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# Profit Analysis for a Stochastic Model on a Cement Grinding System with Categorisation of Failure on the Basis of Cost for Its Nine Components

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**Abstract**

A stochastic model for profit analysis of a cement grinding system with failure in the nine important components namely; Belt Conveyor, Bucket Elevator, Separator, Roller Press, Diverting Gate, Process Fan, Cyclone, Ball Mill and Fly Ash System has been developed. The failure in these components has been divided into various categories on the basis of cost of repair/replacement. The fly ash system is a component in which a failure may not cause the failure of the complete system instantly. Data on time to repair and cost of repair/replacement for different types of failure have been collected from Shree Cement Ltd., Khushkhera, Rajasthan, India. The system has been analysed by using semi – Markov processes and regenerative point technique and various measures of system effectiveness have been obtained. Profit incurred to the system is obtained and graphs are plotted for the model for better interpretation of results.

**Keywords:** Stochastic Model, Cement Grinding System, Categorisation of Failure, Measures of System Effectiveness, Profit Analysis.

## 1. Introduction

A large number of stochastic models for analysing profit of one or multi unit system have been developed and reported in the literature of reliability. These researchers include Hashim, M., Hidekazu, M. T., Ming Yang (2013), Padmavathi, N., Rizwan, S. M., Pal Anita and Taneja G. (2012), Taneja, G. and Singh Dalip (2013). The review of the academic literature revels that the reliability models have been developed for working of many industries but still many situations have been left unattended. One of the situations that has left unattended is the reliability modelling on cement grinding system on which the work has been initiated by Gupta and Taneja(2014).

Cement is an important input into the production of concrete, an essential material needed for construction related activities. The grinding of cement clinker is an important step in cement manufacturing process. Cement is manufactured through five significant steps;

1) crushing
2) raw meal grinding
3) clinkerisation
4) cement grinding
5) packing for dispatch

In the present paper, we have developed and analysed a stochastic model on a cement grinding system with failure in its nine important components namely:

(1) Belt Conveyor (2) Bucket Elevator (3) Separator
(4) Roller Press (5) Diverting Gate (6) Process Fan
(7) Cyclone (8) Ball Mill (9) Fly Ash System

Gupta and Taneja considered one type of failure in the nine components except the diverting gate. However, the cost of repairing any unit varies depending upon the severity in failure and thus there is need to categorise the type of failure.

Keeping the above in view, we, in the present paper, analyse a stochastic model wherein various categories of failure have been taken into consideration on the basis of amount of cost involved.

In diverting gate, initially two types of failure – minor and major have been observed. Minor failure means the partial failure due to which system does not stop its working i.e. it remains operative and the faults can be removed simultaneously whereas a major failure causes the complete system shutdown. On occurrence of the failure in fly ash system, it does not go to failed state immediately and may remain operable for some stipulated time period during which the efforts may be made to remove or repair the faults. However, if the faults are not removed within the stipulated time period, the system becomes inoperable i.e. goes to failed state. Various measures of the system effectiveness and reliability characteristics such as mean time to system failure (MTSF), availability, expected number of replacements or repairs of the nine components, expected number of visits by the repairman and profit function are evaluated in steady state using semi-Markov processes and regenerative point technique. Graphs are plotted to draw various important conclusions for the model.

## 2. Categorisation of Failure

Failures in the components of cement grinding system have been categorised on the basis of costs involved as follows:

| Component | Category as per Cost of Repair (Rs) | | | Category-wise Frequency of Failures | | |
|---|---|---|---|---|---|---|
| | I | II | III | | | |
| 1 | <10000 | 10000-20000 | ≥100000 | 37 | 6 | 15 |
| 2 | <50000 | 50000-100000 | ≥100000 | 103 | 10 | 10 |
| 3 | <10000 | 10000-20000 | ≥20000 | 6 | 16 | 12 |
| 4 | <50000 | 50000-100000 | ≥100000 | 20 | 13 | 5 |
| 5 | Minor | Major | - | 14 | 12 | - |
| | ≤500 | >500 | | | | |
| 6 | <10000 | 10000-20000 | ≥20000 | 18 | 5 | 6 |
| 7 | <20000 | 20000-50000 | ≥50000 | 15 | 11 | 4 |
| 8 | <10000 | 10000-50000 | ≥100000 | 17 | 5 | 10 |
| 9 | <10000 | 10000-50000 | ≥50000 | 48 | 20 | 9 |

The probabilities of different types of failures for nine components on the basis of information gathered from Shree Cement Ltd., Khushkhera, Rajasthan, India, are:

$p_{11}$=0.6379310, $p_{12}$=0.1034483, $p_{13}$=0.2586207, $p_{21}$=0.8373984, $p_{22}$=0.0813008, $p_{23}$=0.0813008, $p_{31}$=0.1764706, $p_{32}$=0.4705882, $p_{33}$=0.3529412, $p_{41}$=0.5263158, $p_{42}$=0.3421053, $p_{43}$=0.1315789, $p_1$=0.5392, $q_1$=0.4608, $p_{61}$=0.6206897, $p_{62}$=0.1724138, $p_{63}$=0.2068966, $p_{71}$=0.5, $p_{72}$=0.3666667, $p_{73}$=0.1333333, $p_{81}$=0.53125, $p_{82}$=0.15625, $p_{83}$=0.3125, $p_{91}$=0.6233766, $p_{92}$=0.2597402, $p_{93}$=0.1168831

## 3. Notations

O : cement grinding system is operative

$\lambda_i$ : constant failure rate of $i^{th}$ component of the system; i = 1,2,...............,9

$G_{ij}(t)$, $g_{ij}(t)$ : cdf and pdf of repair time of $j^{th}$ type of failure in $i^{th}$ component; i = 1,2,3,4,6,7,8,9;j=1,2,3

$p_1$, $q_1$ : probability of minor and major failure in diverting gate

$G_{51}(t)$, $g_{51}(t)$ : cdf and pdf of repair time for minor failure in diverting gate

$G_{52}(t)$, $g_{52}(t)$ : cdf and pdf of repair time for major failure in diverting gate

$p_2$ : probability that failure in fly ash system is repaired before the fly ash in the bin is consumed completely

$q_2$ : probability that fly ash in the bin is consumed completely but the component is not repaired

I(t), i(t) : pdf and cdf of allowable time during which dry fly ash is there in the bin.

$F_{rij}$ : completely failed $i^{th}$ component under repair; i =1,2,3,4,6,7,8,9;j=1,2,3

$F_{r5}$ : completely failed $5^{th}$ component under repair

$pf_{r5}$ : partially failed $5^{th}$ component under repair

$O_{ir}$ : online repair is going on after the failure of fly ash system but within the stipulated time

| | | |
|---|---|---|
| $p_{ij}$ | : | probability of $j^{th}$ category of failure in $i^{th}$ component; i =1,2,3,4,6,7,8,9;j=1,2,3 |
| $q_{ij}(t)$, $Q_{ij}(t)$ | : | probability density function (p.d.f.), cumulative distribution function (c.d.f.) of first passage time from a regenerative state i to a regenerative state j without visiting any other regenerative state in (0,t] |
| $A_i(t)$ | : | probability that the system is in up state at the instant t given that the system entered regenerative state i at t=0 |
| $ER_i^{jk}(t)$ | : | expected number of replacements/repairs in $j^{th}$ component due to $k^{th}$ type of failure at instant t given that the system started from the regenerative state i at t=0; j=1,2,3,4,6,7,8,9;k=1,2,3 |
| $ER_i^{51}(t)$ | : | expected number of replacements/repairs due to minor failure in $5^{th}$ component at instant t given that the system started from the regenerative state i at t=0 |
| $ER_i^{52}(t)$ | : | expected number of replacements/repairs due to major failure in $5^{th}$ component at instant t given that the system started from the regenerative state i at t=0 |
| $V_i(t)$ | : | expected number of visits of the repairman in (0,t] given that the system entered regenerative state i at t=0 |

## 4. Transition Probabilities and Mean Sojourn Times:

A transition diagram showing the various states of the system is shown in Fig.1. The epochs of entry into states 0 to 29 are regeneration points and hence these states are regenerative states. States 0,13,24,25 and 26 are up states. States 1 to 12, 14 to 23 and 27,28,29 are failed states. The non zero elements $p_{ij} = \lim_{s\to 0} q_{ij}{}^*(s)$ are given below:

$$p_{0j} = \frac{p_{1j}\lambda_1}{\sum_{i=1}^{9}\lambda_i}, \quad p_{0,j+3} = \frac{p_{2j}\lambda_2}{\sum_{i=1}^{9}\lambda_i}, \quad p_{0,j+6} = \frac{p_{3j}\lambda_3}{\sum_{i=1}^{9}\lambda_i}$$

$$p_{0,j+9} = \frac{p_{4j}\lambda_4}{\sum_{i=1}^{9}\lambda_i}, \quad p_{0,13} = \frac{p_1\lambda_5}{\sum_{i=1}^{9}\lambda_i}, \quad p_{0,14} = \frac{q_1\lambda_5}{\sum_{i=1}^{9}\lambda_i}$$

$$p_{0,j+14} = \frac{p_{6j}\lambda_6}{\sum_{i=1}^{9}\lambda_i}, \quad p_{0,j+17} = \frac{p_{7j}\lambda_7}{\sum_{i=1}^{9}\lambda_i}, \quad p_{0,j+20} = \frac{p_{8j}\lambda_8}{\sum_{i=1}^{9}\lambda_i},$$

$$p_{0,j+23} = \frac{p_{9j}\lambda_9}{\sum_{i=1}^{9}\lambda_i} \quad (j=1,2,3)$$

$p_{i,0}=1$ (i=1,2,.......,23)

$p_{24,0} = p_{25,0} = p_{26,0} = p_2$

$p_{24,27} = p_{25,28} = p_{26,29} = q_2$

$p_{27,0} = p_{28,0} = p_{29,0} = 1$

By these transition probabilities, it can be verified that $\sum_{j=1}^{26} p_{0,j} = 1, p_{24,0} + p_{24,27} = 1$

$p_{25,0} + p_{25,28} = 1$ , $p_{26,0} + p_{26,29} = 1$

and $p_{i,0} = 1 (i = 1,2,.....,23), p_{27,0} = p_{28,0} = p_{29,0} = 1$

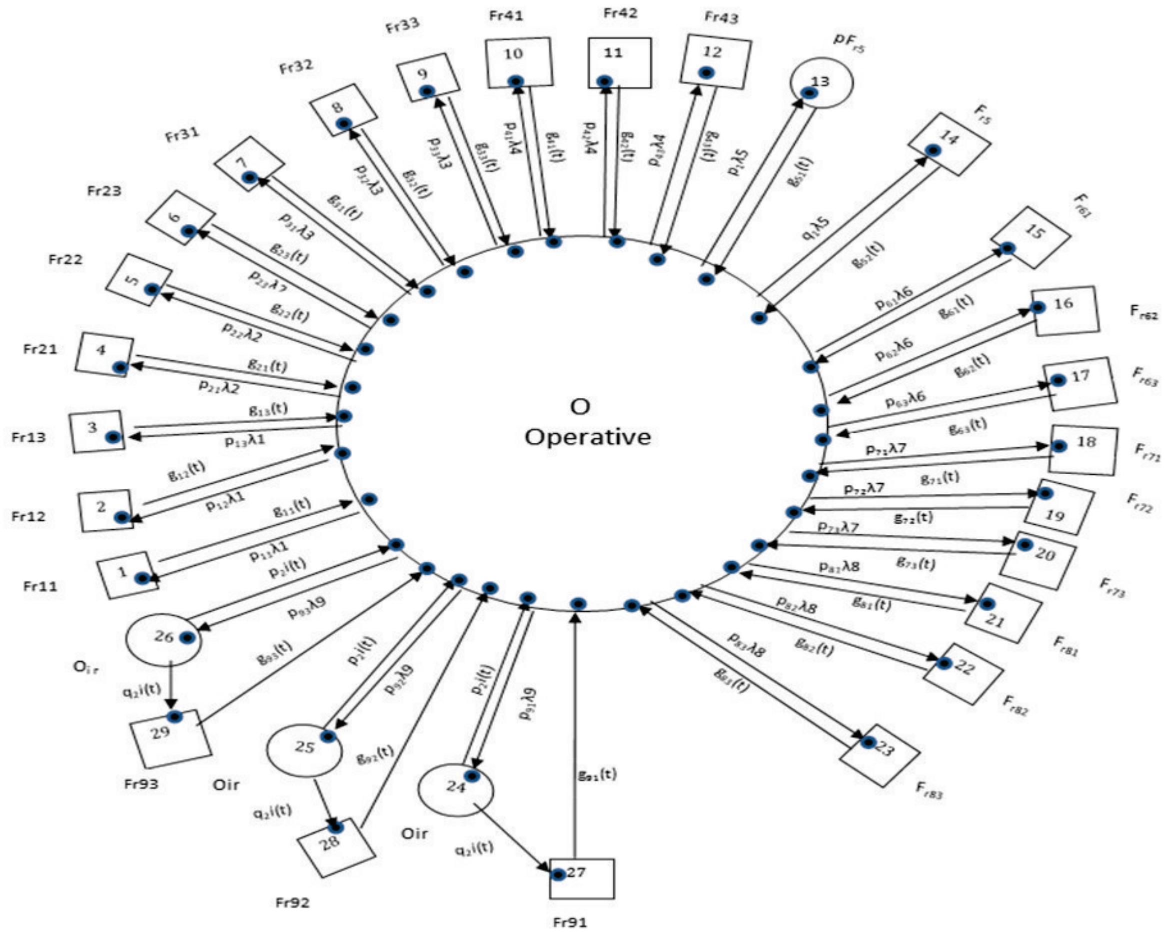
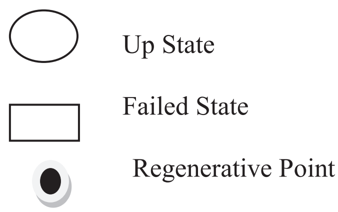



**Figure 1: State Transition Diagram**




The mean sojourn time ($\mu_i$) in state i is given by:

$$\mu_0 = \int_0^\infty e^{-\left(\sum_{i=1}^{9}\lambda_i\right)t} dt = \frac{1}{\sum_{i=1}^{9}\lambda_i}$$

$$\mu_1 = -g_{11}{*'}(0), \mu_2 = -g_{12}{*'}(0), \mu_3 = -g_{13}{*'}(0), \mu_4 = -g_{21}{*'}(0), \mu_5 = -g_{22}{*'}(0), \mu_6 = -g_{23}{*'}(0),$$
$$\mu_7 = -g_{31}{*'}(0), \mu_8 = -g_{32}{*'}(0), \mu_9 = -g_{33}{*'}(0), \mu_{10} = -g_{41}{*'}(0), \mu_{11} = -g_{42}{*'}(0), \mu_{12} = -g_{43}{*'}(0),$$
$$\mu_{13} = -g_{51}{*'}(0), \mu_{14} = -g_{52}{*'}(0), \mu_{15} = -g_{61}{*'}(0), \mu_{16} = -g_{62}{*'}(0), \mu_{17} = -g_{63}{*'}(0), \mu_{18} = -g_{71}{*'}(0),$$
$$\mu_{19} = -g_{72}{*'}(0), \mu_{20} = -g_{73}{*'}(0), \mu_{21} = -g_{81}{*'}(0), \mu_{22} = -g_{82}{*'}(0), \mu_{23} = -g_{83}{*'}(0),$$
$$\mu_{24} = \mu_{25} = \mu_{26} = -i{*'}(0), \mu_{27} = -g_{91}{*'}(0), \mu_{28} = -g_{92}{*'}(0), \mu_{29} = -g_{93}{*'}(0),$$

The unconditional mean time taken by the system to transit for any regenerative state j when the time is counted from epoch of entrance into state i is given as:

$$m_{ij} = \int_0^\infty t q_{ij}(t)\,dt$$

Thus,
$$\sum_{j=1}^{26} m_{0,j} = \mu_0, m_{i,0} = \mu_i (i = 1,2,....,23,27,28,29), m_{24,0} + m_{24,27} = \mu_{24}, m_{25,0} + m_{25,28} = \mu_{25},$$
$$m_{26,0} + m_{26,29} = \mu_{26}$$

## 5. Measures of System Effectiveness

Various measures of system effectiveness obtained in steady state using the arguments of the theory of regenerative process are:

(1) The Mean Time to System Failure (MTSF) = N/D
(2) The Availability of the System ($A_0$) = $N_1/D_1$
(3) Expected Number of Replacements/Repairs of parts in Belt Conveyor:
$ER_0^{11} = N_2 / D_1$ , $ER_0^{12} = N_3 / D_1$ , $ER_0^{13} = N_4 / D_1$
(4) Expected Number of Replacements/Repairs of parts in Bucket Elevator:
$ER_0^{21} = N_5 / D_1$ , $ER_0^{22} = N_6 / D_1$ , $ER_0^{23} = N_7 / D_1$
(5) Expected Number of Replacements/Repairs of parts in Separator:
$ER_0^{31} = N_8 / D_1$ , $ER_0^{32} = N_9 / D_1$ , $ER_0^{33} = N_{10} / D_1$
(6) Expected Number of Replacements/Repairs of parts in Roller Press:
$ER_0^{41} = N_{11} / D_1$ , $ER_0^{42} = N_{12} / D_1$ , $ER_0^{43} = N_{13} / D_1$
(7) Expected Number of Replacements/Repairs of parts in Diverting Gate on Minor Failure:
$ER_0^{51} = N_{14} / D_1$
(8) Expected Number of Replacements/Repairs of parts in Diverting Gate on Major Failure:
$ER_0^{52} = N_{15} / D_1$
(9) Expected Number of Replacements/Repairs of parts in Process Fan:
$ER_0^{61} = N_{16} / D_1$ , $ER_0^{62} = N_{17} / D_1$ , $ER_0^{63} = N_{18} / D_1$
(10) Expected Number of Replacements/Repairs of parts in Cyclone:
$ER_0^{71} = N_{19} / D_1$ , $ER_0^{72} = N_{20} / D_1$ , $ER_0^{73} = N_{21} / D_1$
(11) Expected Number of Replacements/Repairs of parts in Ball Mill:
$ER_0^{81} = N_{22} / D_1$ , $ER_0^{82} = N_{23} / D_1$ , $ER_0^{83} = N_{24} / D_1$
(12) Expected Number of Replacements/Repairs of parts in Fly Ash System:
$ER_0^{91} = N_{25} / D_1$ , $ER_0^{92} = N_{26} / D_1$ , $ER_0^{93} = N_{27} / D_1$
(13) Expected Number of Visits by the Repairman ($V_0$) = $N_{28}/D_1$

where

$$N = \mu_0 + p_{0,13}\mu_{13} + p_{0,24}\mu_{24} + p_{0,25}\mu_{25} + p_{0,26}\mu_{26}$$

$$N_1 = \mu_0 + p_{0,13}\mu_{13} + p_{0,24}\mu_{24} + p_{0,25}\mu_{25} + p_{0,26}\mu_{26}$$

$N_2 = p_{01}$, $N_3 = p_{02}$ , $N_4 = p_{03}$, $N_5 = p_{04}$ , $N_6 = p_{05}$ , $N_7 = p_{06}$ , $N_8 = p_{07}$ , $N_9 = p_{08}$ , $N_{10} = p_{09}$ ,

$N_{11} = p_{0,10}$ , $N_{12} = p_{0,11}$ , $N_{13} = p_{0,12}$ , $N_{14} = p_{0,13}$ , $N_{15} = p_{0,14}$ , $N_{16} = p_{0,15}$ , $N_{17} = p_{0,16}$ ,

$N_{18} = p_{0,17}$ , $N_{19} = p_{0,18}$ , $N_{20} = p_{0,19}$ , $N_{21} = p_{0,20}$ , $N_{22} = p_{0,21}$ , $N_{23} = p_{0,22}$ , $N_{24} = p_{0,23}$ ,

$N_{25} = p_{0,24}$ , $N_{26} = p_{0,25}$ , $N_{27} = p_{0,26}$ , $N_{28} = \sum_{i=1}^{28} p_{0i} = 1$

$$D = 1 - p_{0,13} - p_{0,24}p_{24,0} - p_{0,25}p_{25,0} - p_{0,26}p_{26,0}$$

$D_1 = \mu_0 + \sum_{i=1}^{26} p_{0i}\,\mu_i + p_{0,24}\,p_{24,27}\,\mu_{27} + p_{0,25}\,p_{25,28}\,\mu_{28} + p_{0,26}\,p_{26,29}\,\mu_{29}$

## 6. Profit Analysis

Expected profit incurred to the system is given as:

$$P = C_0A_0 - C_{11}ER_0^{11} - C_{12}ER_0^{12} - C_{13}ER_0^{13} - C_{21}ER_0^{21} - C_{22}ER_0^{22} - C_{23}ER_0^{23} - C_{31}ER_0^{31} - C_{32}ER_0^{32} - C_{33}ER_0^{33} - C_{41}ER_0^{41} - C_{42}ER_0^{42} - C_{43}ER_0^{43} - C_{51}ER_0^{51} - C_{52}ER_0^{52} - C_{61}ER_0^{61} - C_{62}ER_0^{62} - C_{63}ER_0^{63} - C_{71}ER_0^{71} - C_{72}ER_0^{72} - C_{73}ER_0^{73} - C_{81}ER_0^{81} - C_{82}ER_0^{82} - C_{83}ER_0^{83} - C_{91}ER_0^{91} - C_{92}ER_0^{92} - C_{93}ER_0^{93} - C_{100}V_0$$

where
$C_0$ = revenue per unit up time of the system
$C_{1j}$ = cost per replacement/repair of parts in Belt Conveyor on failure of $j^{th}$ category; j=1,2,3
$C_{2j}$ = cost per replacement/repair of parts in Bucket Elevator on failure of $j^{th}$ category; j=1,2,3
$C_{3j}$ = cost per replacement/repair of parts in Separator on failure of $j^{th}$ category; j=1,2,3
$C_{4j}$ = cost per replacement/repair of parts in Roller Press on failure of $j^{th}$ category; j=1,2,3
$C_{51}$= cost per replacement/repair of parts in Diverting Gate on minor failure
$C_{52}$ = cost per replacement/repair of parts in Diverting Gate on major failure
$C_{6j}$ = cost per replacement/repair of parts in Process Fan on failure of $j^{th}$ category; j=1,2,3
$C_{7j}$ = cost per replacement/repair of parts in Cyclone on failure of $j^{th}$ category; j=1,2,3
$C_{8j}$ = cost per replacement/repair of parts in Ball Mill on failure of $j^{th}$ category; j=1,2,3
$C_{9j}$ = cost per replacement/repair of parts in Fly Ash System on failure of $j^{th}$ category; j=1,2,3
$C_{100}$ = cost per visit of the repairman

## 7. Results and Discussion

The following particular case is considered for graphical study:

$g_{ij}(t) = \alpha_{ij}e^{-\alpha_{ij}t}$ , i =1,2,...........,9 , i≠5; j=1,2,3

$g_{51}(t) = \alpha_{51}e^{-\alpha_{51}t}$ , $g_{52}(t) = \alpha_{52}e^{-\alpha_{52}t}$ , $i(t) = \beta e^{-\beta t}$

The following values have been estimated from the gathered data/information:

$\lambda_1$=0.0004235,$\lambda_2$=0.0005802,$\lambda_3$=0.0003948,$\lambda_4$=0.0008738,$\lambda_5$=0.0008158,$\lambda_6$=0.0002789,$\lambda_7$=0.0004236, $\lambda_8$=0.0003778,$\lambda_9$=0.0002783,$\alpha_{11}$=0.3834197,$\alpha_{12}$=0.1538462,$\alpha_{13}$=0.0877193,$\alpha_{21}$=0.1079665,$\alpha_{22}$=0.1219512, $\alpha_{23}$=0.0265957,$\alpha_{31}$=0.0909091,$\alpha_{32}$=0.0615385,$\alpha_{33}$=0.0652174,$\alpha_{41}$=0.1176471,$\alpha_{42}$=0.1780822,$\alpha_{43}$=0.0358938, $\alpha_{51}$=0.2692308,$\alpha_{52}$=0.1165049,$\alpha_{61}$=0.1132075,$\alpha_{62}$=0.0961538,$\alpha_{63}$=0.0697674,$\alpha_{71}$=0.0955414,$\alpha_{72}$=0.1047619, $\alpha_{73}$=0.0465116,$\alpha_{81}$=0.1393443,$\alpha_{82}$=0.0735294,$\alpha_{83}$=0.0193798,$\alpha_{91}$=0.1441441,$\alpha_{92}$=0.0840336,$\alpha_{93}$=0.1,$\beta$=3, $p_1$=0.5392,$q_1$=0.4608, $p_2$=0.1, $q_2$=0.9,$C_o$=1540,$C_{11}$=2804.05,$C_{12}$=16666.67,$C_{13}$=201000,$C_{21}$=9706.80, $C_{22}$=86000,$C_{23}$=1114000,$C_{31}$=4083.33,$C_{32}$=14187.50,$C_{33}$=22000,$C_{41}$=14117.5,$C_{42}$=59230.77,$C_{43}$=10750000, $C_{51}$=310.71,$C_{52}$=1108.33,$C_{61}$=2533.33,$C_{62}$=13200,$C_{63}$=34666.67,$C_{71}$=11760,$C_{72}$=22454.55,$C_{73}$=83750, $C_{81}$=2576.47,$C_{82}$=25000,$C_{83}$=660000,$C_{91}$=2047.92,$C_{92}$=22550,$C_{93}$=89000, $C_{100}$=20000

Using the above estimated values, the following measures of system effectiveness are obtained:

Table 1

| Measure | Value |
|---|---|
| MTSF | 251.7539484 |
| $A_0$ | 0.9569234 |
| $ER_0^{11}$ | 0.0002581 |
| $ER_0^{12}$ | 0.0000419 |
| $ER_0^{13}$ | 0.0001046 |
| $ER_0^{21}$ | 0.0004641 |
| $ER_0^{22}$ | 0.0000451 |
| $ER_0^{23}$ | 0.0000451 |
| $ER_0^{31}$ | 0.0000666 |
| $ER_0^{32}$ | 0.0001775 |
| $ER_0^{33}$ | 0.0001331 |
| $ER_0^{41}$ | 0.0004393 |
| $ER_0^{42}$ | 0.0002856 |
| $ER_0^{43}$ | 0.0001098 |
| $ER_0^{51}$ | 0.0004202 |
| $ER_0^{52}$ | 0.0003591 |
| $ER_0^{61}$ | 0.0001654 |
| $ER_0^{62}$ | 0.0000459 |
| $ER_0^{63}$ | 0.0000551 |
| $ER_0^{71}$ | 0.0002023 |
| $ER_0^{72}$ | 0.0001484 |
| $ER_0^{73}$ | 0.0000540 |
| $ER_0^{81}$ | 0.0001917 |
| $ER_0^{82}$ | 0.0000564 |
| $ER_0^{83}$ | 0.0001128 |
| $ER_0^{91}$ | 0.0001657 |
| $ER_0^{92}$ | 0.0000691 |
| $ER_0^{93}$ | 0.0000311 |
| $V_0$ | 0.0042478 |
| Profit | 3.4580387 |

Various graphs have also been plotted using the above particular case. All of these graphs cannot be shown here but some of the graphs are shown in Figs 2 to 5 as a sample. Estimated values of those parameters which have been fixed are taken as mentioned above, whereas the parameters for which variation is considered, the values have been varied within the 99% confidence limits for them.

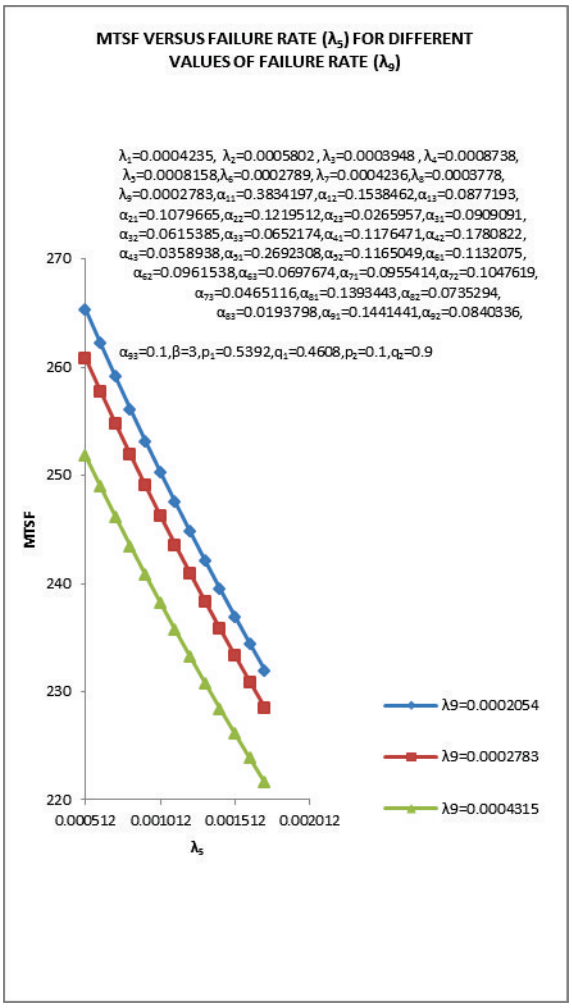

MTSF VERSUS FAILURE RATE (λ5) FOR DIFFERENT VALUES OF FAILURE RATE (λ9)
λ1=0.0004235, λ2=0.0005802, λ3=0.0003948, λ4=0.0008738, λ5=0.0008158, λ6=0.0002789, λ7=0.0004236, λ8=0.0003778, λ9=0.0002783, α11=0.3834197, α12=0.1538462, α13=0.0877193, α21=0.1079665, α22=0.1219512, α23=0.0265957, α31=0.0909091, α32=0.0615385, α33=0.0652174, α41=0.1176471, α42=0.1780822, α43=0.0358938, α51=0.2692308, α52=0.1165049, α61=0.1132075, α62=0.0961538, α63=0.0697674, α71=0.0955414, α72=0.1047619, α73=0.0465116, α81=0.1393443, α82=0.0735294, α83=0.0193798, α91=0.1441441, α92=0.0840336,
α93=0.1, β=3, p1=0.5392, q1=0.4608, p2=0.1, q2=0.9
MTSF
270
260
250
240
230
220
0.000512
0.001012
0.001512
0.002012
λ5
λ9=0.0002054
λ9=0.0002783
λ9=0.0004315

Fig. 2

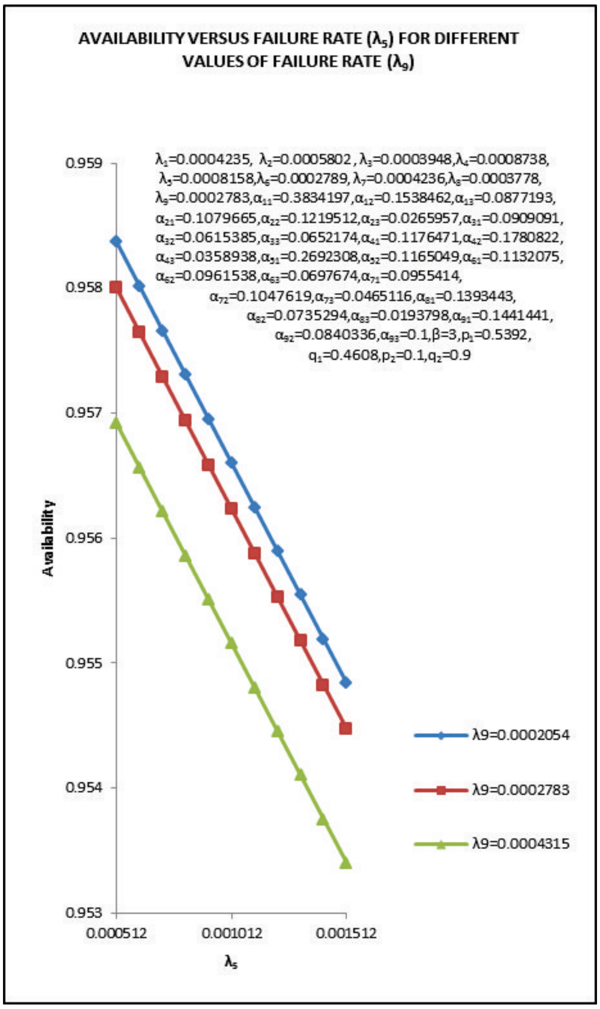
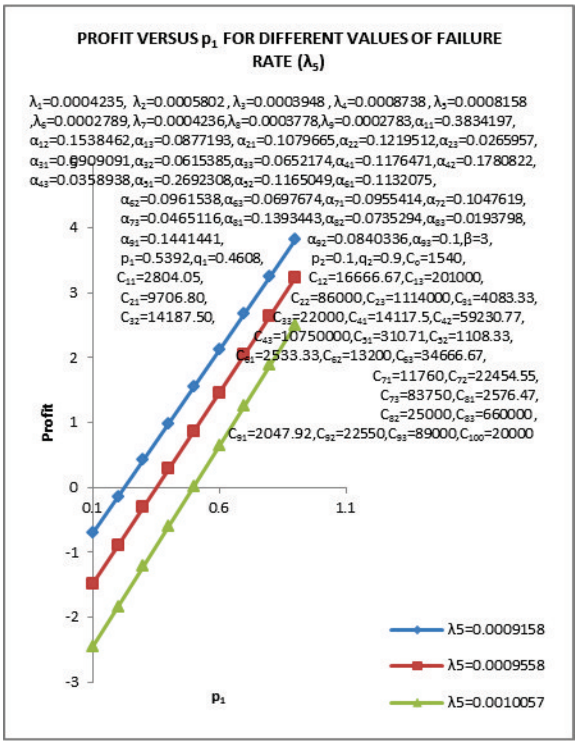

AVAILABILITY VERSUS FAILURE RATE (λ5) FOR DIFFERENT VALUES OF FAILURE RATE (λ9)
λ1=0.0004235, λ2=0.0005802, λ3=0.0003948, λ4=0.0008738, λ5=0.0008158, λ6=0.0002789, λ7=0.0004236, λ8=0.0003778, λ9=0.0002783, α11=0.3834197, α12=0.1538462, α13=0.0877193, α21=0.1079665, α22=0.1219512, α23=0.0265957, α31=0.0909091, α32=0.0615385, α33=0.0652174, α41=0.1176471, α42=0.1780822, α43=0.0358938, α51=0.2692308, α52=0.1165049, α61=0.1132075, α62=0.0961538, α63=0.0697674, α71=0.0955414, α72=0.1047619, α73=0.0465116, α81=0.1393443, α82=0.0735294, α83=0.0193798, α91=0.1441441, α92=0.0840336, α93=0.1, β=3, p1=0.5392, q1=0.4608, p2=0.1, q2=0.9
Availability
0.959
0.958
0.957
0.956
0.955
0.954
0.953
0.000512
0.001012
0.001512
λ5
λ9=0.0002054
λ9=0.0002783
λ9=0.0004315

Fig. 3



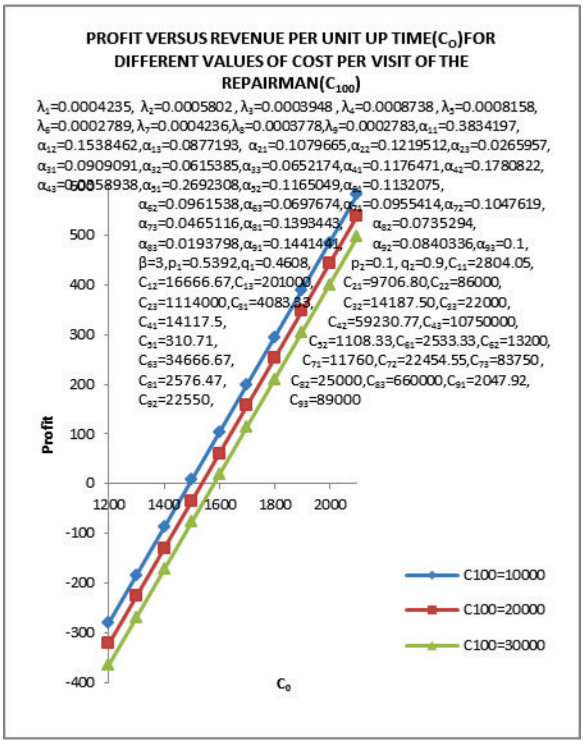




Fig. 4 Fig. 5

## 8. Conclusion

Following conclusions are drawn on the basis of the graphs, irrespective of the fact whether they are being shown here or not:

- The MTSF and Availability gets decreased as the failure rate ($\lambda_5$) increases and also gets lowered for higher values of failure rate ($\lambda_9$).

Other interpretations are given in Table 2. The values of those parameters which have not been mentioned in each case in the table are the same as mentioned in Section 7.

**Table 2**

| S.No. | Graph | Other fixed parameters | Profit | | For | Profit ≥ 0 If |
|---|---|---|---|---|---|---|
| | | | Increases | Decreases | | |
| 1 | Profit versus $\lambda_5$ | $\beta$=3,$p_1$=0.5392,$C_o$=1540, $C_{100}$=20000, $C_{11}$=2804.05 | - | With increase in $\lambda_5$ and $\lambda_9$ | $\lambda_9$ = 0.0002054 | $\lambda_5 \leq$ 0.0011749 |
| | | | | | $\lambda_9$ = 0.0002783 | $\lambda_5 \leq$ 0.0010216 |
| | | | | | $\lambda_9$ = 0.0003154 | $\lambda_5 \leq$ 0.0009435 |
| 2 | Profit versus $p_1$ | $\lambda_9$=0.0002783,$\beta$=3,$C_o$=1540,$C_{100}$=20000, $C_{11}$=2804.05 | With increase in $p_1$ | With increase in $\lambda_5$ | $\lambda_5$=0.0009158 | $p_1 \geq$0.1840283 |
| | | | | | $\lambda_5$=0.0009558 | $p_1 \geq$0.3276139 |
| | | | | | $\lambda_5$=0.0010057 | $p_1 \geq$0.4907336 |
| 3 | Profit versus $C_0$ | $\lambda_5$=0.0008158,$\lambda_9$=0.0002783,$\beta$=3,$p_1$=0.5392, $C_{11}$=2804.05 | With increase in $C_0$ | With increase in $C_{100}$ | $C_{100}$=10000 | $C_0 \geq$1491.9959828 |
| | | | | | $C_{100}$=20000 | $C_0 \geq$1536.3863382 |
| | | | | | $C_{100}$=30000 | $C_0 \geq$1580.7766936 |
| 4 | Profit versus $\lambda_9$ | $\lambda_5$=0.0008158,$p_1$=0.5392, $C_o$=1540,$C_{100}$=20000, $C_{11}$=2804.05 | - | With increase in $\lambda_9$ and $\beta$ | $\beta$=1 | $\lambda_9 \leq$0.0003868 |
| | | | | | $\beta$=3 | $\lambda_9 \leq$0.0003761 |
| | | | | | $\beta$=5 | $\lambda_9 \leq$0.0003740 |
| 5 | Profit versus $C_0$ | $\lambda_5$=0.0008158,$\lambda_9$=0.0002783, $\beta$=3,$p_1$=0.5392, $C_{100}$=20000 | With increase in $C_0$ | - | $C_{11}$=2804.05 | $C_0 \geq$1536.3863341 |

**References**

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