A Study on Comparative Analysis of Two Stochastic Models for Single Unit footwear Machine

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Article Info
Page Number: 5614-5626
Publication Issue:
Vol. 71 No. 4 (2022)

Article History
Article Received: 25 March 2022
Revised: 30 April 2022
Accepted: 15 June 2022
Publication: 19 August 2022

Abstract - Since footwear industry is playing an important role in the society and is also vital for overall industrial growth, it is necessary that the footwear industry may perform well. Therefore, the main concern of an industry is to maintain system performance measures such as reliability, excepted up time, busy period of repairmen etc. to achieve high profit and productivity of the system. Present paper deals with the analysis of a single unit footwear machine having electrical/mechanical faults. These faults are further bifurcated into minor, major and neglected faults. Here two stochastic models of footwear machine have been discussed for comparison thereof. In model-1, all neglected faults revolve to be major faults due to delay in maintenance whereas in model-2, neglected faults sorted out automatically under preventive maintenance. However, in both the models, minor faults are assumed as repairable and major faults are non-repairable. In both the models, various measures of system effectiveness such as MTSF, Reliability, Expected up time and busy period of serviceman have been obtained using Semi Markov Process and Regenerative Point Technique. Finally, the comparison of both models with respect to reliability and profit has been carried out using graphs and numerical calculations. Conclusions are drawn on the basis of graphs, which may be helpful for the maintenance team of the footwear machine.
Keywords: Comparative Analysis, Electrical Faults, Mechanical faults, Profit Analysis, Reliability Measures.

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 characterized two type of faults .i.e. electrical and mechanical. These faults are further categorized as minor electrical 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.

So many Researchers and Scientists are trying to improve the performance of industries using various reliability techniques. Kumar et al. (1989) analysed the reliability and availability behaviour of subsystems of paper industry by using probabilistic approach [1]. Gupta et al. (2005) worked on the system reliability and availability in butter oil processing plant by using Markov Process and R-K method [2]. Kumar and Bhatia (2011) discussed reliability and cost analysis of a one unit centrifuge system with single repairman and Inspection [3]. Modgil V and Sharma S.K. (2012) analyzed the performance modeling and availability analysis of sole lasting in shoe making industry [4]. Bhatia and Kumar (2013) studied Performance and Profit Evaluations of a Stochastic Model on Centrifuge System Working in Thermal Power Plant Considering Neglected Faults [5]. Sharma and Vishwakarma (2014) applied Markov Process in performance analysis of feeding system of sugar industry [6]. Renu and Bhatia (2017) dealt with reliability analysis for removing shortcomings using stochastic processes and applied for maintenance in industries [7]. 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 [8]. Kalwar and Khan (2020) studied the increasing performance of footwear stitching line by installation of auto trim stitching machines [9]. Ali F., Sarkar, M. R., Hossain (2020) identifying the causes of footwear rejection and devising better solution for the improvement of footwear quality[10]. Bhatia P. and Rani Veena, (2021) analysed a study on Comparative Analysis of two Stochastic Models for Single Unit Paper Machine Considering Repairable/ Non-Repairable Minor and Major Faults[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

In the present paper, on the basis of observation made for the practical situations, two models are considered for the system with various major/ minor/neglected faults. Minor faults are assumed to be repairable as well as major faults are considered non-repairable and require replacement only In model-I, After long time, some neglected faults become major electrical faults as well as major mechanical faults, but in model-II, Neglected faults are sorted out due to preventive maintenance. For each model, various measures of system effectiveness such as MTSF, Reliability, Availability with full capacity and reduced capacity and busy period of repairman have been obtained using Semi Markov Process and Regenerative Point Technique. Finally, the comparison of both models with respect to various measures and profit analysis has been carried out using numerical calculations and graphs.

ASSUMPTIONS:

- The system consists of a single unit,
- The system works with full efficiency 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 distribution of various faults i.e. minor/major/neglected are Exponential while other distributions are general.
- A minor fault leads to partial failure whereas major fault leads to complete failure.
- The system has two types of faults i.e. Electrical and Mechanical faults and these faults are further bifurcated into minor/major/neglected faults.

NOTATIONS:

O: Operative Unit.

λ_1,λ_3 : Rate of minor electrical fault/ minor mechanical fault

λ_2,λ_4 : Rate of major electrical fault/ major mechanical fault

λ_5 : Rate of neglected faults

$g_1(t)/G_1(t)$: pdf/cdf of repair rate of minor electrical faults w.r.t.time.

$g_2(t)/G_2(t)$: pdf/cdf of repair rate of minor mechanical faults w.r.t.time.

$h_1(t)/H_1(t)$: pdf/cdf of replacement rate of major electrical faults w. r. t. time.

$h_2(t)/H_2(t)$: pdf/cdf of replacement rate of major mechanical faults w. r. t. time.

□□□n(t)/N(t) : pdf/cdf of time to delay in maintenance of neglected faults w.r.t.time.

Ⓒ/□ : Laplace convolution/ Laplace stieltjes convolution.

*/** : Laplace transformation/Laplace stieltjes transformation.

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

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.

Model-I

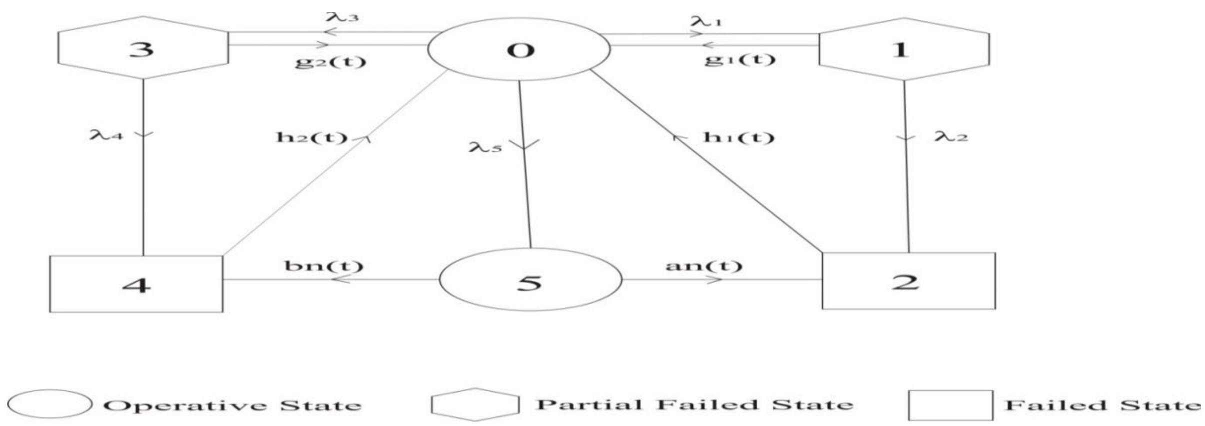

Fig.1

Model-II

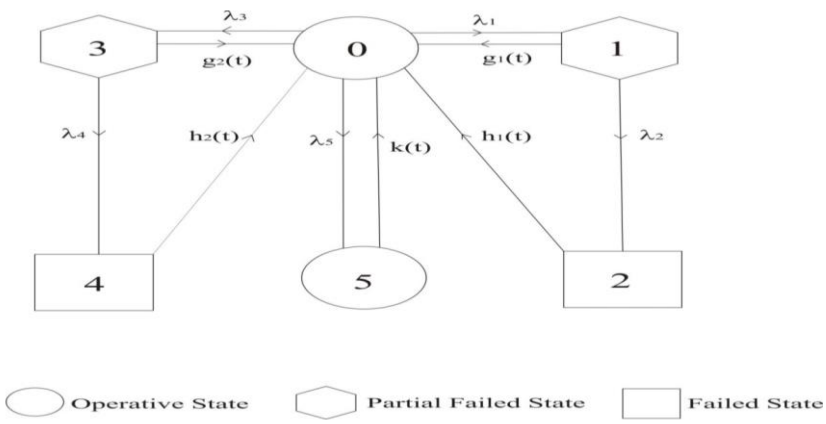

Fig.2

TRANSITION PROBABILITIES FOR BOTH THE MODELS

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□□□□□□□□□□ $g^*_2(\lambda_4)$, $p_{30} =$ $g^*_2(\lambda_4)$,

$p_{50} =$ $k(t)$ dt , p□□□□□b

$p_{52} = a$

Mean Sojourn Time:

The unconditional mean time taken by the system to transit from any regenerative state S_i into state S_j.

When time is counted from epoch of entrance is given by:

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

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

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

$\mu_0 = \frac{1}{\lambda 1+\lambda 3+\lambda 5}$, $\mu_1 = \frac{\beta 1}{\lambda 2+\beta 1}$,

$\mu_2 = \frac{1}{\gamma_1}$, $\mu_3 = \frac{\beta 2}{\lambda 4+\beta 2}$,

$\mu_4 = \frac{1}{\gamma_2}$, $\mu_5 = \frac{1}{\alpha_1}$,

Thus, we see that

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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:

FOR MODEL-I

Mean time to system failure (MTSF) $(T_1) = \frac{N}{D}$

Where $N = \mu_0+p_{03}\mu_3+p_{01}\mu_{1+}\ p_{05}\mu_5$,

and $D = 1- p_{01}p_{10} - p_{03}p_{30}$

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) $(BRP_0) = \frac{N_4}{D_1}$

FOR MODEL-II

Mean time to system failure (MTSF) $(T_0) = \frac{N}{D_2}$

Expected up time of the system $(UT_0) = \frac{N_5}{D_3}$

Expected down time of the system $(DT_0) = \frac{N_6}{D_3}$

Busy period of service man (repair time) $(BR_0) = \frac{N_7}{D_3}$

Busy period of serviceman (replacement time) $(BRP_0) = \frac{N_8}{D_3}$

Where $N = \mu_0+p_{03}\mu_3+p_{01}\mu_{1+}\ p_{05}\mu_5$,

$N_1 = \mu_0+\mu_5p_{05}$,

$N_2 = p_{01}\mu_1+p_{03}\mu_3$

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

$N_4 = \mu_2\,(p_{01}p_{12} + p_{05}p_{52}) + \mu_4(p_{34}p_{03} + p_{05}p_{54})$

$N_5 = \mu_0+\mu_5p_{05}$,

$N_6 = \mu_2 p_{12} p_{01}$,

$N_7 = p_{01}\mu_1 + p_{03}\mu_3$,

$N_8 = \mu_2 p_{01} p_{12} + \mu_4 p_{34} p_{03}$

$D_1 = \mu_0 + \mu_1 p_{01} + \mu_3 p_{03} + \mu_5 p_{05} + \mu_2(p_{01}p_{12} + p_{05}p_{52}) + \mu_4(p_{03}p_{34} + p_{05}p_{54})$

$D_2 = 1 - p_{01}p_{10} - p_{03}p_{30} - p_{05}p_{50}$

$D_3 = \mu_0 + \mu_1 p_{01} + \mu_3 p_{03} + \mu_5 p_{05} + \mu_2 p_{01} p_{12} + \mu_4 p_{03} p_{34}$

PERFORMANCE (PROFIT) ANALYSIS

The performance of the system for both the models in the form of profit can be figured as follows:

FOR MODEL-I

$P_1 = C_0 UT_1 + C_1 DT_1 - C_2 BR_1 - C_3 BRP_1 - C$

FOR MODEL-II

$P_2 = C_0 UT_2 + C_1 DT_2 - C_2 BR_2 - C_3 BRP_2 - C$

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 andconsidering

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

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

$h_2(t) = \gamma_2 e^{-\gamma_2 t}$ $n(t) = \alpha_1 e^{-\alpha_1 t}$, we get,

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

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

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

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

$p_{50} = 1$, $p_{12} = \frac{\lambda 2}{\lambda 2+\beta 1}$,

$P_{34} = \frac{\lambda 4}{\lambda 4+\beta 2}$ $p_{52} = a$,

□p□□□□□b

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

$\alpha = 3.53$, $\alpha_1 = 3.79$, $\beta_1 = 0.53$,

$\beta_2 = 1.21$, $\gamma_1 = 2.25$, $\gamma_2 = 0.53$

We obtained the following values for the measures of system effectiveness:

FOR MODEL - I

Mean Time to System Failure (MTSF) (T_1) = 0.597124

Expected up time of the system (UT_1) = 0.124374

Expected down time of the system (DT_1) = 0.207987

Busy period of serviceman (repair time) (BR_1) = 0.207987

Busy period of serviceman (replacement time) (BRp_1) = 0.557689

FOR MODEL - II

Mean Time to System Failure (MTSF) (T_2) = 0.52633

Expected up time of the system (UT_2) = 0.389616

Expected down time of the system (DT_2) = 0.146723

Busy period of serviceman (repair time) (BR_2) = 0.30224

Busy period of serviceman (replacement time) (BRp_2) = 0.155307

The interpretation and conclusion from the graphs are as follows:

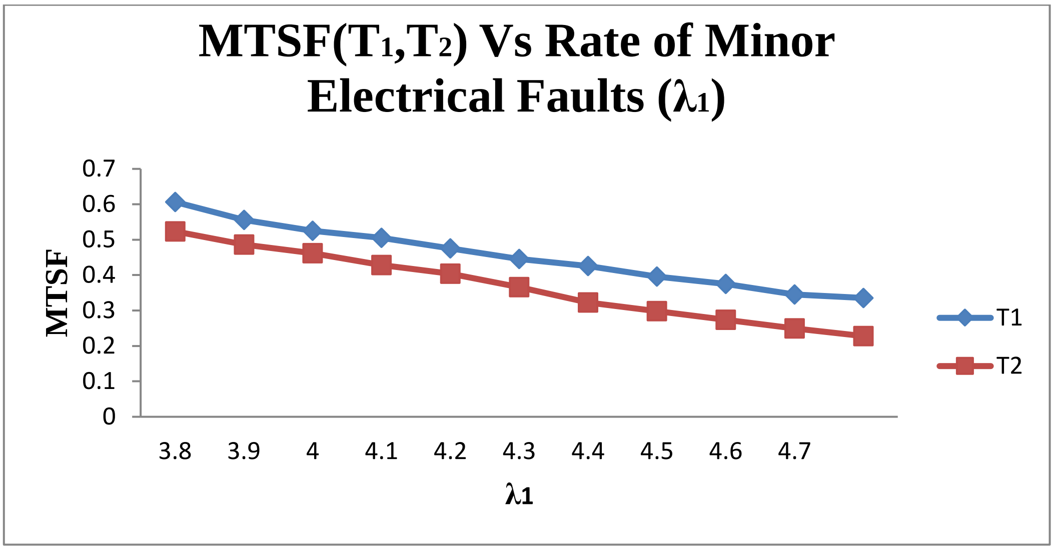

Fig.3

"Fig.3" shows the MTSF (T_1, T_2) of both the models for different rates of minor electrical faults. We observe that MTSF decreases with the increase in the rate of minor electrical faults and is lesser for Model-II comparative to Model-I.

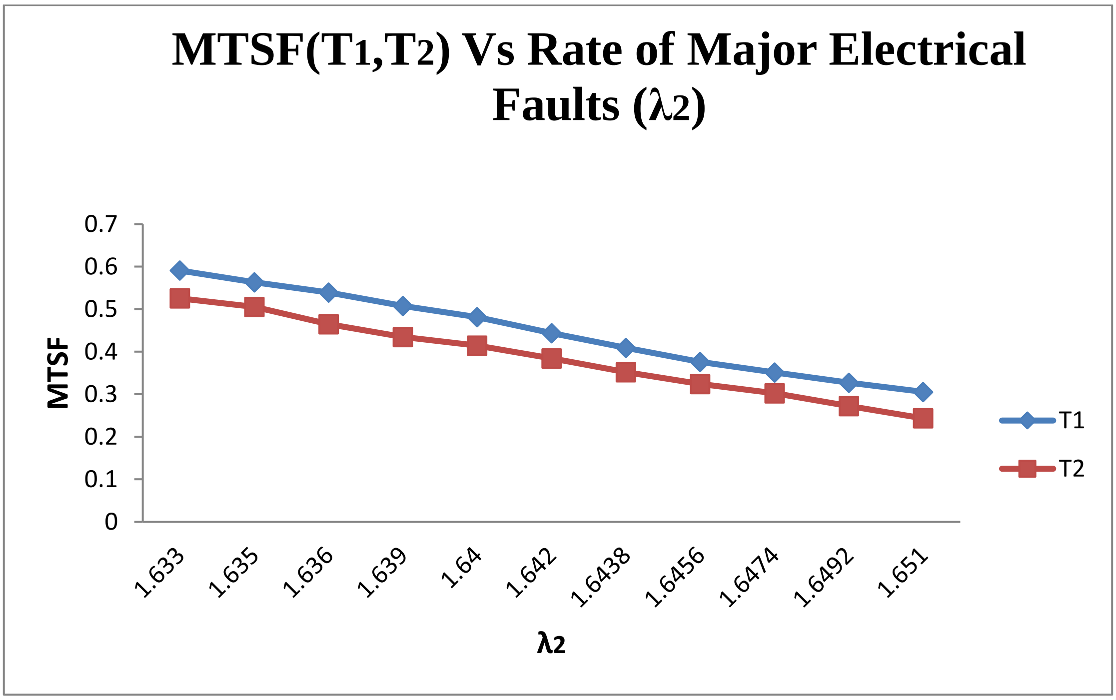

Fig.4

"Fig.4" depicts the MTSF (T_1, T_2) of both the models for different rates of major electrical faults. We observe that MTSF decreases with the increase in the rate of major electrical faults and is lesser for Model-II comparative to Model-I.

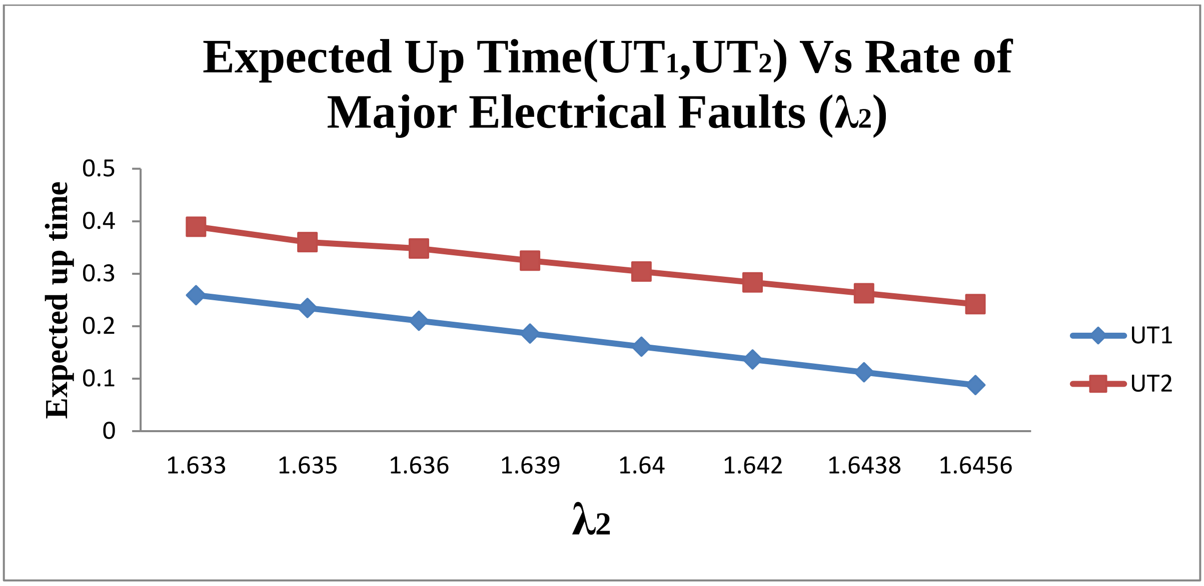

Fig.5

"Fig.5" presents the graph between expected up time (UT_1, UT_2) of both the models for different rates of major electrical faults. We see that expected up time decreases with the increase in the rate of major electrical faults and is lesser for Model-II comparative to Model-I.

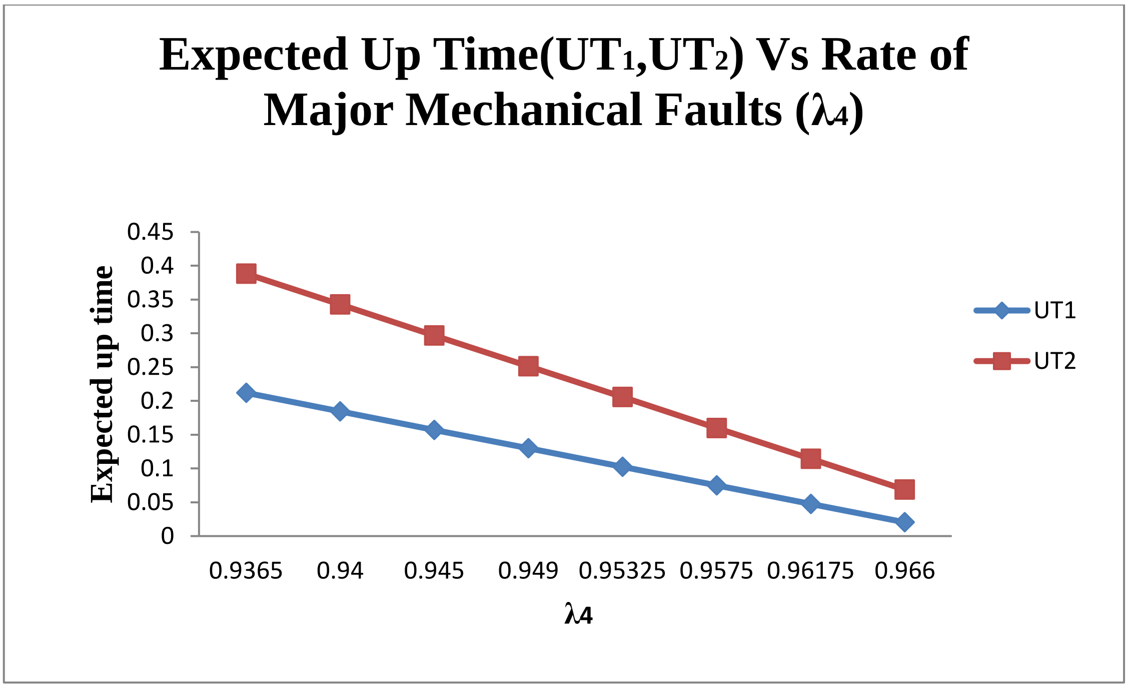

Fig.6

Fig.6" presents the graph between expected up time (UT_1, UT_2) of both the models for different rates of major mechanical faults. We see that expected up time decreases with the increase in the rate of major mechanical faults and is lesser for Model-II comparative to

Model-I. Also, the difference between expected up time of both the models decreases with the increase in the rate of Major mechanical faults.

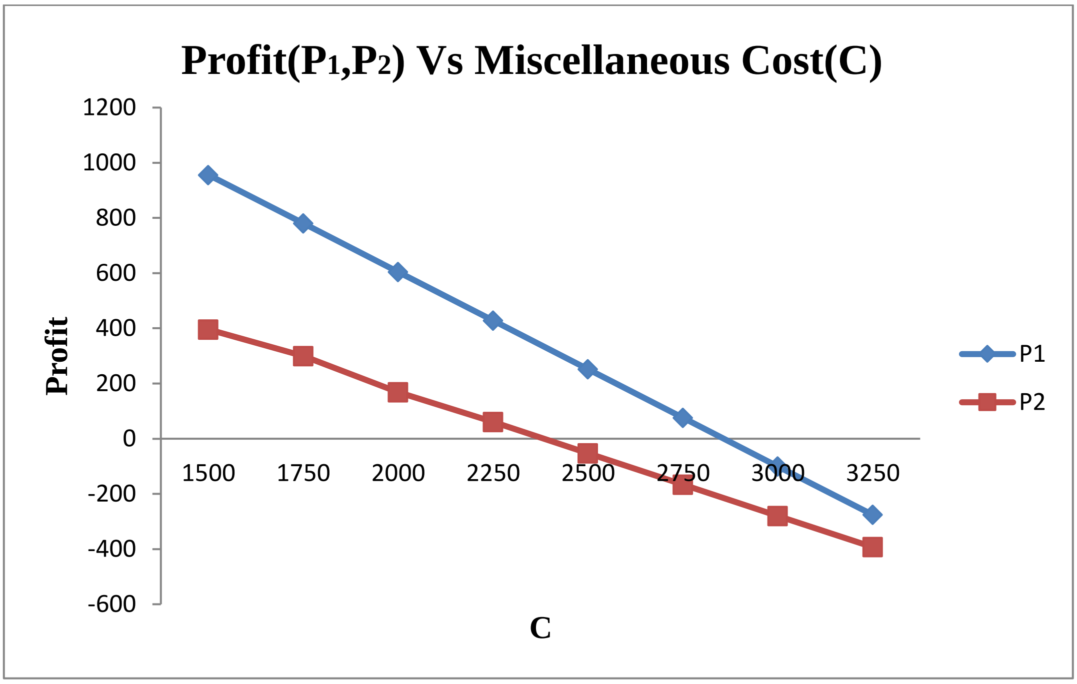

Fig.7

"Fig.7" is the graph between profits (P_1, P_2) for both the models and miscellaneous cost (C).

The conclusions of the graphs are as follows:

I. The profit decreases with the increase in the miscellaneous cost(C) and it has lower values for model-II in comparison of model-I.

II. For model-I, the profit is negative or zero or positive according as C is greater than or equal or less than Rs.2849.798. Thus, the machine will give profit for this when C is less than Rs.2849.798.

III. For model-II, the profit is negative or zero or positive according as C is greater than or equal or less than Rs.2447.75. Thus, the machine will give profit for this when C is less than Rs.2447.75.

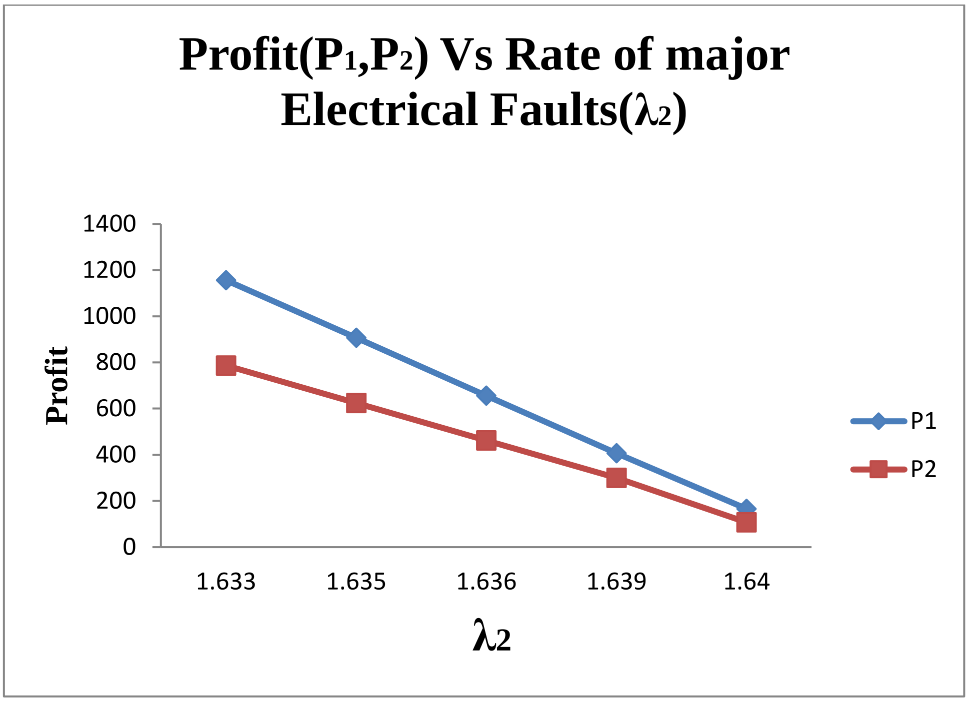

Fig.8

In graph at "Fig.8" relation has shown between profits (P_1 and P_2) for both the models for different values of rates of major faults (λ_2). It reveals that the profit decreases with the increase in the value of rate of major electrical faults in both the models and profit for Model-II is lesser in comparison of Model-I, also it is shown that difference is lower for higher values of rates of major electrical faults.

CONCLUSION

From the analysis of the graph above, it can be concluded that the expected up time and profit per unit time of a footwear machine decreases with increasing values of the rate of minor and major faults for both models. Moreover, the expected up time is higher in the case of Model-II than in the case of Model-I for less time. In case of Model-I considering all neglected faults due to delay in maintenance becomes major fault whereas in case of Model-II considering all neglected faults resolved by preventive maintenance. But for longer duration, Model-II is more reliable than Model-I. We have also obtained cut-off points of profit for different values of revenue for both the models expected up time and miscellaneous costs. We have derived what, for the particular model, must be the greater value of revenue over time or the lesser value of miscellaneous costs, in order to obtain a positive profit. Based on the above comparison, various suggestions can be given to the management team of the footwear industry to make the footwear machine profitable by using the appropriate model.

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