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RESEARCH ARTICLE

PROFIT AND RELIABILITY ANALYSIS OF MANUFACTURING PLANT OF MOSQUITO COIL IN AN INDUSTRY WITH SINGLE REPAIR FACILITY

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ABSTRACT

A model of manufacturing plant of Mosquito coil in an industry is developed for its stochastic analysis by personally visiting the Jyoti Laboratory limited industry situated in Samba district of State J&K. The said system consists of three units- Mixing, Extrusion, Punching Machine. The Mixture machine is in parallel form with the other two units but Extrusion machine and Punching machine are in series form such that if any one of the two units is failed, the other is kept in standby mode. If repair of failed unit is not completed after random period of time then other units are kept in standby mode. A single repair facility is always available with the system to repair a failed unit. All the failure time distributions are taken to be negative exponential. All the repair time distributions are taken as arbitrary.

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INTRODUCTION

In the present manufacturers are highly concerned about the efficiency of the systems to achieve higher production goals. Reliability is essential for proper utilization and maintenance of any system or equipments. Thus it has gained much importance among manufacturers. Although a lot of work has been done in the field of reliability by formulating and analyzing various kinds of system models under different set of assumptions, but most of the work done is of hypothetical nature and is not of much practical utility. Gupta and Shivakar (2003) carried out the analysis w.r.t. reliability characteristics of a cloth manufacturing system model. Gupta *et al*. (2010) carried out stochastic modelling and analysis of milk powder making system in dairy plant, Kumar Pawan and Bharti Ankush (2012) developed a reliability analysis of a battery production system in an industry.

Besides these Arora and Kumar (2000), Malik *et al.* (2014), Neha Kumari and Pawan Kumar (2015), Singh, and Nair Sheeba (1995) have also studied the industrial system models with real existing situations. For the purpose of analyzing real existing system, a model of manufacturing plant of Mosquito coil is developed for its stochastic analysis by personally visiting the Jyoti Laboratory limited industry situated in Bari Brahmana of Samba district of State J&K. Mosquito coil is a mosquito repelling incense, usually shaped into a spiral, and made from a dried paste of Pyrethrum powder. Mosquito coil composition comprising of ingredients like sawdust having a particle size mesh, coconut shell flour, pyrethrum marc, fragrances, etc.

The given plant consists of three units of varying nature. The working of different units of the system is described as follows:

- **Mixing Machine:** A mixing machine is a machine which is used for mixing. All the raw material of mosquito coil composition is put into mixing machine for mixing it to a desired height to achieve suitable density of mixture to make thin sheets of it.

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- **Extrusion Machine:** The Extrusion machine is a device which pushes or pulls a material through a shaped die to form a continuous length of product with a preset cross section. After mixing all ingredients in mixing machine, the mixture is sent to extrusion machine which makes thin sheet of mixture.

- **Punching Machine:** Punching machine is machine tool for punching and cutting. A die is attached to punching machine which gives the required shape to the given product. Thin sheets or ribbons are passed through punching machine which punches sheets in double coil form.

After this coil are sent for drying. Various manufacturers used different techniques for drying the coils.

Using the regenerative point technique the following important reliability characteristics of interest are obtained:

- Transition probabilities and mean sojourn times.
- Reliability and Mean time to system failure.
- Point wise and steady-state availabilities of the system.
- Expected up time of the system.
- Expected busy time of the repairman during (0, t) and in the steady-state.
- Expected number of repairs by repairman during (0, t) and in the steady-state.
- Net expected profit incurred by the system during (0, t) and in the steady-state.

System Description and Assumptions

- The system consists of three non-identical units. Initially all the units are operative.
- The Mixture machine is in parallel form with the other two units but Extrusion machine and Punching machine are in series form such that if any one of the two units is failed, the other is kept in standby mode.
- If repair of failed unit is not completed after random period of time then other units are kept in standby mode.
- The repair facility is FCFS.
- A single repair facility is always available with the system to repair a failed unit.
- A repaired unit is as good as new and is immediately reconnected to the system.
- All the failure time distributions are taken to be negative exponential.
- All the repair time distributions are taken as arbitrary.

NOTATIONS AND SYMBOLS

α_i, $(i = 1,2,3)$: Constant failure rate of Mixing/Extrusion/Punching machine respectively.
θ : Constant rate with which the units are in standby mode.
$G_i(.)$, $(i = 1,2,3)$: C.d.f. of repair time of Mixing/Extrusion/Punching machine respectively.
m_i $(i = 1,2,3)$: mean repair time of Mixing/Extrusion/Punching machine respectively.

Symbols for the states of the system

$M_0/M_s/M_r/M_w$: Mixing Machine is operative/in standby mode/under repair/waiting for repair.
$E_0/E_s/E_r/E_w$: Extrusion Machine is operative/in standby mode/under repair/waiting for repair.
$P_0/P_s/P_r/P_w$: Punching Machine is operative/in standby mode/under repair/waiting for repair.

With the help of the above symbols, the possible states of the system are:

$S_0 = [M_0, E_0, P_0]$ $S_1 = [M_r, E_0, P_0]$
$S_2 = [M_0, E_r, P_s]$ $S_3 = [M_0, E_s, P_r]$
$S_4 = [M_r, E_s, P_s]$ $S_5 = [M_r, E_w, P_s]$
$S_6 = [M_r, E_s, P_w]$ $S_7 = [M_W, E_r, P_s]$
$S_8 = [M_s, E_r, P_s]$ $S_9 = [M_w, E_s, P_r]$
$S_{10} = [M_s, E_s, P_r]$

The transition diagram along with all transitions is shown in Fig.1.

TRANSITION PROBABILITIES AND SOJOURN TIMES

Let $T_0(\equiv 0), T_1, T_2$ .... denotes the regenerative epochs and X_n denotes the state visited at epoch T_{n^+} i.e just after the transition at T_n. Then $\{X_n, T_n\}$ constitute a Markov-Renewal process with state space E, set of regenerative states and

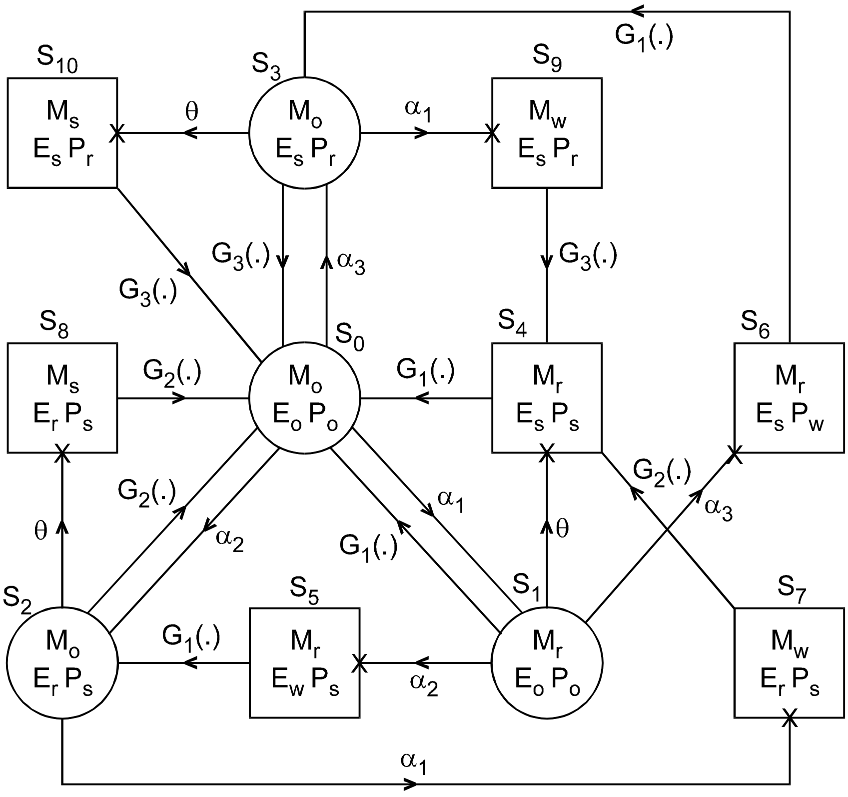

Fig. 1. Transition diagram

$$Q_{ij}(t) = P[X_{n+1} = j, T_{n+1} - T_n \leq t | X_n = i]$$

is the semi Markov kernel over E.

Thus steady state transition probabilities can be obtained as follows:

$p_{ij} = \lim_{t\to\infty} Q_{ij}(t)$

So that,

$p_{01} = \frac{\alpha_1}{(\alpha_1+\alpha_2+\alpha_3)}$ $\qquad$ $p_{02} = \frac{\alpha_2}{(\alpha_1+\alpha_2+\alpha_3)}$

$p_{03} = \frac{\alpha_3}{(\alpha_1+\alpha_2+\alpha_3)}$ $\qquad$ $p_{10} = \widetilde{G}_1(\alpha_2 + \alpha_3 + \theta)$

$p_{10}^{(4)} = \frac{\theta}{(\alpha_2+\alpha_3+\theta)}\left[1 - \widetilde{G}_1(\alpha_2 + \alpha_3 + \theta)\right]$ $\qquad$ $p_{12}^{(5)} = \frac{\alpha_2}{(\alpha_2+\alpha_3+\theta)}\left[1 - \widetilde{G}_1(\alpha_2 + \alpha_3 + \theta)\right]$

$p_{13}^{(6)} = \frac{\alpha_3}{(\alpha_2+\alpha_3+\theta)}\left[1 - \widetilde{G}_1(\alpha_2 + \alpha_3 + \theta)\right]$ $\qquad$ $p_{20} = \widetilde{G}_2(\alpha_1 + \theta)$

$p_{20}^{(8)} = \frac{\theta}{(\alpha_1+\theta)}\left[1 - \widetilde{G}_2(\alpha_1 + \theta)\right]$ $\qquad$ $p_{24}^{(7)} = \frac{\alpha_1}{(\alpha_1+\theta)}\left[1 - \widetilde{G}_1(\alpha_1 + \theta)\right]$

$p_{30} = \widetilde{G}_3(\alpha_1 + \theta)$ $\qquad$ $p_{30}^{(10)} = \frac{\theta}{(\alpha_1+\theta)}\left[1 - \widetilde{G}_3(\alpha_1 + \theta)\right]$

$p_{34}^{(9)} = \frac{\alpha_1}{(\alpha_1+\theta)}\left[1 - \widetilde{G}_3(\alpha_1 + \theta)\right]$ (1-13)

It can be easily seen that the following results hold good:

$p_{01} + p_{02} + p_{03} = 1$ $\qquad$ $p_{10} + p_{10}^{(4)} + p_{12}^{(5)} + p_{13}^{(6)} = 1$

$p_{20} + p_{20}^{(8)} + p_{24}^{(7)} = 1$ $\qquad$ $p_{30} + p_{30}^{(10)} + p_{34}^{(9)} = 1$

$p_{40} = p_{52} = p_{63} = p_{74} = p_{80} = p_{94} = p_{10,0} = 1$ (14-18)

Mean sojourn times

The mean sojourn time in state S_i denoted by Ψ_i is defined as the expected time taken by the system in state S_i before transiting to any other state. To obtain mean sojourn time Ψ_i, in state S_i, we observe that as long as the system is in state S_i, there is no transition from S_i to any other state. If T_i denotes the sojourn time in state S_i then mean sojourn time Ψ_i in state S_i is:

$\Psi_i = E[T_i] = \int P(T_i > t)dt$ (19)

Thus

$$\Psi_0 = \int e^{-(\alpha_1+\alpha_2+\alpha_3)t}\,dt = \frac{1}{(\alpha_1+\alpha_2+\alpha_3)}$$
$$\Psi_1 = \int e^{-(\alpha_2+\alpha_3+\theta)t}\,\overline{G}_1(t)dt = \frac{1}{(\alpha_2+\alpha_3+\theta)}\left[1-\widetilde{G}_1(\alpha_2+\alpha_3+\theta)\right]$$
$$\Psi_2 = \int e^{-(\alpha_1+\theta)t}\,\overline{G}_2(t)dt = \frac{1}{(\alpha_1+\theta)}\left[1-\widetilde{G}_2(\alpha_1+\theta)\right]$$
$$\Psi_3 = \int e^{-(\alpha_1+\theta)t}\,\overline{G}_3(t)dt = \frac{1}{(\alpha_1+\theta)}\left[1-\widetilde{G}_3(\alpha_1+\theta)\right]$$
$$\Psi_4 = \Psi_5 = \Psi_6 = \int \overline{G}_1(t)dt = m_1$$
$$\Psi_7 = \Psi_8 = \int \overline{G}_2(t)dt = m_2$$
$$\Psi_9 = \Psi_{10} = \int \overline{G}_3(t)dt = m_3 \quad (20\text{-}26)$$

ANALYSIS OF RELIABILITY AND MTSF

Let the random variable T_i be the time to system failure when system starts up from state $S_i \in E_i$, the the reliability of the system is given by

$R_i(t) = P[T_i > t]$

To determine, $R_i(t)$ we assume that the down states $(S_4, S_5, S_6, S_7, S_8, S_9, S_{10})$ of the system as absorbing. Using the simple probabilistic arguments, one can easily develop the recurrence relations among $R_i(t)$; i = 0, 1, 2, 3. Taking the Laplace Transforms of these relations and simplifying the resulting set of algebraic equations for, $R_0^*(s)$ we get after omitting the arguments 's' for brevity.

$R_0^*(s) = N_1(s)/D_1(s)$ (27)
where,

$N_1(s) = (Z_0^* + q_{01}^* Z_1^* + q_{02}^* Z_2^* + q_{03}^* Z_3^*)$

And

$D_1(s) = [1 - (q_{01}^* q_{10}^* + q_{02}^* q_{20}^* + q_{03}^* q_{30}^*)]$

where, $Z_0^*, Z_1^*, Z_2^*, Z_3^*$ are the Laplace transform of

$Z_0(t) = e^{-(\alpha_1+\alpha_2+\alpha_3)t}$ $\qquad Z_1(t) = e^{-(\alpha_2+\alpha_3+\theta)t}\,\overline{G}_1(t)$
$Z_2(t) = e^{-(\alpha_1+\theta)t}\,\overline{G}_2(t)$ $\qquad Z_3(t) = e^{-(\alpha_1+\theta)t}\,\overline{G}_3(t)$

Taking inverse Laplace Transform of (27) we get reliability of the system.

To get MTSF, we use the well known formula

$E(T_0) = \int R_0(t)dt = \lim_{s\to 0} R_0^*(s) = N_1(0)/D_1(0)$ (28)

where,

$N_1(0) = (\Psi_0 + p_{01}\Psi_1 + p_{02}\Psi_2 + p_{03}\Psi_3)$

and

$D_1(0) = [1 - (p_{01}p_{10} + p_{02}p_{20} + p_{03}p_{30})]$

Here we use the relations $q_{ij}^*(0) = p_{ij}$ and $\lim_{s\to 0} Z_i^*(s) = \int Z_i(t)dt = \Psi_i$.

AVAILABILITY ANALYSIS

Define $A_i(t)$ as the probability that the system is up at epoch't' when it initially started from regenerative state S_i . Using the definition of $A_i(t)$ and probabilistic concepts, the recurrence relations among $A_i(t)$ where i = 0, 1, 2, 3, 4 can easily be developed.

Using the technique of L.T., the value of $A_i(t)$ in terms of their L.T. are as follows:

$$A_0^*(s) = N_2(s)/D_2(s) \tag{29}$$

where,

$$N_2(s) = \left[Z_0^* + q_{01}^* Z_1^* + \left(q_{02}^* + q_{01}^* q_{12}^{(5)*}\right) Z_2^* + \left(q_{03}^* + q_{01}^* q_{13}^{(6)*}\right) Z_3^*\right]$$

and

$$D_2(s) = 1 - \left[q_{01}^*\left(q_{10}^* + q_{10}^{(4)*}\right) + \left(q_{02}^* + q_{01}^* q_{12}^{(5)*}\right)\left(q_{20}^* + q_{20}^{(8)*} + q_{24}^{(7)*} q_{40}^*\right) + \left(q_{03}^* + q_{01}^* q_{13}^{(6)*}\right)\left(q_{30}^* + q_{30}^{(10)*} + q_{34}^{(9)*} q_{40}^*\right)\right] \tag{30}$$

The steady state availability of the system will be up in the long run is given by

$$A_0 = \lim_{t\to\infty} A_0(t) = \lim_{s\to 0} s\, A_0^*(s) = \lim_{s\to 0} \frac{sN_2(s)}{D_2(s)} = \lim_{s\to 0} N_2(s) \lim_{s\to 0} \frac{s}{D_2(s)}$$

As $s \to 0$, the above equation becomes indeterminate form.

Hence on using L'Hospital's rule, A_0 becomes

$$A_0 = N_2(0)/D_2'(0) \tag{31}$$

where,

$$N_2(0) = \left[\Psi_0 + p_{01}\Psi_1 + \left(p_{02} + p_{01} p_{12}^{(5)}\right)\Psi_2 + \left(p_{03} + p_{01} p_{13}^{(6)}\right)\Psi_3\right] \tag{32}$$

and

$$D_2'(0) = \Psi_0 + p_{01}\Psi_1 + \left(p_{02} + p_{01} p_{12}^{(5)}\right)\Psi_2 + \left(p_{03} + p_{01} p_{13}^{(6)}\right)\Psi_3 + Am_1 \tag{33}$$

where, $A = p_{24}^{(7)}\left(p_{02} + p_{01} p_{12}^{(5)}\right) + p_{34}^{(9)}\left(p_{03} + p_{01} p_{13}^{(6)}\right)$

The expected up time of the system during $(0, t)$ is given by

$\mu_{up}(t) = \int_0^t A_0(u)\, du$
So that,
$$\mu_{up}^*(s) = A_0^*(s)/s. \tag{34}$$

BUSY PERIOD ANALYSIS

Define $B_i(t)$ as the probability that the system having started from regenerative state $S_i \in E$ at time $t = 0$, is under repair at time t due to failure of the unit. Using the definition of $B_i(t)$ and probabilistic concepts, the recurrence relations among $B_i(t)$ where i = 0, 1, 2, 3, 4 can easily be developed.

Using the technique of L.T., the value of $B_i(t)$ in terms of their L.T. are as follows:

$$B_0^*(s) = N_3(s)/D_2(s) \tag{35}$$

where,

$$N_3(s) = q_{01}^* Z_1^* + \left(q_{02}^* + q_{01}^* q_{12}^{(5)*}\right)\left(Z_2^* + q_{24}^{(7)*} Z_4^*\right) + \left(q_{03}^* + q_{01}^* q_{13}^{(6)*}\right)\left(Z_3^* + q_{34}^{(9)*} Z_4^*\right) \tag{36}$$

In the steady state, the probability that the repairman will be busy is given by

$$B_0 = \lim_{t\to\infty} B_0(t) = \lim_{s\to 0} s\, B_0^*(s) = N_3(0)/D_2'(0) \tag{37}$$
also as $s \to 0$, $q_{ij}^*(s)/_{s=0} = q_{ij}^*(0) = p_{ij}$ and $\lim_{s\to 0} Z_i^*(s) = \int Z_i(t)dt = \Psi_i$
where,

$$N_3(0) = p_{01}\Psi_1 + \left(p_{02} + p_{01}p_{12}^{(5)}\right)\left(\Psi_2 + p_{24}^{(7)}\Psi_4\right) + \left(p_{03} + p_{01}p_{13}^{(6)}\right)\left(\Psi_3 + p_{34}^{(9)}\Psi_4\right) \quad (38)$$

The expected busy period of the repairman during (0, t) is given by

$\mu_b(t) = \int_0^t B_0(u)\, du$

So that,

$\mu_b^*(s) = B_0^*(s)/s.$

EXPECTED NUMBER OF REPAIRS

Let us define $V_i(t)$ as the expected number of repairs of the failed units during the time interval $(0, t]$ when the system initially starts from regenerative state S_i.Using the definition of $V_i(t)$ and probabilistic concepts, the recurrence relations among $V_i(t)$ where i = 0, 1, 2, 3, 4 can easily be developed.

Using the technique of L.T., the value of $V_i(t)$ in terms of their L.T. are as follows:

$$\widetilde{V}_0(s) = N_4(s)/D_4(s) \quad (39)$$

where,

$$N_4(s) = \widetilde{Q}_{01}\left(\widetilde{Q}_{10} + \widetilde{Q}_{10}^{(4)} + \widetilde{Q}_{12}^{(5)} + \widetilde{Q}_{13}^{(6)}\right) + \left(\widetilde{Q}_{02} + \widetilde{Q}_{01}\widetilde{Q}_{12}^{(5)}\right)\left(\widetilde{Q}_{20} + \widetilde{Q}_{20}^{(8)} + \widetilde{Q}_{24}^{(7)} + \widetilde{Q}_{24}^{(7)}\widetilde{Q}_{40}\right) + \left(\widetilde{Q}_{03} + \widetilde{Q}_{01}\widetilde{Q}_{13}^{(6)}\right)\left(\widetilde{Q}_{30} + \widetilde{Q}_{30}^{(10)} + \widetilde{Q}_{34}^{(9)} + \widetilde{Q}_{34}^{(9)}\widetilde{Q}_{40}\right) \quad (40)$$

$D_4(s)$ can be written on replacing q_{ij}^* by $\widetilde{Q}_{ij}$ in $D_2(s)$.

In the steady state, the expected number of repairs per unit time is given by

$V_0 = \lim_{t\to\infty} \frac{V_0(t)}{t} = \lim_{s\to 0} s\,\widetilde{V}_0(s) = N_4(0)/D_2'(0)$

And also as $s \to 0, q_{ij}^*(s)/_{s=0} = q_{ij}^*(0) = p_{ij}$ and $\lim_{s\to 0} Z_i^*(s) = \int Z_i(t)dt = \Psi_i$

where,

$$N_4(0) = 1 + p_{01}\left(p_{12}^{(5)} + p_{13}^{(6)}\right) + p_{24}^{(7)}\left(p_{02} + p_{01}p_{12}^{(5)}\right) + p_{34}^{(9)}\left(p_{03} + p_{01}p_{13}^{(6)}\right) \quad (41)$$

PROFIT FUNCTION ANALYSIS

Two profit functions $P_1(t)$and $P_2(t)$ can easily be obtained for the system model under study with the help of characteristics obtained earlier. The expected total profits incurred during $(0, t)$ are:

$P_1(t) =$ Expected total revenue in (0, t)− Expected total expenditure in (0, t)

$$= K_0\mu_{up}(t) - K_1\mu_b(t) \quad (42)$$

Similarly,

$$P_2(t) = K_0\mu_{up}(t) - K_2V_0(t) \quad (43)$$

where,

K_0 is revenue per unit up time.

K_1 is the cost per unit time for which repair man is busy in repair of the failed unit.

K_2 is per unit repair cost.

The expected total profits per unit time, in steady state, is

$P_1 = \lim_{t\to\infty}[P_1(t)/t] = \lim_{s\to 0} s^2 P_1^*(s)$

$P_2 = \lim_{t\to\infty}[P_2(t)/t] = \lim_{s\to 0} s^2 P_2^*(s)$

So that,

$$P_1 = K_0A_0 - K_1B_0 \quad (44)$$

and

$$P_2 = K_0A_0 - K_2V_0 \quad (45)$$

PARTICULAR CASE

If the repair time distributions are taken as negative exponential i.e.

$G_i(t) = 1 - e^{-\beta_i t}$; where, $(i = 1,2,3)$

Then the changed transition probabilities and mean sojourn times are as follows:

$p_{10} = \frac{\beta_1}{(\alpha_2+\alpha_3+\theta+\beta_1)}$ $p_{10}^{(4)} = \frac{\theta}{(\alpha_2+\alpha_3+\theta+\beta_1)}$ $p_{12}^{(5)} = \frac{\alpha_2}{(\alpha_2+\alpha_3+\theta+\beta_1)}$

$p_{13}^{(6)} = \frac{\alpha_3}{(\alpha_2+\alpha_3+\theta+\beta_1)}$ $p_{20} = \frac{\beta_2}{(\alpha_1+\theta+\beta_2)}$ $p_{20}^{(8)} = \frac{\theta}{(\alpha_1+\theta+\beta_2)}$

$p_{24}^{(7)} = \frac{\alpha_1}{(\alpha_1+\theta+\beta_2)}$ $p_{30} = \frac{\beta_3}{(\alpha_1+\theta+\beta_3)}$ $p_{30}^{(10)} = \frac{\theta}{(\alpha_1+\theta+\beta_3)}$

$p_{34}^{(9)} = \frac{\alpha_1}{(\alpha_1+\theta+\beta_3)}$ $\Psi_1 = \frac{1}{(\alpha_2+\alpha_3+\theta+\beta_1)}$ $\Psi_2 = \frac{1}{(\alpha_1+\theta+\beta_2)}$

$\Psi_3 = \frac{1}{(\alpha_1+\theta+\beta_3)}$ $\Psi_4 = \Psi_5 = \Psi_6 = \frac{1}{\beta_1}$ $\Psi_7 = \Psi_8 = \frac{1}{\beta_2}$

$\Psi_9 = \Psi_{10} = \frac{1}{\beta_3}$

GRAPHICAL STUDY OF THE SYSTEM MODEL

For more concrete study of system behavior, we plot MTSF and Profit functions with respect to α_1(failure rate of Mixing machine) for different values of β_1(repair rate of mixing machine). **Fig. 2** shows the variations in MTSF in respect of $\alpha_1$for different values of β_1 as 0.10, 0.50 and 0.90 while the other parameters are fixed as $\alpha_2 = 0.03, \alpha_3 = 0.05, \beta_2 = 0.30, \beta_3 = 0.50, \theta = 0.20$. It is observed from the graph that MTSF decreases with the increase in the failure parameter α_1 and for higher values of β_1, the MTSF is higher i.e. the repair facility has a better understanding of failure phenomenon resulting in longer lifetime of the system.

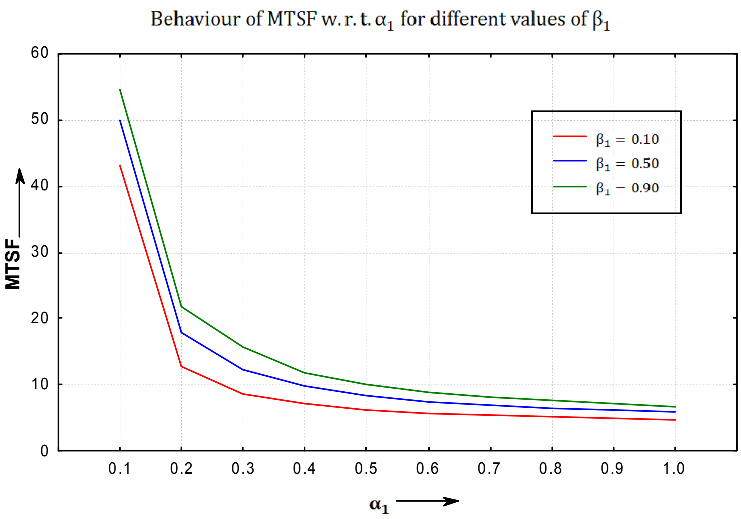

Fig.2

Fig. 3 represents the change in profit function P_1 and P_2 w.r.t. α_1 for different values of β_1 as 0.10, 0.50 and 0.90 while the other parameters are fixed as $\alpha_2 = 0.03, \alpha_3 = 0.05, \beta_2 = 0.30, \beta_3 = 0.50, \theta = 0.20 K_0 = 1000, K_1 = 300, K_2 = 250$. From the graph it is seen that both profit functions decrease with the increase in failure rate α_1 and increase with the increase in β_1. Thus the better understanding of failure phenomenon by the repairman results in better system performance.

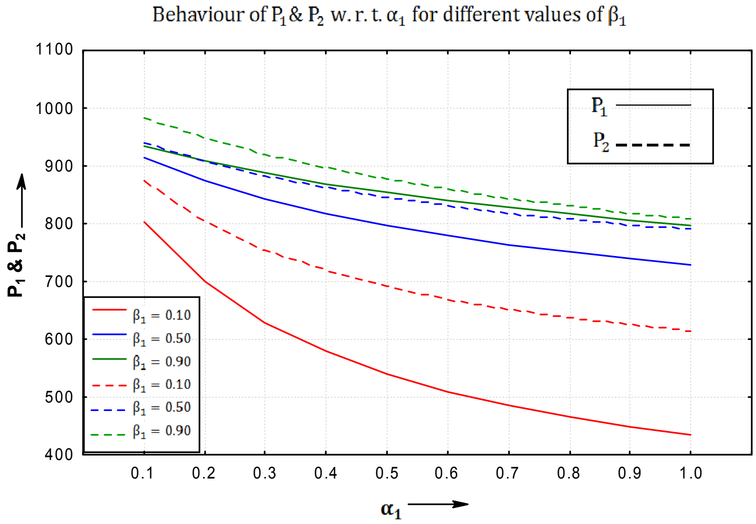

Fig.3

Concluding Remarks: A model of manufacturing plant of Mosquito coil in an industry for its stochastic analysis by personally visiting the Jyoti Laboratory limited industry situated in Bari Brahmana of Samba district of State Jammu and Kashmir is developed and analyzed with respect to various reliability characteristics. The graphical study of some of the reliability characteristics has also been carried out. Hence, it can be concluded that the expected life of the system can be increased by decreasing failure rate and increasing repair rate of the unit which in turn will improve the reliability and hence the effectiveness of the system.

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