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Reliability Analysis of Footwear Considering Mechanical and Electrical faults

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ABSTRACT - The purpose of present paper is to analyze the performance of a footwear machine using stochastic modeling of a single unit considering mechanical and electrical type of faults and removal by repair/replacement of different parts during operation of the machine. These faults are further divided into minor, major and neglected faults. On occurrence of minor faults, machine is working with partial efficiency while due to major faults, machine stopped working completely. A real data related to different failures is collected from Relaxo footwear industry located at Bahadurgarh (Haryana). Measures of system effectiveness such as MTSF and Reliability are derived by using exponential distribution, Semi-Markov process and Regenerative Point technique. . From the graphs obtained, we get cut-off points for different values/rates which will be helpful for the maintenance team of the Relaxo footwear industry to enhance the system effectiveness.

Keywords: Semi Markov Process, Regenerative Point Technique, Expected up time, system effectiveness.

I. INTRODUCTION

In the present aeon, Our feet are foundation of everyday lives. Every good foundation must have right support and bad shoes can throw the whole body out of alignment. The ankles, knees, hip joints and lower back are all affected by bad shoes. Relaxo Footwear Limited (RWL), a part of Relaxo Group which has major interest in Footwear production was incorporated in Sep 13, 1984 as a private limited company to market the products of group concerns such as hawai slippers light weight slippers, canvas shoes and PVC footwear the list is endless. In the present scenario of competitive market, improvement in performance of the machines with minimum operating cost is the main objective of each industry. In the present paper, real data relating to a footwear machine, installed in Relaxo Footwear Industry Limited, Bahadurgarh has been collected (personally by visiting from time to time) and a stochastic model is developed considering its various types of faults using Semi-Markov Process and Regenerative Point Technique. The footwear making machine is a complex system with various sub systems wherein different faults occur during operation. We have characterize two type of faults .i.e. electrical and mechanical. These faults are further categorised as minor electical and major electrical faults as well as minor mechanical and major mechanical faults on the basis of down time and cost which are repairable as well as non-repairable. It is observed that on occurrence of a minor fault, machine partially stopped and we get the product with reduced capacity, whereas in case of major fault, operation of the machine is completely stopped. There is a single serviceman who visits the machine immediately whenever needed. Serviceman observes and decides whether the fault is repairable or non-repairable. In case of repairable fault, the defective part is repaired whereas in case of non-repairable fault, the defective part of the machine is replaced. From the collected data various rates and probabilities are find out following Exponential Distributions. On the basis of that real data, by using Semi- Markov Process and Regenerative Point Technique, various measures of system effectiveness such as MTSF, Reliability, Expected up time, Expected down time and Busy Period of repairman are obtained. Finally, numerical calculations and graphs drawn on the basis thereof have been used for evaluation of performance of the machine which is useful for smooth and better functioning of the RWL.

So many Researchers and Scientists are trying to improve the performance of industries using various reliability techniques. Branson and Shah (1971) discussed a system with exponential failure and arbitrary repair distributions while adopting Semi-Markov Process [1]. Goel et al. (1986) obtained the reliability analysis of a system with preventive maintenance [2]. Kumar et al. (1989) analysed the reliability and availability behaviour of subsystems of paper industry by using probabilistic approach [3]. Gupta et al. (2005) worked on the system reliability and availability in butter oil processing plant by using Markov Process and R-K method [4]. Kumar and Bhatia (2011) discussed reliability and cost analysis of a one unit centrifuge system with single repairman and Inspection [5]. Modgil V and Sharma S.K. (2012) analyzed the performance modeling and availability analysis of sole lasting in shoe making industry [6]. Bhatia and Kumar (2013) studied Performance and Profit Evaluations of a Stochastic Model

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on Centrifuge System Working in Thermal Power Plant Considering Neglected Faults [7]. Sharma and Vishwakarma (2014) applied Markov Process in performance analysis of feeding system of sugar industry [8]. Renu and Bhatia (2017) dealt with reliability analysis for removing shortcomings using stochastic processes and applied for maintenance in industries [9]. A few of the Researchers have worked for real data of paper machine. Veena Rani and Pooja Bhatia discussed about Performance Evaluation of Stochastic Model of a Paper Machine Having Three Types of Faults [10]. Kalwar and Khan (2020) studied the increasing performance of footwear stitching line by installation of auto trim stitching machines [11].

For the purpose of performance evaluation, a stochastic model is developed by using Regenerative Point Technique and following measures of system effectiveness are obtained:

- Transition Probabilities
- Mean Sojourn Time
- Mean Time to System Failure (MTSF)
- Expected up time/Expected down time
- Busy Period of serviceman (Repair and Replacement time)
- Profit analysis

II. ASSUMPTIONS

- The system consists of a single unit,
- The system is as good as new after each repair and replacement.
- The Service man reaches the system in negligible time.
- A single Service man facility is provided to the system for repair and replacement of the components.
- Time distributions of various faults i.e. minor/major/neglected are Exponential distribution and other time distributions are general.
- A minor fault leads to partially stopped failure whereas major fault leads to complete failure.
- The system has two type of faults i.e. Electrical and Mechanical faults. And these are further bifurcated into minor/major/neglected.
- Each neglected faults is repaired during maintenance.

III. NOTATIONS:

O : Operative Unit.

$\lambda1,\lambda3$: Rate of minor electrical fault/ minor mechanical fault

$\lambda2,\lambda4$: Rate of major electrical fault/ major mechanical fault

$\lambda5$: Rate of neglected faults

g1(t)/G1(t) : pdf/cdf of repair rate of minor electrical faults w.r.t. time.

g2(t)/G2(t) : pdf/cdf of repair rate of minor mechanical faults w.r.t. time.

h1(t)/H1(t) : pdf/cdf of replacement rate of major electrical faults w. r. t. time.

h2(t)/H2(t) : pdf/cdf of replacement rate of major mechanical faults w. r. t. time.

k(t)/K(t) : pdf/cdf of rate of neglected faults w.r.t. time.

ⓒ/Ⓢ : Laplace convolution/ Laplace stieltjesconvolution.

*/** : Laplace transformation/ Laplace stieltjestransformation.

qij(t)/Qij(t) : pdf/cdf for the transition of the system from one regenerative state Si to anotherregenerative state Sj or to a failed state Sj.

IV. THE MODEL DESCRIPTION

Different stages of the system model are as follows:

State 0: Initial operative state.

State 1: Operative unit partially failed due to some minor electrical faults.

State 2: Unit completely failed due to some major electrical faults.

State 3: Unit partially failed due to some minor mechanical faults.

State 4: Unit completely due to some major mechanical faults.

State 5: Unit temporarily failed due to some neglected faults.

Here, state 0 is operative state with full capacity whereas 1,3 are partially failed states with reduced capacity, state 5 is temporarily failed and states 2 and 4 are failed states.

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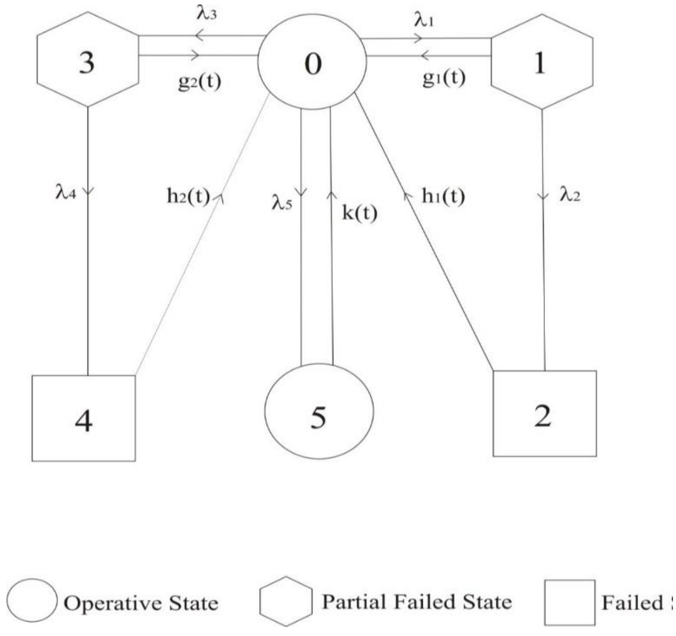

Fig. 1

V. RELIABILITY INDICATORS:

Transition Probabilities:

By simple probabilistic arguments, we can find transition probabilities given by:

It is simple to verify that

$p_{ij} = \lim_{s \to 0} Q_{ij}^{**}(s)$

where $Q_{ij}^{**}(s) = \int_0^\infty e^{-st} dQ_{ij}(t)dt$

$p_{01} = \frac{\lambda 1}{\lambda 1+\lambda 3+\lambda 5}$, $p_{03} = \frac{\lambda 3}{\lambda 1+\lambda 3+\lambda 5}$,

$p_{05} = \frac{\lambda 5}{\lambda 1+\lambda 3+\lambda 5}$, $p_{10} = g_1^*(\lambda_2)$,

$p_{20} = h_1(t)$ dt $p_{40} = h_2(t)$ dt,

$p_{50} = k(t)$ dt , $p_{12} = 1 - g_1^*(\lambda_2)$

□p□□□□□□□□□□□ $g_2^*(\lambda_4)$, $p_{30} = g_2^*(\lambda_4)$,

Mean Sojourn Time:

The unconditional mean time taken by the system to transit from any regenerative state Si into state Sj when time is counted from epoch of entrance is given by:

$m_{ij} = \int_0^\infty t dQ_{ij}(t)dt = - Q_{ij}^{*\prime}(0)$

Also, Mean Sojourn Time in state Si is given by:

$\mu_i = \int_0^\infty P(T > t)dt$

$\mu_o = \frac{1}{\lambda 1+\lambda 3+\lambda 5}$, $\mu_1 = \frac{\beta 1}{\lambda 2+\beta 1}$, $\mu_2 = \frac{1}{\gamma_1}$,

$\mu_3 = \frac{\beta 2}{\lambda 4+\beta 2}$, $\mu_4 = \frac{1}{\gamma_2}$, $\mu_5 = \frac{1}{\alpha}$,

Other Measures of System Effectiveness:

Using probabilistic arguments for regenerative processes, various recursive relations are obtained and are solved to find different measures of system effectiveness, which are as follows:

Mean time to system failure (MTSF) $(T_0) = \frac{N}{D}$

Where, $N = \mu_0 + p_{03}\mu_3 + p_{01}\mu_1 + p_{05}\mu_5$,

And $D = 1 - p_{01}p_{10} - p_{03}p_{30} - p_{05}p_{50}$

Expected up time of the system $(UT_0) = \frac{N_1}{D_1}$

Expected down time of the system $(DT_0) = \frac{N_2}{D_1}$

Busy period of service man (repair time) $(BR_0) = \frac{N_3}{D_1}$

Busy period of serviceman (replacement time) $(BRP_0) = \frac{N_4}{D_1}$

Where, $N_1 = \mu_0 + \mu_5 p_{05}$,

$N_2 = \mu_2 p_{12} p_{01}$,

$N_3 = p_{01}\mu_1 + p_{03}\mu_3$,

$N_4 = \mu_2 p_{01} p_{12} + \mu_4 p_{34} p_{03}$

and $D_1 = \mu_0 + \mu_1 p_{01} + \mu_3 p_{03} + \mu_5 p_{05} + \mu_2 p_{01} p_{12} + \mu_4 p_{03} p_{34}$

Profit Analysis:

The performance of the system in the form of profit (P_R) canbe figured as follows:

$P_R = C_0UT_0 + C_1DT_0 - C_2BR_0 - C_3BRP_0 - C$

Where, C_0 = Revenue per unit up time of the system

C_1 = Revenue per unit down time of the system

C_2 = Cost per unit time of repair

C_3 = Cost per unit time of replacement

C = Miscellaneous costs

Numerical Study and Graphical Analysis:

Giving some particular values to the parameters and considering

$K(t) = \alpha e^{-\alpha t}$, $g_1(t) = \beta_1 e^{-\beta_1 t}$,

$g_2(t) = \beta_2 e^{-\beta_2 t}$ $h_1(t) = \gamma_1 e^{-\gamma_1 t}$,

$h_2(t) = \gamma_2 e^{-\gamma_2 t}$

we get,

$p_{01} = \frac{\lambda 1}{\lambda 1+\lambda 3+\lambda 5}$, $p_{03} = \frac{\lambda 3}{\lambda 1+\lambda 3+\lambda 5}$, $p_{05} = \frac{\lambda_5}{\lambda 1+\lambda 3+\lambda 5}$,

$p_{01} + p_{03} + p_{05} = 1$, $p_{10} + p_{12} = 1$, $p_{30} + p_{34} = 1$,

$p_{20} = 1$, $p_{40} = 1$, $p_{50} = 1$,

$p_{12} = \frac{\lambda 2}{\lambda 2+\beta 1}$, $P_{34} = \frac{\lambda 4}{\lambda 4+\beta 2}$

For the above particular cases taking values from the collected data and some assumed values;

$\alpha = 3.53$, $\beta_1 = 0.53$, $\beta_2 = 1.21$, $\gamma_1 = 2.25$, $\gamma_2 = 0.53$

We obtained the following values for the measures of systemeffectiveness:

Mean Time to System Failure (MTSF) (T_0)

= 0.52633

Expected up time of the system (UT_0)

= 0.389616

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Expected down time of the system (DT_0)

= 0.146723

Busy period of serviceman (repair time) (BR_0)

= 0.30224

Busy period of serviceman (replacement time) (BRp_0)

= 0.155307

Using above numerical values, various graphs for MTSF and Profit of the system for different values of rate of minor faults, major faults and neglected faults (λ_1,λ_3,λ_5) and different costs(C_0 ,C) has been drawn.

The interpretation and conclusion from the graphs are as follows:

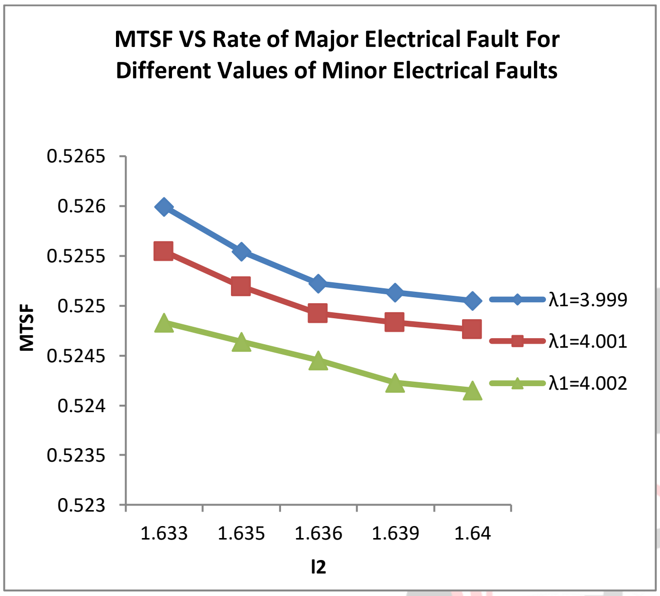

Fig.2

Figure 2 gives the graph between MTSF (T_0) and rate of major electrical faults (λ2) for different values of rate of minor electrical faults (λ1). The graph shows that the MTSF decreases with the increases in the values of rate of major electrical faults. It has lower values for higher values of rate of minor electrical faults.

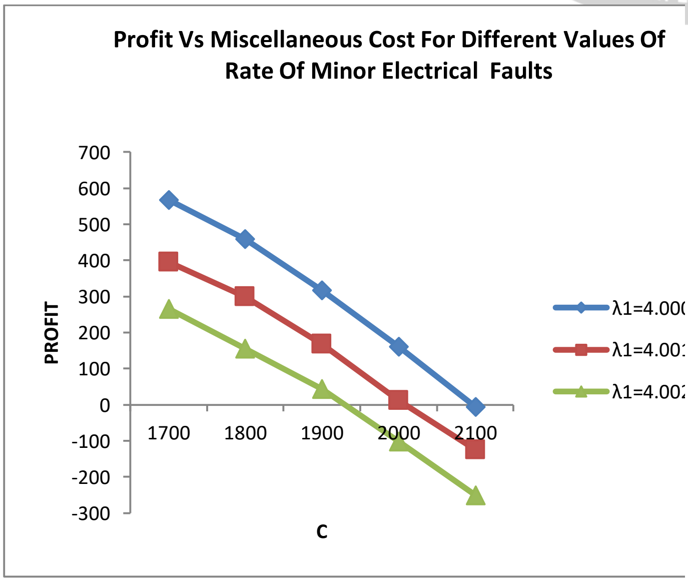

Fig.3

In the graph figure 3 shows the relation between profit and miscellaneous cost for different values of rate of minor electrical faults.

The conclusion of the graph as follows:

I. The profit decreases with increases the values of miscellaneous cost and it has lower values for higher values of rate of minor faults.

II. For λ_1 =4.000, the profit is negative or zero or positive according to C as greater than or equal or less than Rs.2094.73. Thus the machine will give profit for this when C is less than Rs.2094.73.

III. For λ_1 = 4.002, the profit is negative or zero or positive according to C as greater than or equal or less than Rs.1988.735. Thus the machine will give profit for this when C is less than Rs.1988.735.

IV. For λ_1 = 4.003, the profit is negative or zero or positive according to C as greater than or equal or less than Rs.1897.59. Thus the machine will give profit for this when C is less than 1897.59.

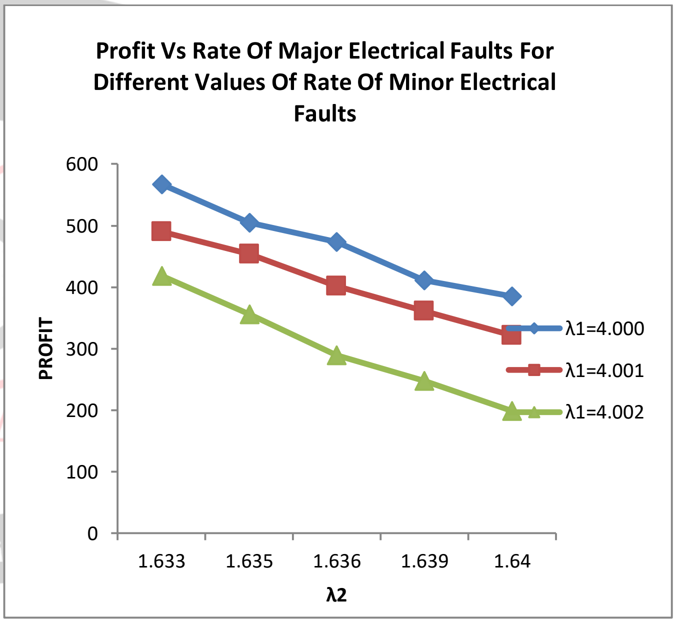

Fig.4

In graph at figure 4 gives the relation between profit and rate of major electrical faults for different values of rate of minor electrical faults. It explains that the profit decreases with increases the rate of major electrical faults and it has lower values for higher values of rate of minor electrical faults.

VI. CONCLUSION

From analysis of the graphs above, we conclude that mean time to system failure and the profit per unit time of the footwear machine decreases with the increase in the values of the rate of minor as well as major faults. Further, we obtained cut off points of profit for different values of rates of minor/major faults etc. We derived that, for particular value of rate of minor/major fault what should be the

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greater value or lower value of miscellaneous costs to get positive profit. On the basis of these values, various suggestions can be given to the management team of the footwear industry to the footwear makes profitable.

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