Profit And Cost Benefit Analysis Of A Hardware-Software System Incorporating Interaction Failure, Human Error Common Cause Failure And Location Coverage

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ABSTRACT
In the present paper, a stochastic model for a hardware-software system has been developed considering various kinds of failure that the system may encounter and recovery mechanism may be employed. The system may have hardware, software or hardware-based software interaction failures wherein the hardware-based software interaction failures occur due to undetected hardware faults in the system. Consequently, the system may transits from normal operative mode to either degraded hardware, software or to complete failure mode. The possibilities of human errors and common cause failures have also been taken wherein the common cause failures lead the system to complete failure mode whereas human errors may lead to hardware/software failure mode or to complete failure mode. Two types of automatic fault recovery mechanism-one each for hardware and software components have been considered apart from availability of an external repair facility. It is assumed that a fault in the system is auto detected by the system however detected fault may or may not be located. Further only the located faults can be auto recovered by the system otherwise the external engineer is called to repair the system. The measures of system performance such as mean time to system failure, mean up and degradation time are computed by making use of Markov Process. The expected cost-benefit of the system is also evaluated. Various conclusions regarding performance and cost-benefit of the system are drawn on the basis of graphical studies.
KEYWORDS: Human error failure, common cause failure, reliability, mean up time, mean degradation time, profit, Markov process and regenerative point technique.

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I. INTRODUCTION

Hardware/Software failures occur due to faults in design and manufacturing processes, faulty operations, poor quality control, poor maintenance and etc. In the past researchers investigated reliability of the hardware/software system dealing with hardware reliability and software reliability. For the reliability analyses of the whole system, combined reliability models, i.e. including both hardware and software subsystems were discussed by a few researchers including Friedman and Tran [3], Hecht and Hecht [4], Welke et al. [18] etc. assuming in general that these components are independent of each other. That is, the aspects of interactions between the hardware and software components were not taken up by them. However, Boyd et al. [1] discussed the difficulties in modeling hardware-software interactions.

Several researchers in the past justified that there exist remarkable interactions between hardware and software components and have significant effect on reliability of the system, e.g. see Iyer and Velardi [6], Martin and Mathur [11], Kanoun and Ortalo-Borrel [9], Haung et al.[5]. Taking this into account, Teng et al. [16] discussed the reliability of the combined system has been obtained by considering different models for hardware, software and hardware based software failure and not in fact in integrated way.

Recently, Kumar and Kumar [10] extended the above work by considering combined reliability model for the systems having hardware, software and hardware based software failures with different types of recovery methods. Environmental factors such as human error and common cause failures may affect the system performance. Human errors are important while predicting the reliability and safety measures of any computer system. In a real life situation, many faults are caused directly or indirectly due to human errors such as wrong action, poor communication, wrong interpretation, poor handling, poor maintenance and operation procedure, etc. According to the work done by Meister [13] about 30% of failures are directly or indirectly due to human errors. Further, common cause failure is also key factor that should be incorporated to predict the system performance. The common cause failure may occur due to equipment design deficiency, power supply, humidity, temperature, etc. An example of a human error is the fire in a room where the redundant units are located Jain et al. [8] discussed availability analysis of embedded computer system with two types of failure and common cause failure. Chae et al. [7] discussed system reliability in the presence of common-cause failures. Mahmoud and Moshref [12] discussed two unit cold standby system considering hardware, human error failures and preventative maintenance. The system performance can be obtained more accurately by the use of these concepts. Hence realistic reliability model must include the occurrence of human errors, common cause failure, hardware failures and software failures. Trivedi [17] describe the location of faults when faults are present. Pradhan [14] and Seong [15] defined coverage as the conditional probability that a system recovers, given that fault has occurred. Fault detection coverage is the conditional probability that, given the existence of fault, the system detects it. Similarly, Fault location coverage is the conditional probability that, given the existence of fault, the system locates it. Moreover, fault detection coverage is the system's ability to detect a fault; fault location coverage is the system's ability to locate the cause of fault.

Keeping facts in view, the present paper is an attempt to develop a stochastic model for a hardware-software system considering various kinds of failure that the system may encounter and recovery mechanism may be employed. The system may have hardware, software or hardware-based software interaction failures wherein the hardware-based software interaction failures occur due to undetected hardware faults in the system. Consequently, the system may transits from normal operative mode to either degraded hardware, software or to complete failure mode. The possibilities of human errors and common cause failures have also been taken wherein the common cause failures lead the system to complete failure mode whereas human errors may lead to hardware/software failure mode or to complete failure mode. Two types of automatic fault recovery mechanism-one each for hardware and software components have been considered apart from availability of an external repair facility. It is assumed that a fault in the system is auto detected by the system however detected fault may or may not be located. Further only the located faults can be auto recovered by the system otherwise the external engineer is called to repair the system. The measures of system performance such as mean time to system failure, mean up and degradation time are computed by making use of Markov Process. The expected cost-benefit of the system is also evaluated. Various conclusions regarding performance and cost-benefit of the system are drawn on the basis of graphical studies.

II. ASSUMPTIONS

Others assumptions taken as under:

1. The complete failure of hardware/software components is self announced whereas partial failure may or may not be immediately detected.
2. On detection of a partial failure, the system is automatically recovered using software methods otherwise external engineer is called to repair it.
3. Undetected hardware fault leads to complete software failure due to hardware-based software interactions.
4. The external engineer reaches the system in negligible time whenever called and perfectly repair the hardware/software components of the system.
5. The failure time distributions are assumed exponential whereas other time distributions are taken general.
6. All random variables are mutually independent.

III. STATES OF THE SYSTEM

HS Normal operative mode

$\hat{\mathrm{H}}\mathrm{S}$ Partial (degraded) hardware mode

$\mathrm{H}\hat{\mathrm{S}}$ Partial (degraded) software mode

$\mathrm{H}\tilde{\mathrm{S}}$ Undetected software mode

$\tilde{\mathrm{H}}\mathrm{S}$ Undetected hardware mode

$\bar{\mathrm{H}}\mathrm{S}$ Hardware failure mode

$\mathrm{H}\bar{\mathrm{S}}$ Software failure mode

$\overline{\mathrm{HS}}$ Hardware-software failure mode

$\mathrm{H}\hat{\mathrm{S}}_u$ Unlocated software degraded mode

$\hat{\mathrm{H}}_u\mathrm{S}$ Unlocated hardware degraded mode

$H\hat{S}_l$ Located software degraded mode

$\hat{H}_l S$ Located hardware degraded mode

State Transition Diagram

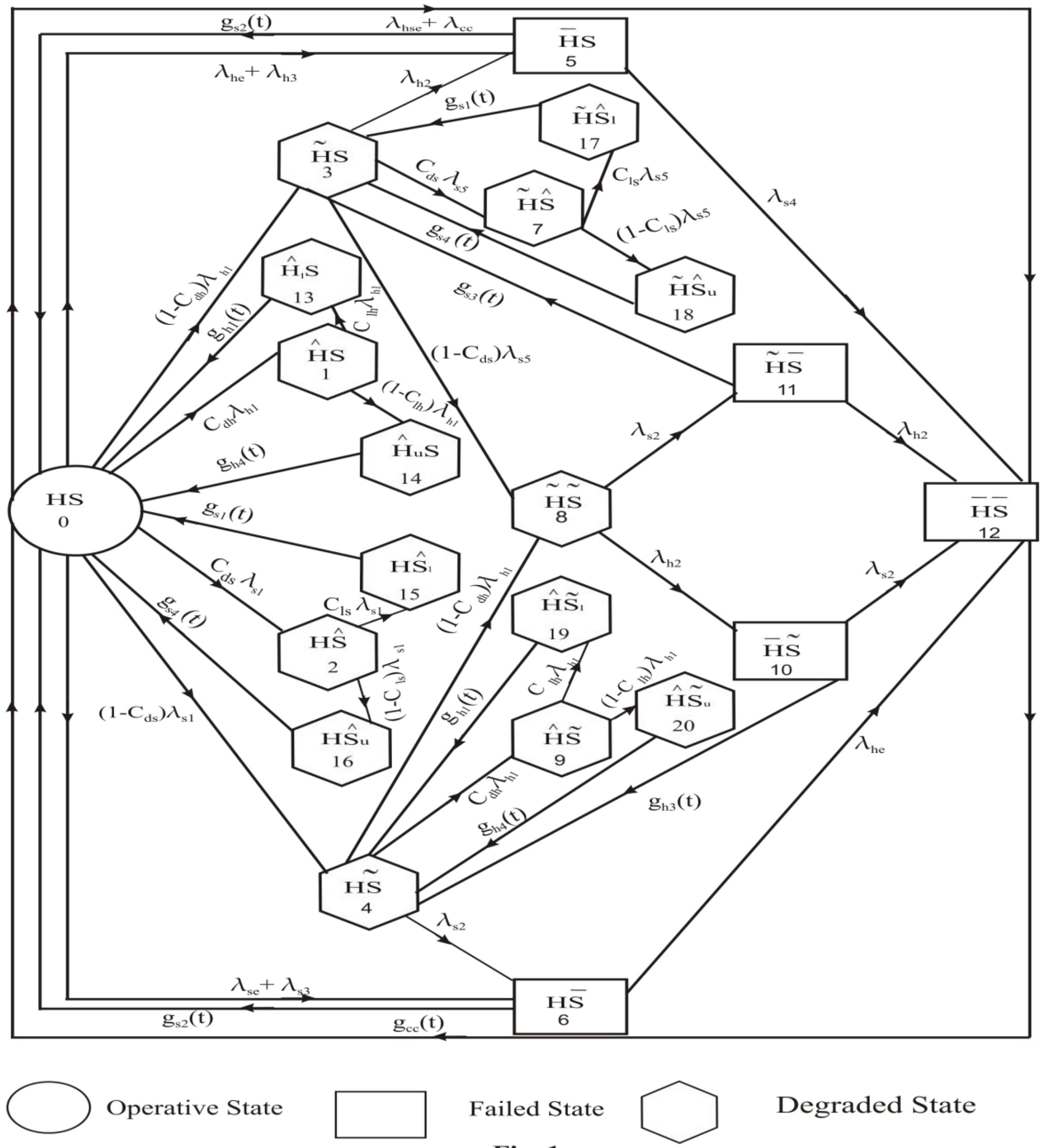

Fig. 1

IV. NOTATIONS

λ_{h1} : Hardware failure rate from normal mode to hardware degraded mode.

λ_{h2} : Hardware failure rate from hardware degraded mode to complete hardware failed mode.

λ_{h3} : Hardware failure rate from normal mode to complete hardware failed mode.

λ_{s1} : Software failure rate from normal mode to software degraded mode.

λ_{s2} : Software failure rate from hardware degraded mode to complete hardware failed mode.

λ_{s3} : Software failure rate from normal mode to complete software failed mode.

λ_{s4} : Hardware based software interaction failure rate.

λ_{s5} : Hardware based software interaction failure rate when hardware fault is undetected.
λ_{he} : Hardware failure rate due to human error.
λ_{se} : Software failure rate due to human error.
λ_{hse} : Hardware-Software failure rate due to human error.
λ_{cc} : Common cause failure rate.
C_{dh} : Hardware fault detection coverage.
C_{ds} : Software fault detection coverage.
C_{lh} : Hardware fault location coverage.
C_{ls} : Software fault location coverage.
$g_{h1}(t)/G_{h1}(t)$: P.d.f./C.d.f of time for automatic hardware recovery.
$g_{s1}(t)/G_{s1}(t)$: P.d.f./C.d.f of time for automatic software recovery.
$g_{h2}(t)/G_{h2}(t)$: P.d.f./C.d.f of time to hardware repair from hardware failed mode to normal mode by external engineer.
$g_{s2}(t)/G_{s2}(t)$: P.d.f./C.d.f of time to software repair from software failed mode to normal mode by external engineer.
$g_{h3}(t)/G_{h3}(t)$: P.d.f./C.d.f. of time to hardware repair from hardware failed mode to undetected software mode by external engineer.
$g_{s3}(t)/G_{s3}(t)$: P.d.f./C.d.f. of time to software repair from software failed mode to undetected hardware mode by external engineer.
$g_{cc}(t)/G_{cc}(t)$: P.d.f./C.d.f. of time to complete system repair by external engineer.

V. TRANSITION PROBABILITIES AND MEAN SOJOURN TIME

The non-zero element p_{ij} are given by

$$p_{01}=C_{dh}\lambda_{h1}/A;\ p_{02}=C_{ds}\lambda_{s1}/A;\ p_{03}=(1-C_{dh})\lambda_{h1}/A;\ p_{04}=(1-C_{ds})\lambda_{s1}/A;$$
$$p_{05}=(\lambda_{he}+\lambda_{h3})/A;\ p_{06}=(\lambda_{se}+\lambda_{s3})/A;\ p_{0,12}=(\lambda_{hse}+\lambda_{cc})/A;\ p_{1,13}=C_{lh};\ p_{1,14}=(1-C_{lh});$$
$$p_{2,15}=C_{ls};\ p_{2,16}=(1-C_{ls});\ p_{35}=\lambda_{h2}/B;\ p_{37}=C_{ds}\lambda_{s5}/B;\ p_{38}=(1-C_{ds})\lambda_{s5}/B;\ p_{46}=\lambda_{s2}/C;$$
$$p_{48}=(1-C_{dh})\lambda_{h1}/C;\ p_{49}=C_{dh}\lambda_{h1}/C;\ p_{50}=g^*_{h2}(\lambda_{s4});\ p_{5,12}=1-g^*_{h2}(\lambda_{s4});\ p_{60}=g^*_{s2}(\lambda_{he});$$
$$p_{6,12}=1-g^*_{s2}(\lambda_{he});\ p_{7,17}=C_{ls};\ p_{7,18}=(1-C_{ls});\ p_{8,10}=\lambda_{h2}/D;\ p_{8,11}=\lambda_{s2}/D;\ p_{9,19}=C_{lh};$$
$$p_{9,20}=(1-C_{lh});\ p_{10,4}=g^*_{h3}(\lambda_{s2});\ p_{10,12}=1-g^*_{h3}(\lambda_{s2});\ p_{11,3}=g^*_{s3}(\lambda_{h2});\ p_{11,12}=1-g^*_{s3}(\lambda_{h2});$$
$$p_{12,0}=p_{12,0}=p_{13,0}=p_{14,0}=p_{15,0}=p_{16,0}=p_{16,0}=p_{17,3}=p_{18,3}=p_{19,4}=p_{20,4}=1,\ A=\lambda_{s1}+\lambda_{h1}$$
$$+\lambda_{s3}+\lambda_{h3}+\lambda_{he}+\lambda_{se}+\lambda_{hse}+\lambda_{cc};\ B=\lambda_{h2}+\lambda_{s5};\ C=\lambda_{h1}+\lambda_{s2};\ D=\lambda_{h2}+\lambda_{s2}.$$

Mean sojourn time μ_i in the i[th] state is the expected first passage time taken by the i[th] state before transiting to any other state.

$$\mu_i=\int_0^\infty \Pr(T_i>t)\,dt\ ,$$

where T_i is of life time of the system.
Therefore,

$$\mu_0=1/A\ ;\ \mu_1=1/\lambda_{h1}\ ;\ \mu_2=1/\lambda_{s1}\ ;\ \mu_3=1/B\ ;\ \mu_4=1/C\ ;\ \mu_5=\{1-g^*_{h2}(\lambda_{s4})\}/\lambda_{s4}\ ;$$
$$\mu_6=\{1-g^*_{s2}(\lambda_{he})\}/\lambda_{he}\ ;\ \mu_7=1/\lambda_{s5}\ ;\ \mu_8=1/D\ ;\ \mu_9=1/\lambda_{h1}\ ;\ \mu_{10}=\{1-g^*_{h3}(\lambda_{s2})\}/\lambda_{s2}\ ;$$
$$\mu_{11}=\{1-g^*_{s3}(\lambda_{h2})\}/\lambda_{h2}\ ;\ \mu_{12}=-g_{cc}^{*\prime}(0)\ ;\ \mu_{13}=-g_{h1}^{*\prime}(0)\ ;\ \mu_{14}=-g_{h4}^{*\prime}(0)\ ;\ \mu_{15}=-g_{s1}^{*\prime}(0)\ ;$$
$$\mu_{16}=-g_{s4}^{*\prime}(0)\ ;\ \mu_{17}=-g_{s1}^{*\prime}(0)\ ;\ \mu_{18}=-g_{s4}^{*\prime}(0)\ ;\ \mu_{19}=-g_{h1}^{*\prime}(0)\ ;\ \mu_{20}=-g_{h4}^{*\prime}(0)\ .$$

Mean Time to System Failure (T_1) $\quad = N/D$

Mean Up Time of the System (A_1) $= N_1 / D_1$

Expected Number of Hardware Repairs by External Engineer (D_1) $= N_2 / D_1$

Expected Number of Hardware Repairs by External Engineer (HR_1) $= N_3 / D_1$

Expected Number of Hardware Repairs by Software Methods (HM_1) $= N_4 / D_1$

Expected Number of Software Repairs by External Engineer (SR_1) $= N_5 / D_1$

Expected Number of Software Repairs by Software Methods (SM_1) $= N_6 / D_1$

Expected Number of Visits by External Engineer (VR_1) $= N_7 / D_1$,

where

$$N = (\mu_0 + \mu_1 p_{01} + \mu_2 p_{02})(1 - p_{37})(1 - p_{49}) + p_{03}(1 - p_{49})(\mu_3 + \mu_7 p_{37} + p_{37} p_{7,17} \mu_{17} + \mu_8 p_{38} + p_{38} p_{8,18} \mu_{18}) + p_{04}(1 - p_{37})(\mu_4 + \mu_9 p_{49} + p_{48} p_{8,19} \mu_{19} + \mu_8 p_{48} + p_{48} p_{8,20} \mu_{20});$$

$$D = (1 - p_{01} - p_{02})(1 - p_{37})(1 - p_{49});$$

$$N_1 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][\mu_0];$$

$$D_1 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][\mu_0 + p_{01}\mu_1 + p_{02}\mu_2 + p_{05}\mu_5 + p_{06}\mu_6 + p_{0,12}\mu_{12}] + [1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{03}\mu_3 + p_{03} p_{35}\mu_5 + p_{03} p_{35} p_{5,12}\mu_{12} + p_{03} p_{37}\mu_7 + p_{03} p_{38}(\mu_8 + p_{8,12}\mu_{12} + p_{8,10}\mu_{10} + p_{8,11}\mu_{11} + p_{8,10} p_{10,4}\mu_4 + p_{8,11} p_{11,3}\mu_3)] + [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][p_{04}\mu_4 + p_{04} p_{46}\mu_6 + p_{04} p_{46} p_{6,12}\mu_{12} + p_{04} p_{49}\mu_9 + p_{04} p_{48}(\mu_8 + p_{8,12}\mu_{12} + p_{8,10}\mu_{10} + p_{8,10} p_{10,4}\mu_4 + p_{8,11}\mu_{11} + p_{8,11} p_{11,3}\mu_3)];$$

$$N_2 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{01}\mu_1 + p_{02}\mu_2] + [1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{03}\mu_3 + p_{03} p_{37}\mu_7 + p_{03} p_{38}\mu_8 + p_{03} p_{37} p_{7,17}\mu_{17} + p_{03} p_{37} p_{7,18}\mu_{18}] + [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][p_{04}\mu_4 + p_{04} p_{48}\mu_8 + p_{04} p_{49}\mu_9 + p_{04} p_{49} p_{9,19}\mu_{19} + p_{04} p_{49} p_{9,20}\mu_{20}];$$

$$N_3 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{05} p_{50} + p_{0,12} + p_{01} p_{1,14}] + p_{03} p_{38} p_{8,10} p_{10,4}[1 - p_{49} - p_{48} p_{8,10} p_{10,4}] + p_{04}[p_{48} p_{8,10} p_{10,4} + p_{49} p_{9,20} p_{20,4}][1 - p_{37} - p_{38} p_{8,11} p_{11,3}];$$

$$N_4 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{01} p_{10} + p_{01} p_{1,13} p_{13,0}] + p_{04}[1 - p_{37} - p_{38} p_{8,11} p_{11,3}][p_{49} p_{94} + p_{49} p_{9,19} p_{19,4}];$$

$$N_5 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{02} p_{2,16} p_{16,0} + p_{06} p_{60} + p_{0,12} p_{12,0}] + p_{03}[p_{37} p_{7,18} p_{18,3} + p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}] + p_{04} p_{48} p_{8,11} p_{11,3}[1 - p_{37} - p_{38} p_{8,11} p_{11,3}];$$

$$N_6 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{02} p_{20} + p_{02} p_{2,15} p_{15,0}] + p_{03}[1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{37} + p_{37} p_{7,17} p_{17,3}];$$

$$N_7 = [1 - p_{37} - p_{38} p_{8,11} p_{11,3}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}][p_{05} + p_{06} + p_{012}] + [p_{03} p_{35} + p_{03} p_{38} p_{8,10} + p_{03} p_{38} p_{8,11}][1 - p_{49} - p_{48} p_{8,10} p_{10,4}] + [p_{04} p_{46} + p_{04} p_{48} p_{8,10} + p_{04} p_{48} p_{8,11}][1 - p_{37} - p_{38} p_{8,11} p_{11,3}]$$

VI. PROFIT ANALYSIS

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

$$P_1 = C_0 A_1 + C_1 D_1 - C_2 HM_1 - C_3 HR_1 - C_4 SM_1 - C_5 SR_1 - C_6 VR_1 - C_I ,$$

where

C_0 = revenue per unit mean up time of the system.
C_1 =revenue per unit degradation time of the system.
C_2 = cost per unit hardware repair by software methods.
C_3 = cost per unit hardware repair by external engineer.
C_4 = cost per unit software repair by software methods.
C_5 = cost per unit software repair by external engineer.
C_6 = cost per visit of the external engineer.
C_I = software installation cost.

VII. PARTICULAR CASE

The following particular case is considered for the analysis purpose:

$$g_{s1}(t) = \alpha_1 e^{-\alpha_1 t} ; g_{s2}(t) = \alpha_2 e^{-\alpha_2 t} ; g_{s3}(t) = \alpha_3 e^{-\alpha_3 t} ; g_{s4}(t) = \alpha_4 e^{-\alpha_4 t} ; g_{h1}(t) = \beta_1 e^{-\beta_1 t} ;$$
$$g_{h2}(t) = \beta_2 e^{-\beta_2 t} ; g_{h3}(t) = \beta_3 e^{-\beta_3 t} ; g_{h4}(t) = \beta_4 e^{-\beta_4 t} ; g_{cc}(t) = \gamma e^{-\gamma t} .$$

Then, we get

$$p_{5,12} = \frac{\lambda_{s4}}{\beta_2 + \lambda_{s4}} ; \quad p_{60} = \frac{\alpha_2}{\lambda_{he} + \alpha_2} ; \quad p_{6,12} = \frac{\lambda_{he}}{\lambda_{he} + \alpha_2} ; \quad p_{10,4} = \frac{\beta_3}{\lambda_{he} + \beta_3} ;$$
$$p_{10,12} = \frac{\lambda_{he}}{\lambda_{he} + \beta_3} ; \quad p_{11,3} = \frac{\alpha_3}{\lambda_{h2} + \alpha_3} ; \quad p_{11,12} = \frac{\lambda_{h2}}{\lambda_{h2} + \alpha_3} .$$

Mean sojourn time (μ_i) becomes:

$$\mu_5 = \frac{1}{\beta_2 + \lambda_{s4}} ; \mu_6 = \frac{1}{\alpha_2 + \lambda_{he}} ; \quad \mu_{10} = \frac{1}{\beta_3 + \lambda_{s2}} ; \mu_{11} = \frac{1}{\alpha_3 + \lambda_{h2}} ; \mu_{12} = \frac{1}{\gamma} ; \mu_{13} = \frac{1}{\beta_1} ;$$
$$\mu_{14} = \frac{1}{\beta_4} ; \mu_{15} = \frac{1}{\alpha_1} ; \mu_{16} = \frac{1}{\alpha_4} ; \mu_{17} = \frac{1}{\alpha_1} ; \mu_{18} = \frac{1}{\alpha_4} ; \mu_{19} = \frac{1}{\beta_1} ; \mu_{20} = \frac{1}{\beta_4} .$$

The values of the various failure rates and repair rates as given in Lai. et al. (2) i.e. $\lambda_{h1} = .02, \lambda_{h2} = .0248, \lambda_{h3} = .0284, \lambda_{s1} = .00614, \lambda_{s2} = .00674, \lambda_{s3} = .00692,$ $\lambda_{s4} = .05, \lambda_{s5} = .00246 \quad \alpha_2 = .1; \alpha_3 = .16; \alpha_4 = .24; \beta_2 = .12; \beta_3 = .18; \beta_4 = .2$ are taken as a particular case.

For this case values of various measures of system performance are computed from the results given in preceding section for assumed values of failure rates, repair rates, detection coverage factors and various costs a s

$$\beta_1 = .35; \alpha_1 = .12; \gamma = 2; \lambda_{he} = .001; \lambda_{se} = .006; \lambda_{hse} = .0002; \lambda_{cc} = .0005, c_{dh} = .9,$$
$$c_{ds} = .6 C_0 = 10000, C_1 = 100, C_2 = 500, C_3 = 50, C_4 = 400, C_5 = 200, C_I = 2000$$

.

These values are as under:
Mean Time to System Failure = 38.9284
Steady-state availability = 0. .8819551
Expected Number of Hardware Repairs by External engineer = .096709
Expected Number of Hardware Repairs by software methods = .003482
Expected Number of Software Repairs by External engineer = .09121528
Expected Number of Software Repairs by software methods = .0056426
Expected Profit = 6767.93

VIII. GRAPHICAL INTERPRETATIONS

Various graphs have been plotted using the above particular case by giving some numerical values to the parameters involved. The following interpretations and conclusion have been drawn from the graphs.

Fig. 2 depicts the behaviour of mean time to system failure (T_1) with respect to hardware/software failure rates, software/hardware fault detection coverage and common cause failure rate.

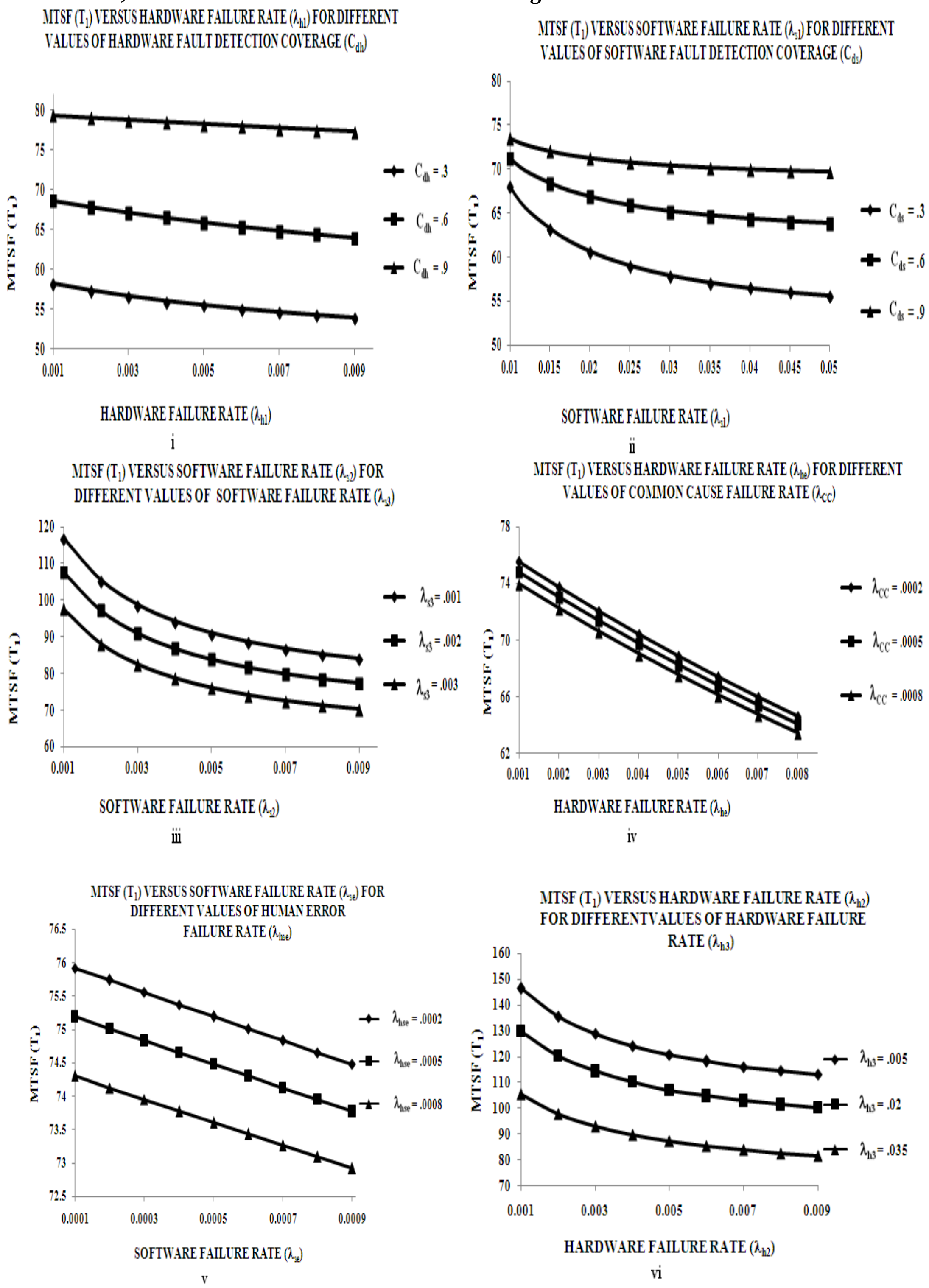

Fig. 2: Mean time to system failure w.r.t. different parameters

From the graphs, it can be concluded that mean time to system failure (T_1) decreases with respect to hardware/software failure rates, common cause failure rate and has higher values for higher values of software/hardware fault detection coverage.

In **fig. 3**, the graphs present the behaviour of mean up time (A_1) with respect to hardware/software failure rates, software/hardware fault detection coverage, software/hardware recovery rate, software/hardware repair rates and common cause failure rate.

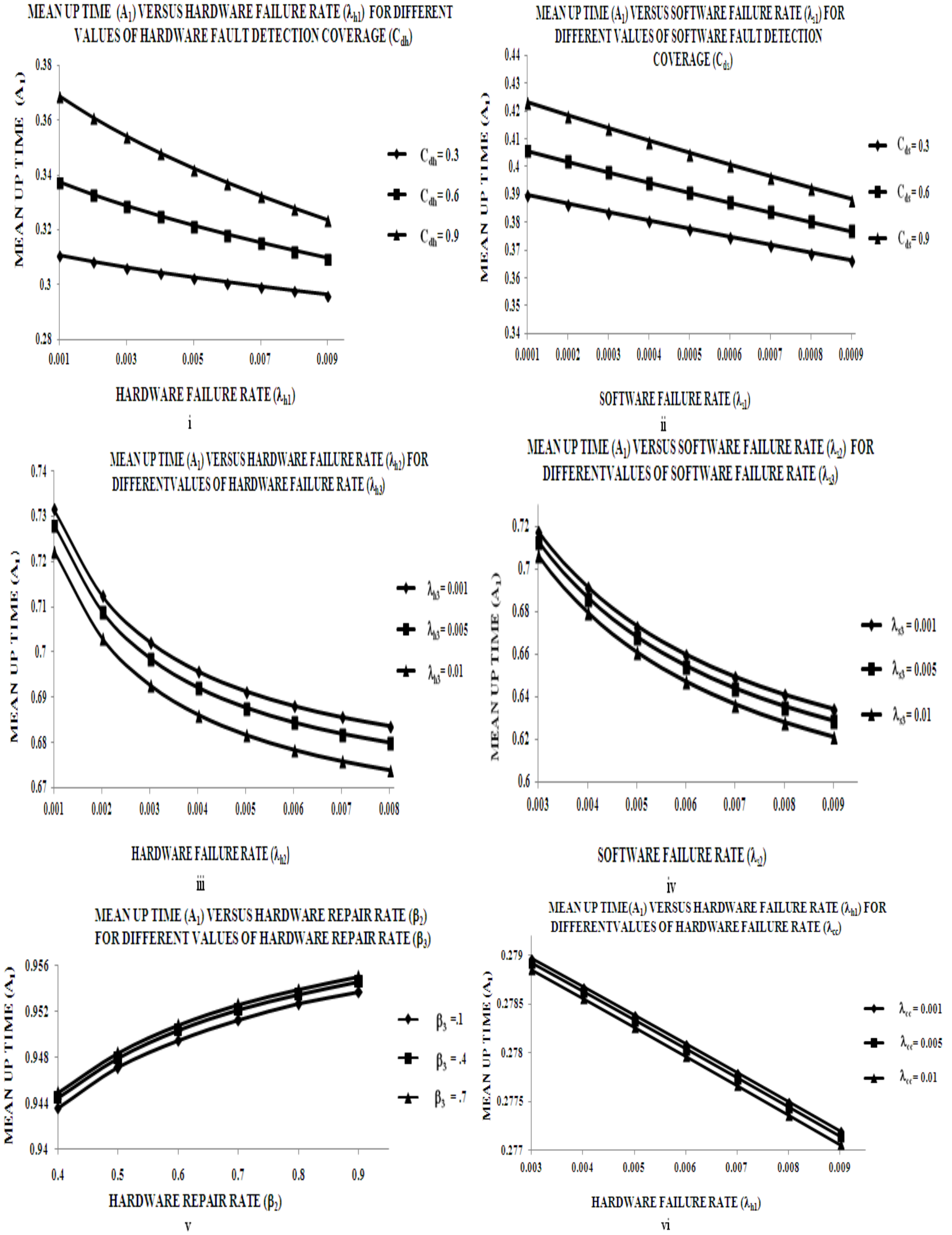

Fig: 3 Mean up time of the system w.r.t. different parameters

From the graphs, it can be concluded that mean up time decreases with respect to hardware/software failure rates and has higher values for higher values of software/hardware fault detection coverage, software/hardware recovery rate, software / hardware repair rates and complete repair rate.

In **fig. 4**, the graphs present the behaviour of mean degradation time with respect to hardware/software failure rates, software/ hardware fault detection coverage, software/hardware recovery rate, software/hardware repair rates and common cause failure rate.

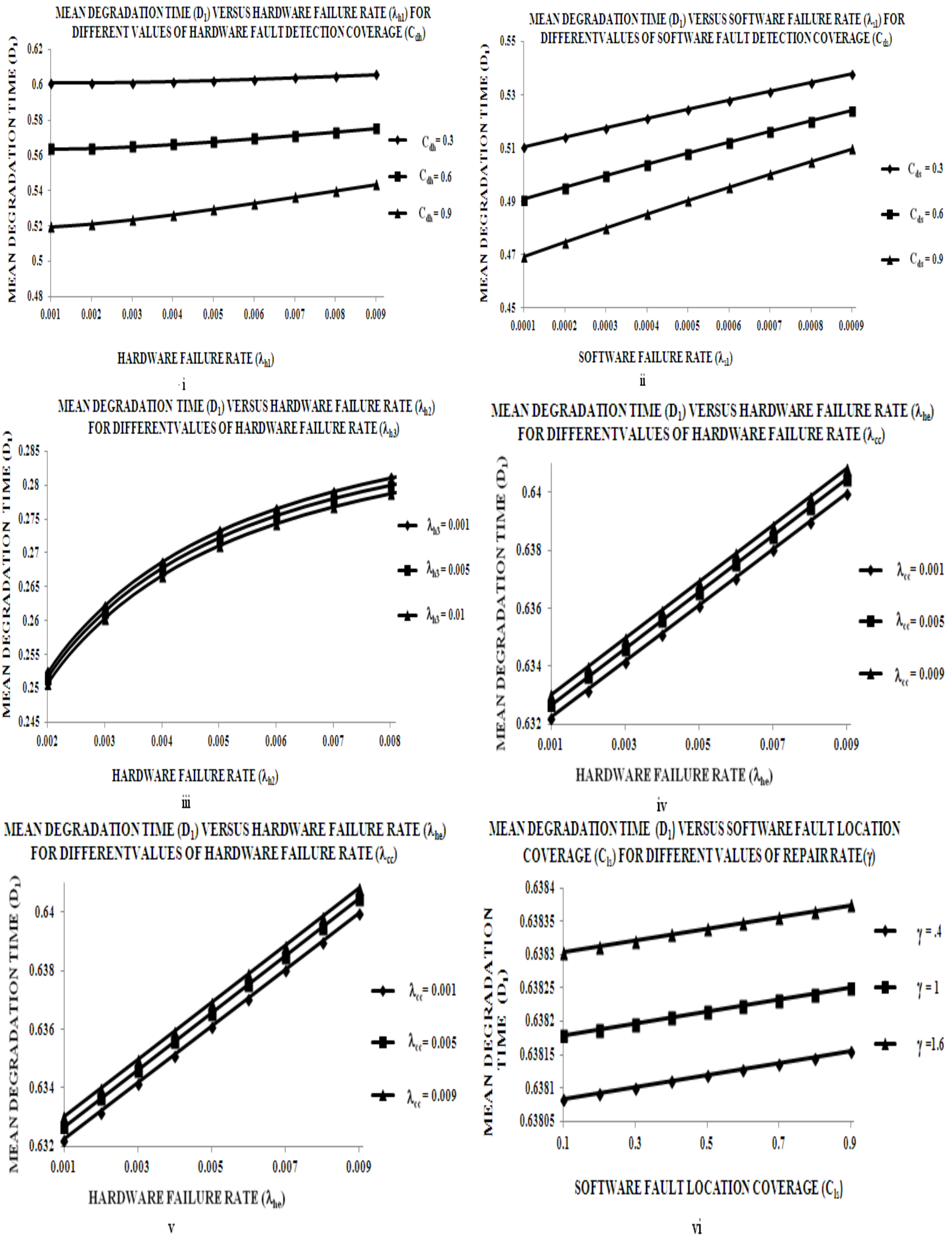

Fig: 4 Mean degradation time of the system failure w.r.t. different parameters

From the graphs, it can be concluded that mean degradation time increases with respect to hardware/software failure rates and has lower values for higher values of software/hardware fault detection coverage, software/hardware recovery rate, software / hardware repair rates and complete repair rate.

In **fig. 5,** the graph reveals the pattern of profit (P_1) with respect revenue cost per unit degradation time C_1 for different values revenue cost per unit up time (C_0)

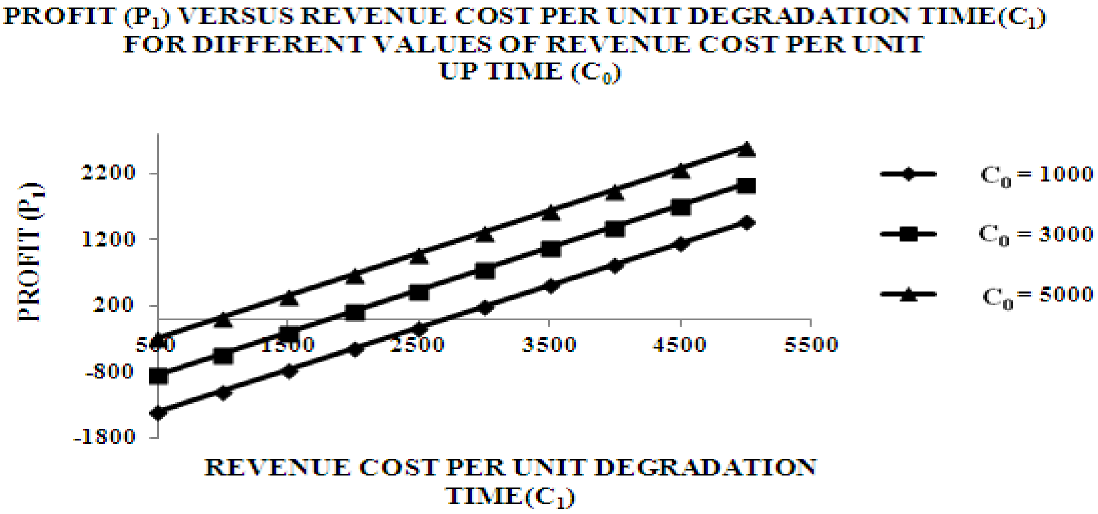

Fig.5

From the **fig. 5**, it can be observed that from the graph for C_0 = 1000, P_0 is positive or negative according as C_1 > or < 856.5. Therefore, the system is profitable whenever revenue per unit degradation time is greater than Rs. 856.5. Similarly for $C_0 = 3000$ and $C_0 = 5000$, the system is profitable whenever revenue per unit degradation time is greater than Rs. 1774.5 and Rs. 2636.5, respectively.

In **fig. 6,** the graph reveals the pattern of profit (P_1) with respect to revenue cost per unit up time (C_0) for different values of hardware fault detection coverage (C_{dh}).

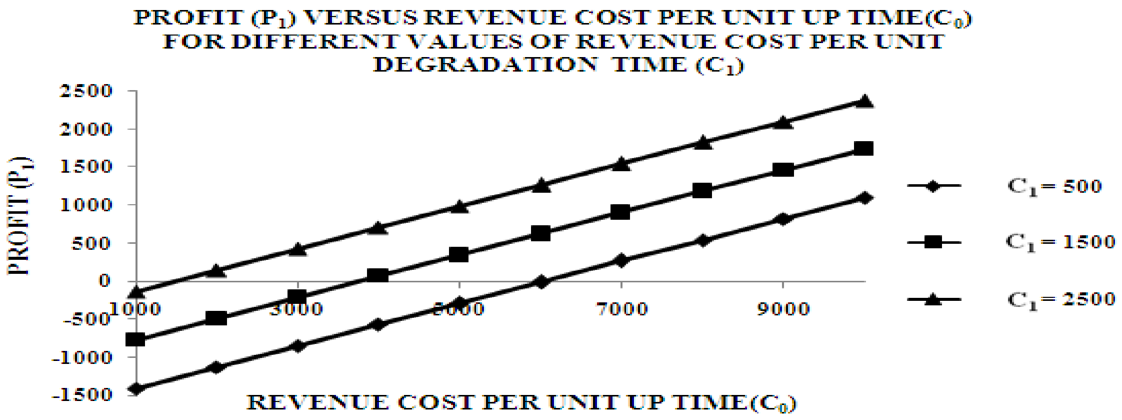

Fig. 6

It can also be observed from the graph that for C_0 = 500, P_1 is positive or negative according as C_1 > or < 856.5. Therefore, the system is profitable whenever C_1 > 856.5. Therefore, the system is profitable whenever revenue per unit up time is greater than Rs. 856.5. Similarly for C_1 = 1500 and C_1 = 2500, the system is profitable whenever revenue per unit up time is greater than Rs. 3715.5and Rs. 5906.5, respectively.

In the **fig. 7** , the graphs shows the behaviour of profit (P_1) of the system with respect to hardware/software failure rates , software /hardware fault detection coverage, software / hardware recovery rate, software/ hardware repair rates and common cause failure rate.

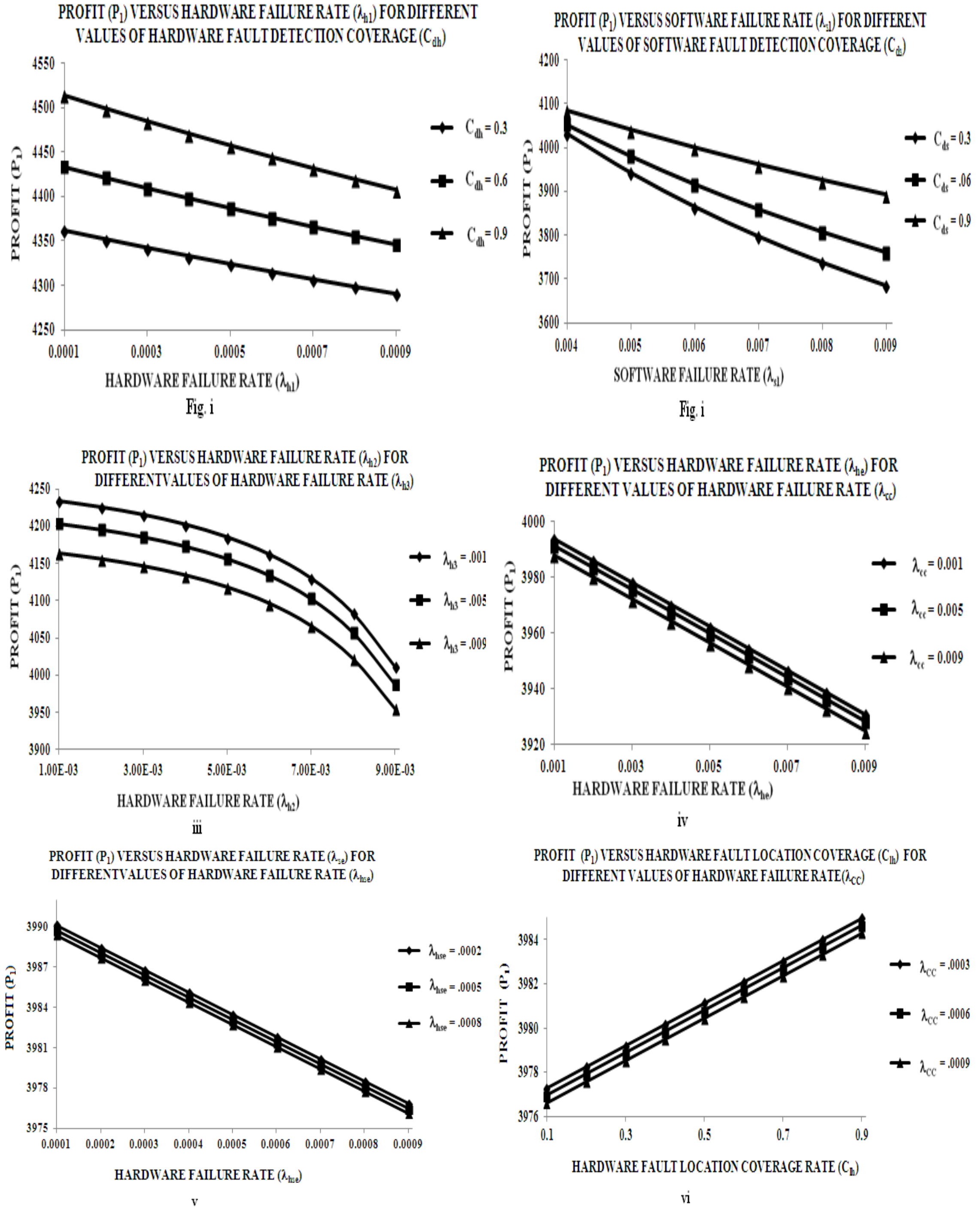

Fig: 7 Profit incurred to the system w.r.t. different parameters

It can be observed from the graphs that profit (P_1) decreases with respect to hardware/software failure rates and has higher values for higher values of software /hardware fault detection coverage, software/hardware recovery rate and software / hardware repair rates.

IX. CONCLUSION

It can be observed that reliability, mean up time and profit of the system decreases with respect to various hardware/software failure rates and has higher values for higher values of hardware/software repair rate, hardware/software fault detection coverage, hardware/software fault location coverage and profit of the system has higher values for higher values of revenue cost per unit up time. On the other hand, mean degradation time increases with respect to various hardware/software failure rates and has lower values for higher values of hardware/software repair rate, hardware/software fault detection coverage.

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