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RELIABILITY MODELLING AND PROFIT ANALYSIS OF A CEMENT GRINDING SYSTEM WITH REST/MAINTENANCE IN CASE OF NO DEMAND

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Abstract

The present paper deals with the probabilistic analysis of a system of grinding cement with failure in its nine important components along with the consideration of maintenance and rest during the period of no demand. In each of the components one type of failure has been taken into consideration except one, namely diverting gate in which two types of failure are considered as observed for the system. The aspect of the component 'Fly Ash System' that, failure may not lead to instantaneous failure of the system, has also been incorporated. General checking is done randomly for preventive/corrective maintenance of the system. Data on various parameters including failures and repairs have been collected from a cement plant 'Shree Cement Ltd.', situated in Khushkhera, Rajasthan, India. The system has been analysed to obtain various measures of system effectiveness by using semi – Markov processes and regenerative point technique. Profit incurred to the system is evaluated and to draw various important conclusions graphical study is also done.

Key Words: Reliability, Cement Grinding System, Demand, Maintenance, Profit Analysis

2010 Mathematics Subject Classification: 60K10, 60K15

1. INTRODUCTION

A large number of research papers on analysis of industrial systems and reliability modelling have been added by various researchers including [2, 4, 7, 8] and [13]. Some of them took the assumed values of the parameters involved whereas the others have used the values of the parameters estimated from the data/information gathered from the industries/companies. Rizwan et al. (2010) [10] discussed reliability analysis of a two-unit hot standby PLC system. Zhag Z et al. (2012) [12] developed a model for a Diesel System in Locomotives using the real failure data of locomotives. Gupta and Taneja (2014) [3] developed a reliability model on the failure of nine components of a cement grinding system by estimating the values of the parameters with the help of the information gathered from a cement plant 'Shree Cement Ltd.', Khushkhera, Rajasthan, India. However, demand of the product, which may vary from time to time can affect the working of the system. The aspect of variation of demand also needs to be considered and hence the present paper.

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A reliability model on cement grinding system is developed and analysed in the present paper wherein failure in its nine components have been considered along with the rest/maintenance during ‘no demand’ period. Five significant stages of manufacturing cement are – crushing of raw material, raw meal grinding, and clinkerisation, grinding of cement and packing of cement for despatch. The nine components involved in cement grinding are:

Belt Conveyor, Bucket Elevator, Separator, Roller Press, Diverting Gate, Process Fan, Cyclone, Ball Mill, Fly Ash System.

Two types of failure ‘minor’ and ‘major’ have been considered in the fifth component i.e. diverting gate. In case of minor failure, this component fails partially and the system still works i.e. the system does not become inoperable whereas in case of major failure, the diverting gate and hence the system fails completely. If fault occurs in the fly ash component, it fails slowly and not immediately and hence the system may operate up to some time with the possibility that the fault may be repaired/removed during this time also. But, if the faults are not taken care of during this time, the system goes to failed state. Demand is considered to vary and sometimes, there may be no demand. During the period of demand, the maintenance is being done bringing the system into rest. The working of the system is resumed as soon as the demand arises again. Also, the general checking of the system is done randomly for preventive/corrective maintenance. Various effectiveness measures of the system and reliability characteristics such as availability, mean time to system failure (MTSF), expected number of replacements/repairs of the nine components, expected time for preventive/corrective maintenance, expected time for general checking, expected time for maintenance in case of no demand, expected rest period in case of no demand etc. are evaluated. The results are represented in the form of graphs for better interpretation. This paper is organised as follows:

Section 1 gives the introduction, Section 2 explains all the notations used in this research, transition diagram and probabilities has been discussed in Section 3 and 4 discuss measures of system effectiveness, Section 5 gives the profit function, Section 6 discusses results followed by conclusion in Section 7.

2. NOTATIONS

O : System is operative

λ_i : Constant failure rate of i^{th} component; $i = 1,2,\ldots,9$

$G_i(t), g_i(t)$: Cumulative distribution function and probability density function of repair time of i^{th} component; $i = 1,2,3,4,6,7,8,9$

$G_{51}(t), g_{51}(t)$: Cumulative distribution function and probability density function of repair time for minor failure in diverting gate

$G_{52}(t), g_{52}(t)$: Cumulative distribution function and probability density

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function of repair time for major failure in diverting gate

p_1, q_1 : Probability of minor and 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 the component is not repaired but fly ash in the bin is consumed completely

$I(t), i(t)$: Cumulative distribution function and probability density function of allowable time for which dry fly ash is present in the bin

p_3 : Probability that there is again demand of cement

q_3 : Probability that there is still no demand of cement

$I_1(t), i_1(t)$: Cumulative distribution function and probability density function of the time for requirement of preventive or corrective maintenance

$I_2(t), i_2(t)$: Cumulative distribution function and probability density function of the time for requirement of general checking

$I_3(t), i_3(t)$: Cumulative distribution function and probability density function of the time to reach the state of no demand

$H_1(t), h_1(t)$: Cumulative distribution function and probability density function of the time consumed in preventive or corrective maintenance

$H_2(t), h_2(t)$: Cumulative distribution function and probability density function of the time consumed in general checking

$H_3(t), h_3(t)$: Cumulative distribution function and probability density function of the time for completion of maintenance in case of no demand

$W(t), w(t)$: Cumulative distribution function and probability density function of the rest time till the demand arises

F_{ri} : Completely failed i^{th} component under repair; $i = 1,2, \ldots ,9$

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

$q_{ij}(t), Q_{ij}(t)$: Probability density function and cumulative distribution function 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 upstate at the instant , given that the system entered regenerative state i at $t = 0$

$ER_i^j(t)$: expected number of repair or replacements in j^{th} component at instant , given that the system started from the regenerative state i at $t = 0$; $j = 1,2,3,4,6,7,8,9$

$ER_i^{51}(t)$: expected number of repair or replacements in 5^{th} component due to minor failure at instant t, given that the system started from the regenerative state i at $t = 0$

$ER_i^{52}(t)$: expected number of repair or replacements in 5^{th} component due to major failure at instant t, given that the system started from the regenerative state i at $t = 0$

$ET_i^{11}(t)$: expected time for preventive/corrective maintenance at instant t, given that system started from the regenerative state i at $t = 0$

$ET_i^{12}(t)$: expected time for general checking at instant t, given that the system started from the regenerative state i at $t = 0$

$ET_i^{13}(t)$: expected time for maintenance in case of no demand at instant t, given that the system started from the regenerative state i at $t = 0$

$ET_i^{14}(t)$: expected rest period in case of no demand 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 $t = 0$

3. TRANSITION PROBABILITIES AND MEAN SOJOURN TIME

Fig.1 represents a transition diagram showing the various states of the system. The states 0 to 15 are called regenerative states as the epochs of entry into these states are regeneration points. States 0, 5 and 10 are up states. States 1 to 4, 6 to 9 and 11 are failed states. States 12, 13 and 14 are down states and 15 is rest state.

The transition probabilities [1, 5] are given by

$$q_{0j}(t) = \lambda_j e^{-(\sum_{i=1}^{9} \lambda_i)t} E_1(t); j = 1,2,3,4 \quad ,$$

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$$q_{05}(t) = p_1\lambda_5 e^{-(\sum_{i=1}^{9}\lambda_i)t}E_1(t),$$

$$q_{06}(t) = q_1\lambda_5 e^{-(\sum_{i=1}^{9}\lambda_i)t}E_1(t),$$

$$q_{0j}(t) = \lambda_{j-1} e^{-(\sum_{i=1}^{9}\lambda_i)t}E_1(t); j = 7,8,9,10$$

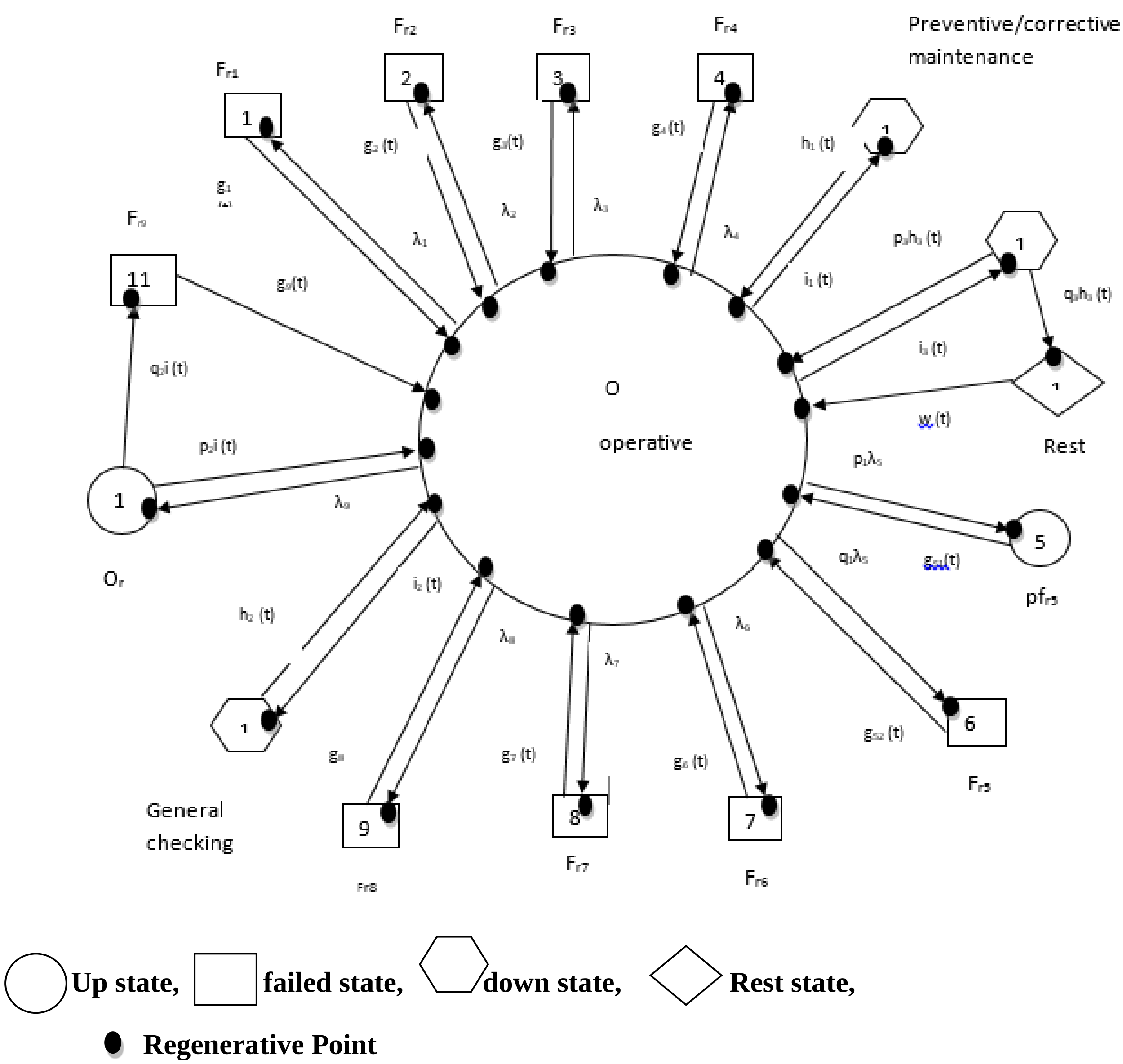

Figure 1: State Transition Diagram

$$q_{0,12}(t) = e^{-(\sum_{i=1}^{9}\lambda_i)t}E_2(t),$$

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$q_{0,13}(t) = e^{-(\sum_{i=1}^{9}\lambda_i)t}E_3(t),$

$q_{0,14}(t) = e^{-(\sum_{i=1}^{9}\lambda_i)t}E_4(t),$

$q_{i0}(t) = g_i(t); i = 1,2,3,4,$

$q_{50}(t) = g_{51}(t), \qquad q_{60}(t) = g_{52}(t),$

$q_{i0}(t) = g_{i-1}(t); i = 7,8,9 \quad ,$

$q_{10,0}(t) = p_2 i(t), \qquad q_{10,11}(t) = q_2 i(t),$

$q_{11,0}(t) = g_9(t), \qquad q_{12,0}(t) = h_1(t),$

$q_{13,0}(t) = h_2(t), \qquad q_{14,0}(t) = p_3 h_3(t),$

$q_{14,15}(t) = q_3 h_3(t), \qquad q_{15,0}(t) = w(t)$ (1-19)

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

$p_{0j} = \lambda_j E_1{}^*(\sum_{i=1}^{9}\lambda_i); j = 1,2,3,4,$

$$p_{05} = p_1\lambda_5 E_1{}^*\left(\sum_{i=1}^{9}\lambda_i\right),$$

$p_{06} = q_1\lambda_5 E_1{}^*(\sum_{i=1}^{9}\lambda_i),$

$$p_{0j} = \lambda_{j-1}E_1{}^*\left(\sum_{i=1}^{9}\lambda_i\right); j = 7,8,9,10,$$

$p_{0,12} = E_2{}^*(\sum_{i=1}^{9}\lambda_i),$

$$p_{0,13} = E_3{}^*\left(\sum_{i=1}^{9}\lambda_i\right),$$

$$p_{0,14} = E_4{}^*\left(\sum_{i=1}^{9}\lambda_i\right),$$

$p_{i0} = 1; i = 1,2, \dots\dots, 9,11,12,13,15,$

$p_{10,0} = p_2, \qquad p_{10,11} = q_2,$

$p_{14,0} = p_3, \qquad p_{14,15} = q_3$ (20-31)

Where

$E_1(t) = \bar{I}_1(t)\bar{I}_2(t)\bar{I}_3(t),$

$E_2(t) = i_1(t)\bar{I}_2(t)\bar{I}_3(t),$

$E_3(t) = \bar{I}_1(t)i_2(t)\bar{I}_3(t),$

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$E_4(t) = \bar{I}_1(t)\bar{I}_2(t)i_3(t)$ (32-35)

by these transition probabilities, it can be verified that

$\sum_{j=1}^{10} p_{0,j} = 1,$

$\sum_{j=12}^{14} p_{0,j} = 1,$

$p_{10,0} + p_{10,11} = 1,$

$p_{14,0} + p_{14,15} = 1,$

$p_{11,0} = 1,$

$p_{i,0} = 1(i = 1,2,\ldots\ldots,9,11,12,13,15)$ (36-41)

The expected time of stay in state i known as the mean sojourn time (μ_i) in state i are obtained as

$\mu_0 = \int_0^\infty e^{-(\sum_{i=1}^{9}\lambda_i)t} E_1(t)dt = E_1^*(\sum_{1=1}^{9}\lambda_i),$

$\mu_k = -g_k *' (0), (k = 1,2,3,4),$

$\mu_5 = -g_{51} *'^{(0)},\quad \mu_6 = -g_{52} *' (0),$

$\mu_7 = -g_6 *'^{(0)},\quad \mu_8 = -g_7 *' (0),$

$\mu_9 = -g_8 *'^{(0)},\ \mu_{10} = -i *' (0),$

$\mu_{11} = -g_9 *'^{(0)},\ \mu_{12} = -h_1 *' (0),$

$\mu_{13} = -h_2 *'^{(0)},\ \mu_{14} = -h_3 *' (0),$

$\mu_{15} = -w * '(0)$ (42-54)

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:

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

$\sum_{j=1}^{10} m_{0,j} = \mu_0,\quad \sum_{j=12}^{14} m_{0,j} = \mu_0,$

$m_{i,0} = \mu_i(i = 1,2,\ldots.,9),\quad m_{10,0} + m_{10,11} = \mu_{10},$

$m_{11,0} = \mu_{11},\quad m_{12,0} = \mu_{12},$

$m_{13,0} = \mu_{13},\quad m_{14,0} + m_{14,15} = \mu_{14},$

$m_{15,0} = \mu_{15}$ (55-64)

4. MEASURES OF SYSTEM EFFECTIVENESS

In steady state, various measures of system effectiveness [9] are obtained by using the arguments of the theory of regenerative process:

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4.1 Mean Time to System Failure

Recursive relations for $\phi_i(t)$ are obtained:

$$\phi_0(t) = Q_{01}(t) + Q_{02}(t) + Q_{03}(t) + Q_{04}(t) + Q_{06}(t) + Q_{07}(t) + Q_{08}(t) + Q_{09}(t) + Q_{05}(t) Ⓢ \phi_5(t) + Q_{0,10}(t) Ⓢ \phi_{10}(t) + Q_{0,12}(t) Ⓢ \phi_{12}(t) + Q_{0,13}(t) Ⓢ \phi_{13}(t) + Q_{0,14}(t) Ⓢ \phi_{14}(t)$$

$$\phi_5(t) = Q_{50}(t) Ⓢ \phi_0(t)$$

$$\phi_{10}(t) = Q_{10,0}(t) Ⓢ \phi_0(t) + Q_{10,11}(t)$$

$$\phi_{12}(t) = Q_{12,0}(t) Ⓢ \phi_0(t)$$

$$\phi_{13}(t) = Q_{13,0}(t) Ⓢ \phi_0(t)$$

$$\phi_{14}(t) = Q_{14,0}(t) Ⓢ \phi_0(t) + Q_{14,15}(t) Ⓢ \phi_{15}(t)$$

$$\phi_{15}(t) = Q_{15,0}(t) Ⓢ \phi_0(t)$$

(65-71)

Thus $\phi_0^{**}(s) = \frac{N(s)}{D(s)}$

Where

$$N(s) = Q_{01}^{**}(s) + Q_{02}^{**}(s) + Q_{03}^{**}(s) + Q_{04}^{**}(s) + Q_{06}^{**}(s) + Q_{07}^{**}(s) + Q_{08}^{**}(s) + Q_{09}^{**}(s) + Q_{0,10}^{**}(s) Q_{10,11}^{**}(s)$$

$$D(s) = 1 - Q_{0,5}^{**}(s) Q_{5,0}^{**}(s) - Q_{0,10}^{**}(s) Q_{10,0}^{**}(s) - Q_{0,12}^{**}(s) Q_{12,0}^{**}(s) - Q_{0,13}^{**}(s) Q_{13,0}^{**}(s) - Q_{0,14}^{**}(s) Q_{14,0}^{**}(s) - Q_{0,14}^{**}(s) Q_{14,15}^{**}(s) Q_{15,0}^{**}(s)$$

(72-74)

Therefore, the MTSF is

$$T_0 = \lim_{s \to 0} \frac{1 - \phi_0^{**}(s)}{s} = \frac{N}{D}$$

Where

$$N = \mu_0 + \mu_5 p_{0,5} + \mu_{10} p_{0,10} + \mu_{12} p_{0,12} + \mu_{13} p_{0,13} + \mu_{14} p_{0,14} + \mu_{15} p_{0,14} p_{14,15}$$

$$D = 1 - p_{0,5} - p_{0,12} - p_{0,13} - p_{0,14} - p_{0,10} p_{10,0}$$

(75-77)

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4.2 Availability of the System

The availability [11] $A_i(t)$ satisfy the following recursive relations:

$A_0(t) = M_0(t) + \sum_{\substack{i=1 \\ i\neq 11}}^{14} q_{0i}(t) \copyright A_i(t)$

$A_i(t) = q_{i,0}(t) \copyright A_0(t); i = 1,2,3,4$

$A_5(t) = M_5(t) + q_{50}(t) \copyright A_0(t)$

$A_i(t) = q_{i,0}(t) \copyright A_0(t); i = 6,7,8,9$

$A_{10}(t) = M_{10}(t) + q_{10,0}(t) \copyright A_0(t) + q_{10,11}(t) \copyright A_{11}(t)$

$A_{11}(t) = q_{11,0}(t) \copyright A_0(t)$

$A_{12}(t) = q_{12,0}(t) \copyright A_0(t)$

$A_{13}(t) = q_{13,0}(t) \copyright A_0(t)$

$A_{14}(t) = q_{14,0}(t) \copyright A_0(t) + q_{14,15}(t) \copyright A_{15}(t)$

$A_{15}(t) = q_{15,0}(t) \copyright A_0(t)$

where

$$M_0(t) = e^{-(\sum_{i=1}^{9} \lambda_i)t} E_1(t), \qquad M_5(t) = \overline{G}_{51}(t), \qquad M_{10}(t) = \overline{I}(t)$$

Thus,

$A_0^*(s) = \frac{N_1(s)}{D_1(s)}$

Where

$N_1(s) = M_0^*(s) + M_5^*(s) q_{05}^*(s) + M_{10}^*(s) q_{0,10}^*(s)$

$D_1(s) = 1 - \sum_{\substack{i=1 \\ i\neq 11}}^{14} q_{0i}{}^*(s)\, q_{i,0}^*(s) - q_{0,10}^*(s) q_{10,11}^*(s) q_{11,0}^*(s) - q_{0,14}^*(s) q_{14,15}^*(s) q_{15,0}^*(s)$

In steady state, the availability of the system is given by,

$A_0 = \lim_{s\to 0} s A_0{}^*(s) = \frac{N_1}{D_1},$

where

$N_1 = \mu_0 + \mu_5 p_{0,5} + \mu_{10} p_{0,10}$

$D_1 = \mu_0 + \sum_{\substack{i=1 \\ i\neq 11}}^{14} p_{0i}\, \mu_i + \mu_{11} p_{0,10} p_{10,11} + \mu_{15} p_{0,14} p_{14,15}$ (78-96)

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4.3 Other Measures

Various other measures which affect the profitability of the system have also been obtained and are given as follows:

- Expected Number of Repairs or Replacements of parts in Belt Conveyor: $ER_0^1 = N_2/D_1$
- Expected Number of Repairs or Replacements of parts in Bucket Elevator:

  $ER_0^2 = N_3/D_1$
- Expected Number of Repairs or Replacements of parts in Separator:

  $ER_0^3 = N_4/D_1$
- Expected Number of Repairs or Replacements of parts in Roller Press:

  $ER_0^4 = N_5/D_1$
- Expected Number of Repairs or Replacements of parts in Diverting Gate on Minor Failure:

  $ER_0^{51} = N_6/D_1$
- Expected Number of Repairs or Replacements of parts in Diverting Gate on Major Failure:

  $ER_0^{52} = N_7/D_1$
- Expected Number of Repairs or Replacements of parts in Process Fan:

  $ER_0^6 = N_8/D_1$
- Expected Number of Repairs or Replacements of parts in Cyclone:

  $ER_0^7 = N_9/D_1$
- Expected Number of Repairs or Replacements of parts in Ball Mill:

  $ER_0^8 = N_{10}/D_1$
- Expected Number of Repairs or Replacements of parts in Fly Ash System: $ER_0^9 = N_{11}/D_1$
- Expected time for preventive / corrective maintenance:

  $ET_0^{11} = N_{12}/D_1$
- Expected time for General Checking:

  $ET_0^{12} = N_{13}/D_1$
- Expected time for Maintenance in case of no demand:

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$ET_0^{13} = N_{14}/D_1$

- Expected rest period in case of no demand:

  $ET_0^{14} = N_{15}/D_1$
- Expected Number of Visits of the Repairman $(V_0) = N_{16}/D_1$

where

$$N_2 = p_{01}, N_3 = p_{02}, N_4 = p_{03}, N_5 = p_{04}, N_6 = p_{05}, N_7 = p_{06}, N_8 = p_{07}, N_9 = p_{08}, N_{10} = p_{09}, N_{11} = p_{0,10}, N_{12} = \mu_{12} p_{0,12}, N_{13} = \mu_{13} p_{0,13}, N_{14} = \mu_{14} p_{0,14}, N_{15} = \mu_{15} p_{0,14} p_{14,15}, N_{16} = \sum_{\substack{i=1 \\ i \neq 11}}^{14} p_{0i} = 1$$

(97-126)

5. PROFIT ANALYSIS

The profit function [6, 9], therefore, is given as:

Profit $(P) = C_0 A_0 - C_1 ER_0^1 - C_2 ER_0^2 - C_3 ER_0^3 - C_4 ER_0^4 - C_{51} ER_0^{51} - C_{52} ER_0^{52} - C_6 ER_0^6 - C_7 ER_0^7 - C_8 ER_0^8 - C_9 ER_0^9 - C_{11} ET_0^{11} - C_{12} ET_0^{12} - C_{13} ET_0^{13} - C_{14} ET_0^{14} - C_{10} V_0$ (127)

Where

C_0 = revenue per unit up time of the system

C_1 = cost per repair or replacement in Belt Conveyor

C_2 = cost per repair or replacement in Bucket Elevator

C_3 = cost per repair or replacement in Separator

C_4 =cost per repair or replacement in Roller Press

C_{51} = cost per repair or replacement in Diverting Gate on minor failure

C_{52} = cost per repair or replacement in Diverting Gate on major failure

C_6 = cost per repair or replacement in Process Fan

C_7 = cost per repair or replacement in Cyclone

C_8 = cost per repair or replacement in Ball Mill

C_9 = cost per repair or replacement in Fly Ash System

C_{10} = cost per visit by the repairman

C_{11} = cost per unit time for preventive/corrective maintenance during working period

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C_{12} = cost per unit time for general checking during working period

C_{13} = cost per unit time for maintenance during the period of 'no demand'

C_{14} = loss per unit time due to rest during the period of 'no demand'

6. RESULTS AND DISSCUSSION

For graphical study the following particular case is considered:

$g_i(t) = \alpha_i e^{-\alpha_i t}; i = 1,2, \dots \dots .., 9, i \neq 5,$

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

$i(t) = \beta e^{-\beta t}, \qquad i_1(t) = \beta_1 e^{-\beta_1 t},$

$i_2(t) = \beta_2 e^{-\beta_2 t}, \qquad i_3(t) = \beta_3 e^{-\beta_3 t},$

$h_1(t) = \gamma_1 e^{-\gamma_1 t}, \qquad h_2(t) = \gamma_2 e^{-\gamma_2 t},$

$h_3(t) = \gamma_3 e^{-\gamma_3 t}, \qquad w(t) = \eta e^{-\eta t}$ (128-138)

The values of various parameters as estimated from the gathered data/information are as follows:

$\lambda_1 = 0.0004235, \lambda_2 = 0.0005802, \lambda_3 = 0.0003948, \lambda_4 = 0.0008738,$

$\lambda_5 = 0.0008158, \lambda_6 = 0.0002789, \lambda_7 = 0.0004236, \lambda_8 = 0.0003778,$

$\lambda_9 = 0.0002783, \beta_1 = 0.0005079, \beta_2 = 0.0004722, \beta_3 = 0.0002315,$

$\alpha_1 = 0.1892333, \alpha_2 = 0.087115, \alpha_3 = 0.0666667, \alpha_4 = 0.0993984,$

$\alpha_{51} = 0.2692308, \alpha_{52} = 0.1165049, \alpha_6 = 0.097643, \alpha_7 = 0.0862069,$

$\alpha_8 = 0.0453258, \alpha_9 = 0.1164902, \beta = 3, \gamma_1 = 0.1175786, \gamma_2 = 0.1344286,$

$\gamma_3 = 0.0066667, \eta = 0.0133333, p_1 = 0.5392, q_1 = 0.4608, p_2 = 0.1,$

$q_2 = 0.9, p_3 = 0.9, q_3 = 0.1, C_0 = 1850, C_1 = 55495.69, C_2 = 105689.43,$

$C_3 = 15161.76, C_4 = 1442167.1, C_{51} = 339.29, C_{52} = 1075,$

$C_6 = 11020.69, C_7 = 25280, C_8 = 211525, C_9 = 17536.36, C_{10} = 20000,$

$C_{11} = 10000, C_{12} = 15000, C_{13} = 5000, C_{14} = 10000$

Various measures of system effectiveness obtained using the above estimated values are given in **Table 1**. Some of the graphs plotted using the above particular case are shown as in **Figs. 2 to 5** along with the interpretations as tabulated in **Table 2**.

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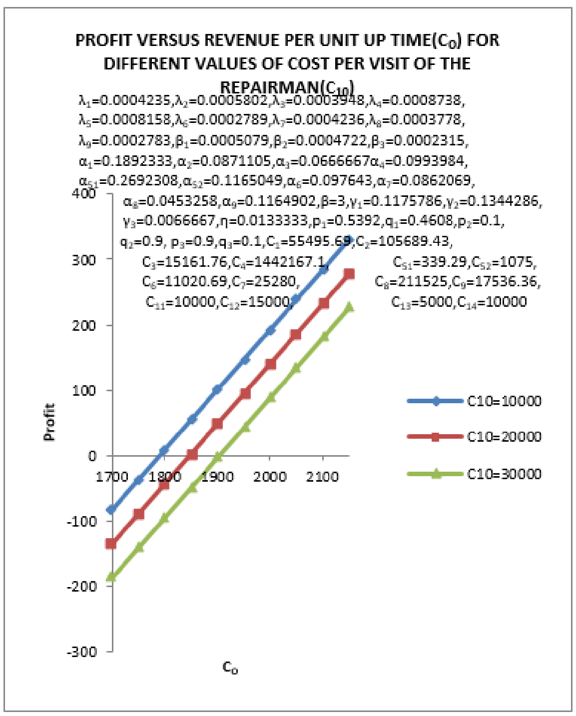
Table 1

Measure	Value
MTSF	262.8857639
A_0	0.9180774
ER_0^1	0.0003881
ER_0^2	0.0005318
ER_0^3	0.0003618
ER_0^4	0.0008008
ER_0^{51}	0.0004031
ER_0^{52}	0.0003445
ER_0^6	0.0002556
ER_0^7	0.0003882
ER_0^8	0.0003463
ER_0^9	0.0002551
ET_0^{11}	0.0039589
ET_0^{12}	0.0032193
ET_0^{13}	0.0318251
ET_0^{14}	0.0015913
V_0	0.0051858
Profit	2.7954530



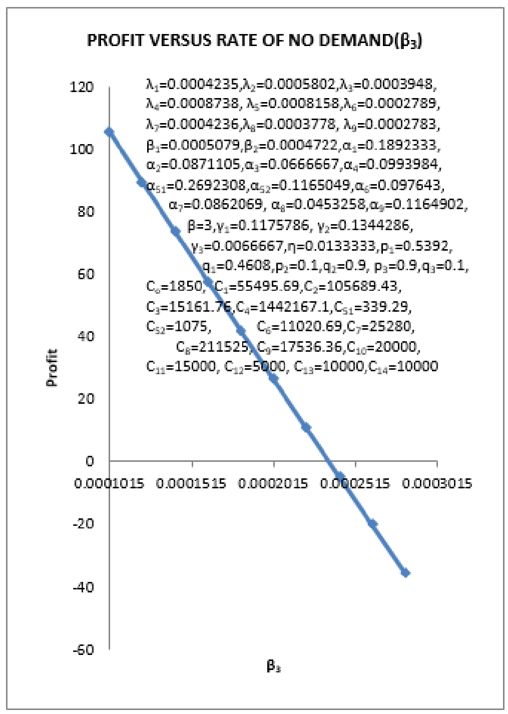


Fig. 2 **Fig. 3**

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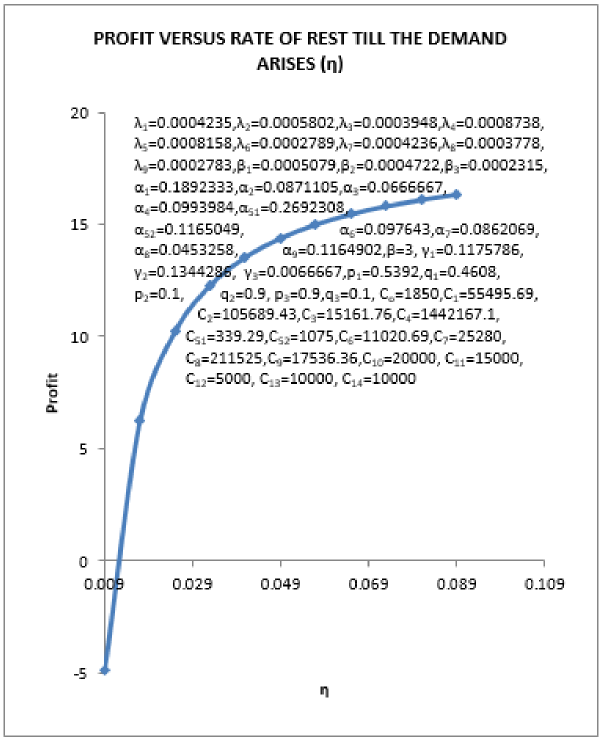

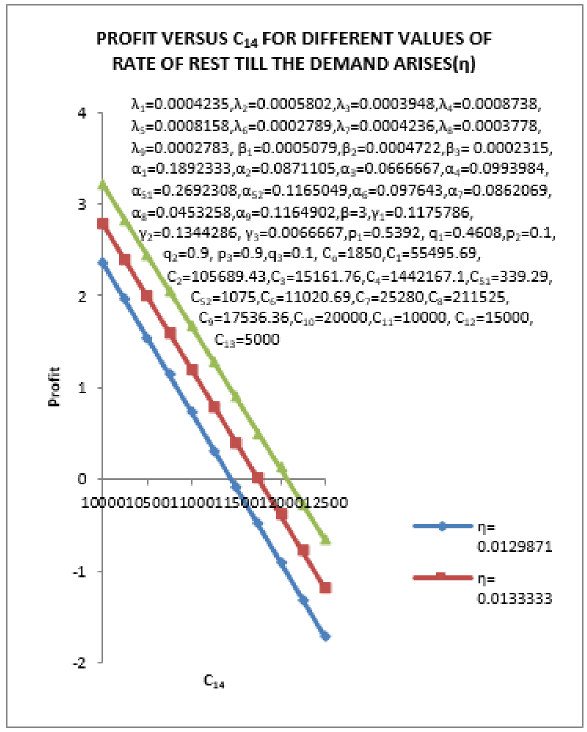

Fig. 4 **Fig. 5**

Table 2

S. No.	Graph	Values of parameters fixed	Profit		For	Profit ≥ 0 If
			Increases	**Decreases**		
1	Profit versus λ_5	$\beta = 3, \gamma_3 = 0.0066667,$ $p_1 = 0.5392, p_3 = 0.9,$ $C_0 = 1850, C_1 = 55495.69,$ $C_{10} = 20000, C_{14} = 10000,$ $\beta_3 = 0.0002315$	-	With increase in λ_5 and λ_9	$\lambda_9 = 0.0002054$	$\lambda_5 \leq 0.0011541$
					$\lambda_9 = 0.0002783$	$\lambda_5 \leq 0.0009955$
					$\lambda_9 = 0.0003054$	$\lambda_5 \leq 0.0009366$
2	Profit versus p_1	$\lambda_9 = 0.0002783, \beta = 3,$ $\gamma_3 = 0.0066667, p_3 = 0.9,$ $C_0 = 1850, C_1 = 55495.69,$ $C_{10} = 20000, C_{14} = 10000,$ $\beta_3 = 0.0002315$	With increase in p_1	With increase in λ_5	λ_5=0.0008958	p_1≥0.2642629
					λ_5=0.0009123	p_1≥0.3139146
					λ_5=0.0010057	p_1≥0.5642324
3	Profit versus C_0	$\lambda_5 = 0.0008158,$ $\lambda_9 = 0.0002783,$ $\beta = 3, \gamma_3 = 0.0066667,$ $p_1 = 0.5392, p_3 = 0.9,$ $C_1 = 55495.69, C_{14} = 10000,$ $\beta_3 = 0.0002315$	With increase in C_0	With increase in C_{10}	C_{10}=10000	C_0≥1790.4696290
					C_{10}=20000	C_0≥1846.9551009
					C_{10}=30000	C_0≥1903.4405729
4	Profit versus C_0	$\lambda_5 = 0.0008158,$ $\lambda_9 = 0.0002783,$ $\beta = 3, \gamma_3 = 0.0066667,$	With increase in C_0	With increase in C_1	C_1=26354.42	C_0≥1834.6350451
					C_1=55495.69	C_0≥1846.9551011
					C_1=84636.96	C_0≥1859.2751571

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		$p_1 = 0.5392, p_3 = 0.9,$ $C_{10} = 20000, C_{14} = 10000,$ $\beta_3 = 0.0002315$				
5	Profit versus λ_9	$\lambda_5 = 0.0008158,$ $\gamma_3 = 0.0066667,$ $p_1 = 0.5392, p_3 = 0.9,$ $C_0 = 1850, C_1 = 55495.69,$ $C_{10} = 20000, C_{14} = 10000,$ $\beta_3 = 0.0002315$	-	With increase in λ_9 and β	$\beta = 1$ $\beta = 3$ $\beta = 5$	$\lambda_9 \leq 0.0003734$ $\lambda_9 \leq 0.0003609$ $\lambda_9 \leq 0.0003585$
6	Profit Vs p_3	$\lambda_5 = 0.0008158,$ $\lambda_9 = 0.0002783,$ $\beta = 3, p_1 = 0.5392,$ $C_0 = 1850, C_1 = 55495.69,$ $C_{10} = 20000,$ $C_{14} =$ $10000,$ $\beta_3 = 0.0002315$	With increase in p_3 and γ_3	-	γ_3=0.0111111 γ_3=0.0125 γ_3=0.0142857	$p_3 \geq 0.4824160$ $p_3 \geq 0.4157508$ $p_3 \geq 0.3490655$
7	Profit versus C_{14}	$\lambda_5 = 0.0008158,$ $\lambda_9 = 0.0002783,$ $\beta = 3, \gamma_3 = 0.0066667,$ $p_1 = 0.5392, p_3 = 0.9,$ $C_0 = 1850, C_1 = 55495.69,$ $C_{10} = 20000,$	-	With increase in C_{14} and β_3	β_3=0.0002302 β_3=0.0002315 β_3=0.0002328	$C_{14} \leq 12402.9199851$ $C_{14} \leq 11756.7451299$ $C_{14} \leq 11117.7870042$

7. CONCLUSION

The study has its applications in cement manufacturing companies which are using such systems. The parameters for which the cut-off points have been obtained in order to have profitable system are:

- The maximum tolerable value of the failure rate.
- The minimum value of revenue per unit up time which help decide the price of the product being manufactured.
- The maximum bearable loss due to period of no demand.
- The value of the rate of no demand beyond which profit becomes negative.
- The lowest rate of going to rest.

Other companies which possess the same system may also adopt this model to take important decisions by finding various cut-off points for the parameters of interest in the manner the author(s) have done in the results and discussion section.

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