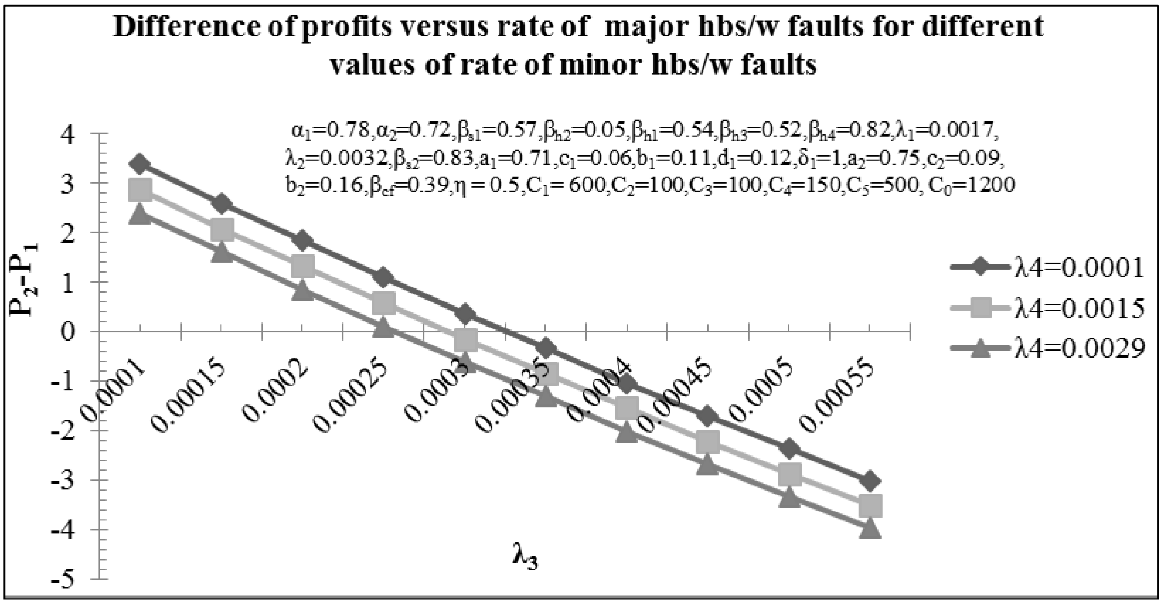

Fig 7

The curves in the fig.7 shows the behavior of the difference of profits (P_2-P_1) with respect to the rate of occurrence of major hardware based software faults of the system (λ_3) for the different values of rate of occurrence of minor hardware based software faults (λ_4). It is evident from the graph that difference of profits decreases with the increase in the values of rate of occurrence of major hardware based software faults and has lower values for higher values of minor hardware based software faults. From the fig.7 it may also be observed that for $\lambda_4 = 0.0001$, the difference of profits is > or = or < 0 according as λ_3 is < or = or > 0.000326. Hence the Model II is better or equally good or worse than Model I whenever λ_3 < or = or >0.000326. Similarly, for λ_4=0.0015 and λ_4=0.0029, the profit difference is > or = or < 0 according as is λ_3 < or = or > 0.00029 and 0.000258 respectively. Thus, in these cases, Model II is better or equally good or worse than Model I whenever λ_3< or = or > 0.00029 and λ_3 < or = or >0.000258.
The curves in the fig.8 shows the behavior of the difference of profits (P_2-P_1) with respect to the repair rate of common cause failures (β_{c_f}) for the different values of rate of occurrence of major faults (λ_1). It is evident from the graph that difference of profits increases with the increase in the values of repair rate of common cause failures and has higher value for higher values of rate of occurrence of major faults. From the fig.8 it may also be observed that for λ_1=0.002 the difference of profits is < or = or > 0 according as β_{c_f} is < = or > 1.34. Hence the Model I is better or equally good or worse than Model II whenever β_{c_f} is < = or > 1.34. Similarly, for λ_1=0.0025 and λ_1=0.003 the difference of profits is < or = or > 0 according as is β_{c_f} < or = or > 0.969 and 0.817 respectively. Thus, in these cases, Model I is better or equally good or worse than Model II whenever β_{c_f} < or = or > 0.969 and β_{c_f} < or = or >0.817.

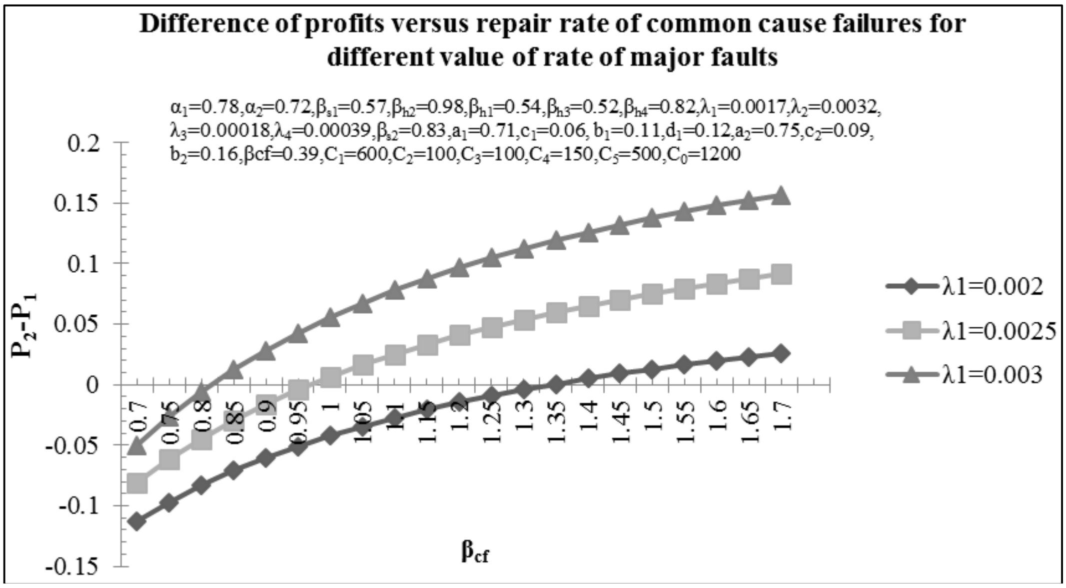

Fig. 8

Conclusion

From the comparative analysis it can be concluded that the difference of mean times to system failure of the models decreases with increase in the rate of occurrence of major faults and has lower values for higher values of rate of occurrence of minor hardware based software faults. It is also concluded that the model given in [6] has higher reliability than model given in [5] for some considered values of the parameters. It also revealed from the analysis that difference of expected uptimes increases with increase in the values of major faults and has lower values for higher values of rate of major hardware based software faults. It is also concluded that the difference of the expected degradation times increases with increase in the values of rate of occurrence of minor faults and has higher values for higher values of rate of minor hardware based software faults. It may also be concluded that expected degradation time of model given in [6] is more than model given in [5] for the given values of parameters. Further it is observed that difference of expected congestion times decreases with increase in the values of rate of network traffic congestion and has higher values for higher values of automatic network restoration rate. It also reveals that expected congestion time of model given in [6] is less than model given in [5].

Also cut-off points for various parameters of importance can be obtained for differences expected uptimes and profits of the models given in [5] and [6] to suggest the stakeholders which model is better and under what conditions.

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