Performance and Profit Evaluations of a Stochastic Model on Centrifuge System Working in Thermal Power Plant Considering Neglected Faults

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Abstract

The paper formulates a stochastic model for a single unit centrifuge system on the basis of the real data collected from the Thermal Power Plant, Panipat (Haryana). Various faults observed in the system are classified as minor, major and neglected faults wherein the occurrence of a minor fault leads to degradation whereas occurrence of a major fault leads to failure of the system. Neglected faults are taken as those faults that are neglected /delayed for repair during operation of the system until the system goes to complete failure such as vibration, abnormal sound, etc. However these faults may lead to failure of the system. There is assumed to be single repair team that on complete failure of the system, first inspects whether the fault is repairable or non repairable and accordingly carries out repairs/replacements. Various measures of system performance are obtained using Markov processes and regenerative point technique. Using these measures profit of the system is evaluated. The conclusions regarding the reliability and profit of the system are drawn on the basis of the graphical studies.

Keywords: Centrifuge System, Neglected Faults, Mean Time to System Failure, Expected Uptime, Profit, Markov Process and Regenerative Point Technique.

1. INTRODUCTION

The centrifuge system or simply centrifuge is related to continuously operating machines with inertial discharge of deposit. These are used for extracting solid deposits and suspensions of liquid media, and separation of medium and highly concentrated suspensions. For instance it is used in Thermal Power Plants for oil purification, milk plants, laboratories for blood fractionation, and liquor industries for wine clarification. As in many practical situations centrifuge systems are used and act as the main systems or sub-systems and therefore play a very significant and crucial role in determining the reliability and cost of the whole system.

In the design, manufacture and operation of centrifuge system evaluation of their reliability is recommended in order to provide accident-free operation [1]. Various authors in the field of reliability modeling including [2-7] analyzed several one and two-unit systems considering various aspects such as different types of failure, maintenances, repairs/replacements policies, inspections, operational stages etc. In the literature of reliability modeling not much work has been reported to analyze the centrifuge systems in terms of their performance and cost.

However [8] carried out reliability and cost analyses of a centrifuge system considering minor and major faults wherein a minor fault leads to down state while a major fault leads to complete failure of the system. In fact while collecting data on faults/ failures and repairs of a centrifuge system working in Thermal Power Plant, Panipat (Haryana), it was also observed that some faults such as vibration, abnormal sound, etc are neglected/ delayed for repair during the operation of the system until system fails. These faults even sometimes lead to complete failure of the system. The aspect of neglected faults in the system was not taken up in [8]. The values of various rates and probabilities estimated from the data collected for the centrifuge system are as under:

Estimated value of rate of occurrence of major faults	=	0.0019
Estimated value of rate of occurrence of minor faults	=	0.0022
Estimated value of rate of occurrence of neglected faults	=	0.0018
Probability that a fault is non repairable major faults	=	0.3672
Probability that a fault is repairable major faults	=	0.6328
Estimated repair rate on occurrence of minor faults	=	0.3846
Estimated repair rate on occurrence of repairable major faults	=	0.3097
Estimated replacement rate on occurrence of non repairable major faults	=	0.3177

Keeping this in view, the present paper formulates a stochastic model for a single unit centrifuge system considering minor, major and neglected faults wherein a minor fault degrades the system whereas a major fault leads to complete failure of the system. The neglected fault is taken as the fault that may be neglected for repair during the operation of the system until system goes to complete failure. During the complete failure the repair team first inspect whether the fault is repairable or non repairable and accordingly carry out repair or replacement of the faulty components. Various measures of system performance such as mean time to system failure, expected up time and expected down time, expected number of repairs/replacements are obtained using Markov processes and regenerative point technique. Using these measures profit of the system is computed. Various conclusions regarding the reliability and profit of the system are drawn on the basis of graphical analysis for a particular case.

2. ASSUMPTIONS

1. Faults are self- announcing.
2. The repair team reaches the system in negligible time.
3. The system is as good as new after each repair/replacement.
4. The neglected faults may occur when system is either operative or degraded**.**
5. Switching is perfect and instantaneous.
6. The failure time distributions are exponential while other time distributions are general.

3. NOTATIONS

$\lambda_1 / \lambda_2 / \lambda_3$	Rate of occurrence of a major/minor/neglected faults
a/b	Probability that a fault is non repairable/repairable, b = 1- a
i(t)/I(t)	p.d.f./c.d.f. of time to inspection of the unit
$g_1(t)/ G_1(t)$,	p.d.f./c.d.f. of time to repair the unit at down state
$g_2(t)/G_2(t)$	p.d.f./c.d.f. of time to repair the unit at failed state
h(t)/H(t)	p.d.f./c.d.f. of time to replacement of the unit
k(t)/K(t)	p.d.f./c.d.f. of time to delay in repair of the neglected fault

O	Operative state
O_n/ O_r	Operative state under neglected fault/repair
F_i/ F_r / F_{rp}	Failed unit under inspection/ repair/ replacement

4. THE MODEL

A diagram showing the various states of transition of the system is shown in Figure 1. The epochs of entry in to state 0, 1, 2, 3, 4, 5 and 6 are regenerative point and thus all the states are regenerative states.

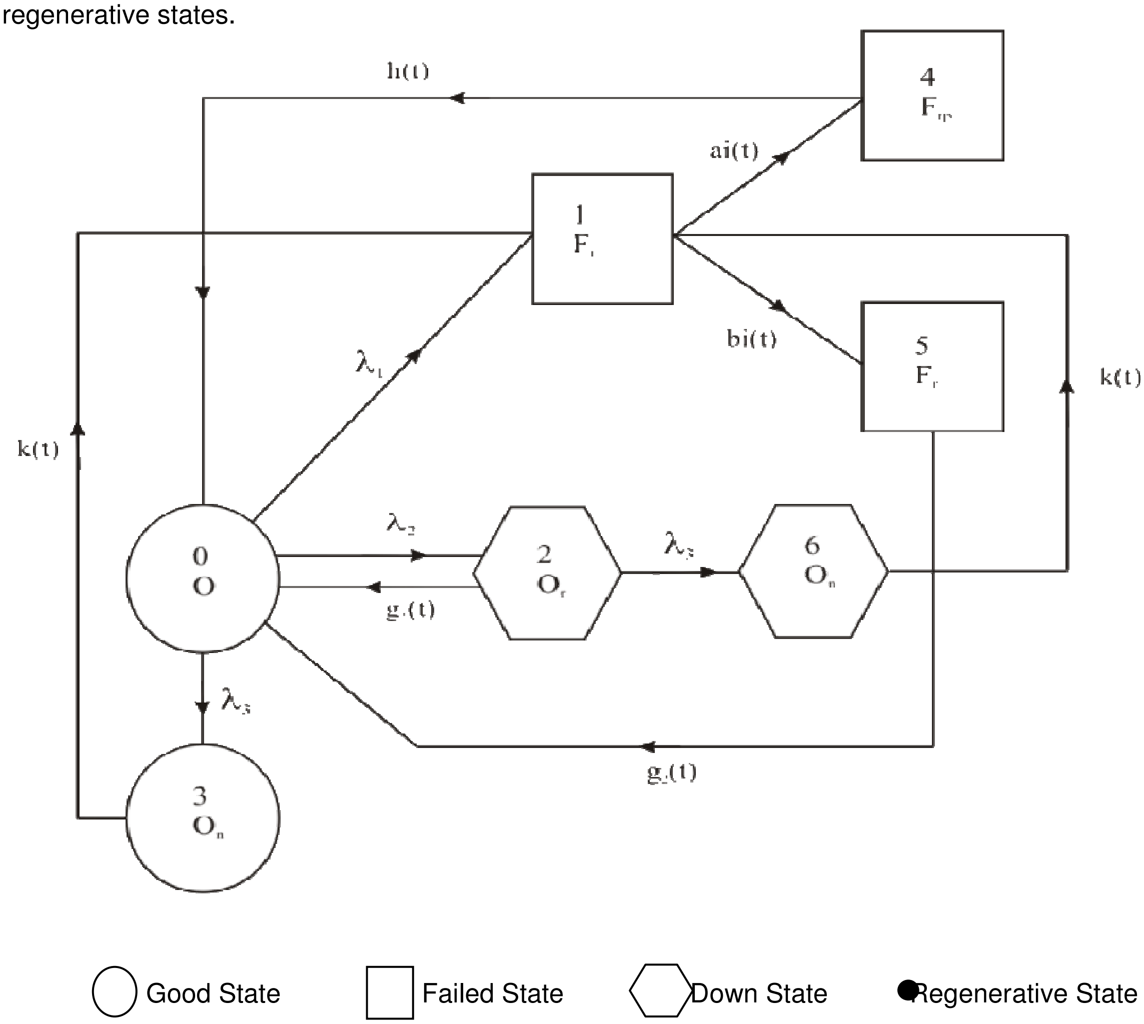

FIGURE 1: State Transition Diagram.

5. Transition Probabilities and Mean Sojourn Time

The transition probabilities are

$$dQ_{01}(t) = \lambda_1 e^{-(\lambda_1+\lambda_2+\lambda_3)t}dt \qquad dQ_{02}(t) = \lambda_2 e^{-(\lambda_1+\lambda_2+\lambda_3)t}dt \qquad dQ_{03}(t) = \lambda_3 e^{-(\lambda_1+\lambda_2+\lambda_3)t}dt$$

$$dQ_{14}(t)=ai(t)dt \qquad dQ_{15}(t) = bi(t)dt \qquad dQ_{20}(t) = g_1(t)e^{-\lambda_3 t}dt$$

$$dQ_{26}(t) = \lambda_3 e^{-\lambda_3 t}\overline{G}_1(t)dt \qquad dQ_{31}(t) = k(t)dt = dQ_{61}(t) \qquad dQ_{40}(t) = h(t)dt$$

$$dQ_{50}(t) = g_2(t)dt$$

The non-zero elements p_{ij} are:

$$p_{01}=\frac{\lambda_1}{\lambda_1+\lambda_2+\lambda_3} \qquad p_{02}=\frac{\lambda_2}{\lambda_1+\lambda_2+\lambda_3} \qquad p_{03}=\frac{\lambda_3}{\lambda_1+\lambda_2+\lambda_3}$$

$$p_{14}=ai^*(0) \qquad p_{15}=bi^*(0) \qquad p_{20}=g_1^*(\lambda_3)$$

$$p_{26}=1-g_1^*(\lambda_3) \qquad p_{31}=k^*(0)=p_{61} \qquad p_{40}=h^*(0)$$

$$p_{50}=g_2^*(0)$$

By these transition probabilities, it can be verified that:

$$p_{01}+p_{02}+p_{03}=1, \qquad p_{14}+p_{15}=1, \qquad p_{20}+p_{26}=1, \qquad p_{31}=p_{40}=p_{50}=p_{61}=1$$

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

$$\mu_0=\frac{1}{\lambda_1+\lambda_2+\lambda_3} \qquad \mu_1=-i^{*\prime}(0) \qquad \mu_2=\frac{1-g_1^*(\lambda_3)}{\lambda_3}$$

$$\mu_3=-k^{*\prime}(0)=\mu_6 \qquad \mu_4=-h^{*\prime}(0) \qquad \mu_5=-g_2^{*\prime}(0)$$

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:

$$m_{ij}=\int_0^\infty t\,dQ_{ij}(t)=-Q_{ij}^{*\prime}(s)$$

Thus,

$$m_{01}+m_{02}+m_{03}=\mu_0 \qquad m_{14}+m_{15}=\mu_1 \qquad m_{20}+m_{26}=\mu_2$$

$$m_{31}=\mu_3 \qquad m_{40}=\mu_4 \qquad m_{50}=\mu_5$$

$$m_{61}=\mu_6$$

6. OTHER MEASURES OF SYSTEM PERFORMANCE

Using probabilistic arguments for regenerative processes, various recursive relations are obtained and are solved to derive important measures of the system performance that are as given below:

Mean time to system failure (T_0) **= N/D**

Expected up time of the system (A_0) **= N_1/ D_1**

Expected down time of the system (A_{01}) **= N_2/ D_1**

Busy period of repair man (Inspection time only)(B_i) **= N_3/ D_1**

Busy period of repair man (Repair time only)(B_r) **= N_4/ D_1**

Busy period of repair man (Replacement time only) (B_{rp}) **= N_5/ D_1**

where

$N = \mu_0 + p_{02}\mu_2 + p_{03}\mu_3 + p_{02}p_{26}\mu_6$

$D = 1 - p_{02}p_{20}$

$N_1 = \mu_0 + p_{03}\mu_3$

$N_2 = p_{02}\mu_2 + p_{02}\, p_{26}\mu_6$

$N_3 = (p_{01}+p_{02}p_{26}p_{61}+p_{03}p_{31})\, \mu_1$

$N_4 = p_{02}\mu_2+(p_{01}+p_{02}p_{26}p_{61}+p_{03}p_{31})\, p_{15}\, \mu_5$

$N_5 = (p_{01}+p_{02}p_{26}p_{61}+p_{03}p_{31})\, p_{14}\, \mu_4$

$D_1 = \mu_0 + p_{02}\mu_2 + p_{03}\mu_3 + p_{02}\, p_{26}\mu_6 + (\mu_1 + p_{14}\mu_4 + p_{15}\mu_5)(p_{01}+p_{02}p_{26}p_{61}+ p_{03}p_{31})$

7. PROFIT ANALYSIS

The expected profit incurred of the system is

$P = C_0\, A_0 - C_1\, A_{01} - C_2\, B_i - C_3\, B_r - C_4 B_{rp} - C$

where

C_0 = revenue per unit uptime of the system
C_1 = revenue per unit downtime of the system
C_2 = cost per unit inspection of the failed unit
C_3 = cost per unit repair of the failed unit
C_4 = cost per unit replacement of the failed unit
C = cost of installation of the unit

8. GRAPHICAL INTERPRETATION AND CONCLUSIONS

For graphical analysis the following particular cases are considered:

$$g_1(t)=\beta_1 e^{-\beta_1(t)} \qquad g_2(t)=\beta_2 e^{-\beta_2(t)} \qquad i(t)=\alpha e^{-\alpha(t)} \qquad k(t)=\delta e^{-\delta(t)}$$
$$h(t)=\gamma e^{-\gamma(t)}$$

Various graphs are drawn for the MTSF, the expected uptime (A_0) and expected profit (P) of the system for the different values of the rate of occurrence of faults (λ_1, λ_2, λ_3), repairs (β_1, β_2), replacement (□), inspection (α) and delay (δ) on the basis of these plotted graphs.

Figure 2 gives the graphs between MTSF (T_0) and the rate of occurrence of neglected faults (λ_3), for different values of rate of occurrence of major faults (λ_1). The graph reveals that the MTSF deceases with increase in the values of rates of occurrence of major and neglected faults.

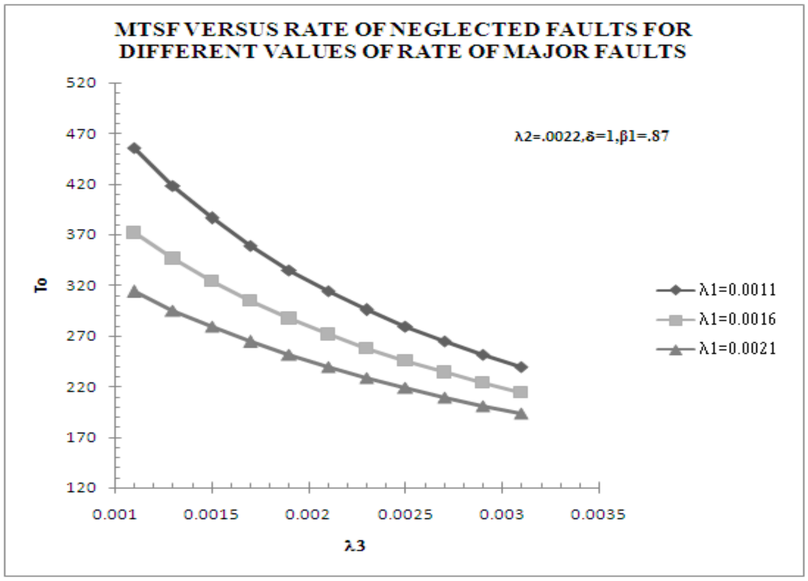

FIGURE 2

Figure 3 gives the graphs between MTSF (T_0) and the rate of occurrence of neglected faults (λ_3) for different values of rate of delay in repair of neglected faults (δ). The graph reveals that the MTSF deceases with increase in the values of rates of occurrence of neglected faults and delay in repair of neglected faults.

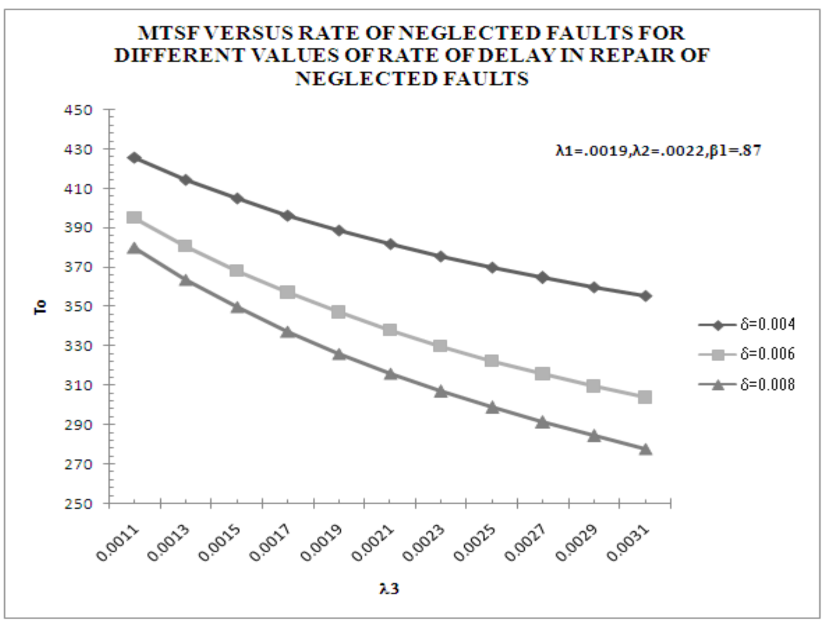

FIGURE 3

Figure 4 gives the graphs of expected uptime (A_0) of the system and rate of occurrence of minor faults (λ_2) for different values of rates of occurrence of major faults (λ_1). The graphs reveal that the expected uptime of the system deceases with increase in the values of failure rates.

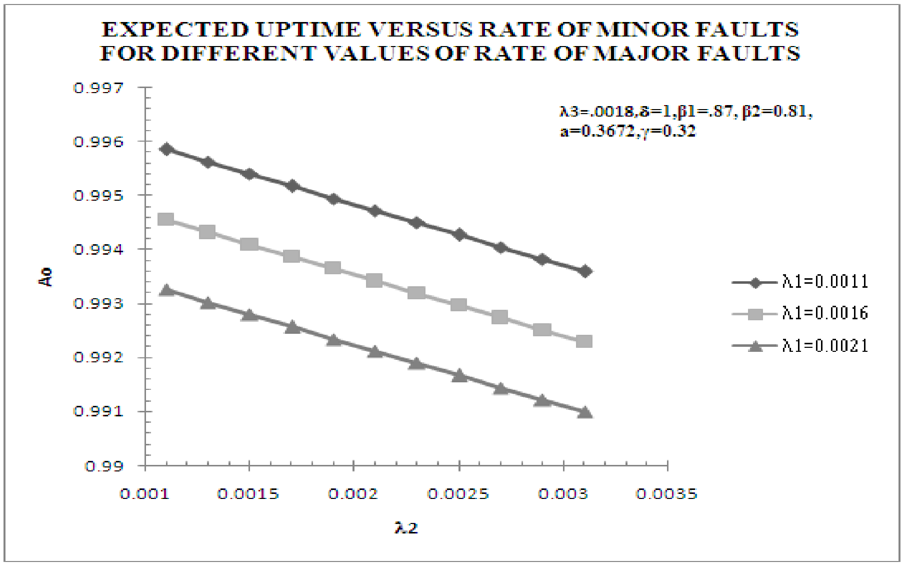

FIGURE 4

The curves in the figure 5 show the behavior of the profit with respect to rate of occurrence of minor faults (λ_2) of the system for the different values of rate of occurrence major faults (λ_1). It is evident from the graph that profit decreases with the increase in the rate due to occurrence of minor faults and major faults respectively when other parameters remain fixed. From the figure 5 it may also be observed that for λ_1 = 0.0001, the profit is > or = or < 0 according as λ_2 is < or = or > 0.0851. Hence the system is profitable to the company whenever $\lambda_2 \leq 0.0851$. Similarly, for λ_1 = 0.0081 and λ_1 = 0.0161 respectively the profit is > or = or < 0 according as λ_2 is < or = or > 0.0762 and 0.0671 respectively. Thus, in these cases, the system is profitable to the company whenever $\lambda_2 \leq$ 0.0762 and 0.0671 respectively

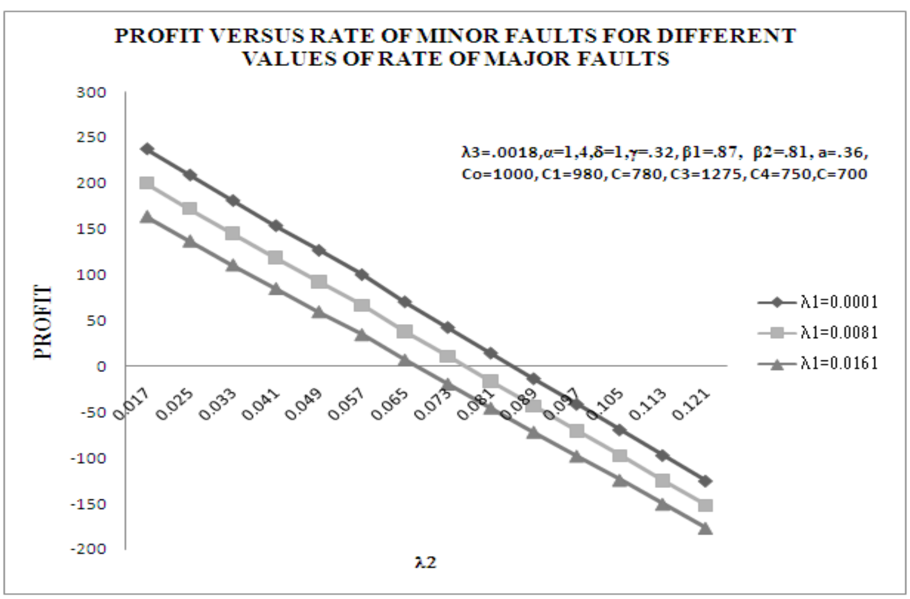

FIGURE 5

The curves in the figure 6 show the behavior of the profit with respect to rate of occurrence of minor faults (λ_2) of the system for the different values of rate of delay in repair of neglected faults (δ). It is evident from the graph that profit decreases with the increase in the rate due to occurrence of minor faults and delay in repair of neglected faults respectively when other parameters remain fixed. From the figure 6 it may also be observed that for δ =0.003, the profit is > or = or < 0 according as λ_2 is < or = or > 0.1038. Hence the system is profitable to the company whenever $\lambda_2 \leq 0.1038$. Similarly, for δ = 0.005 and δ = 0.007 respectively the profit is > or = or < 0 according as λ_2 is < or = or > 0.098 and 0.095 respectively. Thus, in these cases, the system is profitable to the company whenever $\lambda_2 \leq 0.098$ and 0.095 respectively.

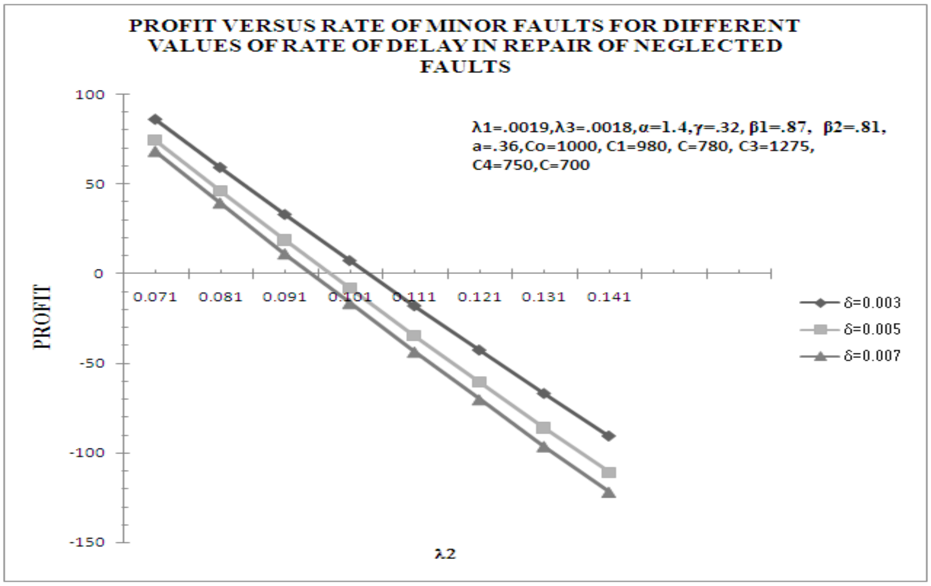

FIGURE 6

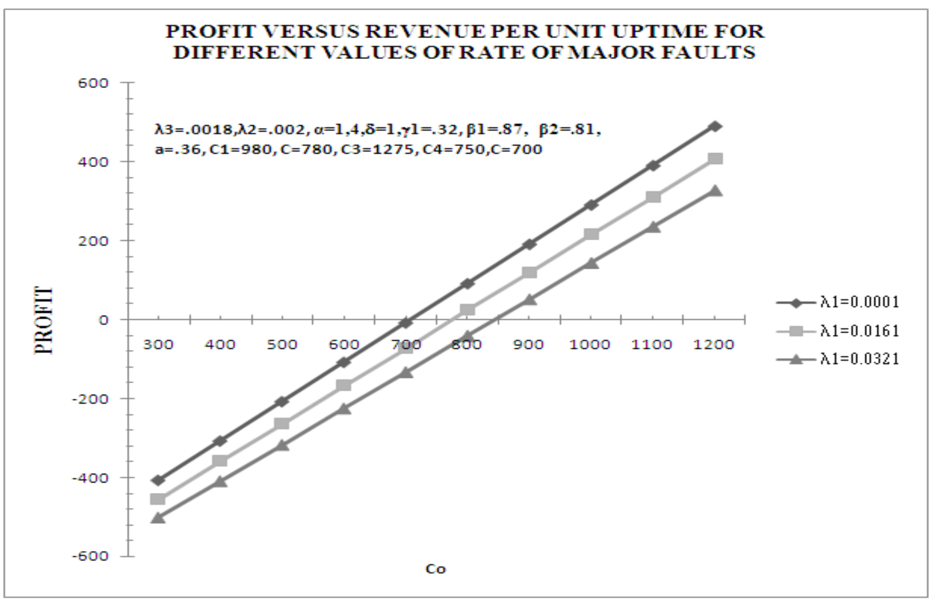

FIGURE 7

The curves in the figure 7 show the behavior of the profit with respect to the revenue per unit up time (C_0) of the system for the different values of rate of occurrence of major faults (λ_1). It is evident from the graph that profit increases with the increase in revenue up time of the system for fixed value of the rate of occurrence of major faults. From the figure 7 it may also be observed that for λ_1 = 0.0001, the profit is > or = or < 0 according as C_0 is > or = or < 707.88. Hence the system is profitable to the company whenever $C_0 \geq$ Rs. 707.88. Similarly, for λ_1 = 0.0161 and λ_1 = 0.0321 respectively the profit is > or = or < 0 according as C_0 is > or = or < Rs.775.98 and Rs.844.08 respectively. Thus, in these cases, the system is profitable to the company whenever $C_0 \geq$ Rs.775.98 and Rs.844.08 respectively.

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