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Profitability Evaluation of Loomtex Textile Units Under Varying Fault Conditions

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Abstract

This study examines the reliability and availability of a Raschel machine used at **Shiv Shakti Loomtex Pvt. Ltd., Panipat**, operated by a master technician. The machine faults are classified into three categories—**minor, major, and software faults**—based on the time and cost required for repair or replacement. While minor and software faults result in temporary downtime, major faults lead to complete machine failure.When a failure occurs, the master technician first assesses the fault's reparability before performing corrective actions. In cases involving software faults, a computer expert is called to resolve the issue. Using **regenerative point techniques**, various measures of system effectiveness, such as reliability and availability, are calculated.Graphical analyses are also conducted to evaluate the machine's performance, offering insights into its reliability, downtime behavior, and associated maintenance costs. The findings provide practical recommendations for improving the **reliability** and **cost-efficiency** of warping machines in textile operations.

Keywords: *Raschel Machine, MTSF, Expected Uptime, Markov Process, Regenerative Point Techniques*

Introduction

Numerous researchers have conducted extensive analytical studies in the field of Reliability Modelling, focusing on a wide range of systems affected by diverse types of faults. Researchers like Quataert, J. H. (1985)[1],Bartko, J. J., & Carpenter, W. T. (1976)[2], Roberts, P., & Priest, H. (2006)[3], Kumar, R., & Bhatia, P. (2013)[4], Choudhary, A., Goyal, D., Shimi, S. L., & Akula, A. (2019)[5], Orrù, P. F., Zoccheddu, A., Sassu, L., Mattia, C., Cozza, R., & Arena, S. (2020)[6], Kaya, D., Çanka Kılıç, F., & Öztürk, H. H. (2021)[7], Sunal, C. E., Dyo, V., & Velisavljevic, V. (2022)[8], Li, H., & Zhang, Y. (2023)[9], Bhatia, P. (2024)[10] , Sakran, H. K., Abdul Aziz, M. S., & Khor, C. Y. (2024)[11] explain about the working, functions, reliability modelling.

The tremendous progress and development in textile technology and machinery have led to the development of the warp-knitted fabric industry to provide everything new and distinctive to the consumer. The warp-knitted fabric industry has developed greatly, especially in recent years, to the point that it has come to compete with woven fabrics on a large scale and in many fields. Knitted fabrics are considered one of the most common fabrics used in clothing production processes that are widely used in various fields of fashion and which cover parts of the human body, such as socks, hats, gloves, underwear, and outer clothing. Warp knitting is the most flexible and versatile textile production system. It can be produced with elastic, elastic compositions, or non-elastic compositions, and it can be produced with open or closed structures, it can also be produced in flat or flat form Tubular or multi-layered, warp knitting fabrics can also be produced with widths exceeding (6) six meters. Warp knitting machines are divided into tricot machines and Raschel machines. Among the types of fabrics that are produced on Raschel machines are lace fabrics. Lace is a type of fabric produced on warp knitting machines. A thin, mesh-like fabric that textile producers can manufacture using a wide range of techniques. We utilize the raschel machine to make blankets. The blanket is a soft-textured textile product made primarily of wool or other comparable fibres that can be used as a winter covering or as an adornment. Blankets are characterized as woven or knitted based on their manufacturing technologies. Blankets are made from various basic materials depending on their intended purpose. While wool is the most common fabric used in blankets, acrylic, polyester, and cotton fibres are also popular because wool fibre is expensive and difficult to maintain. Knitted blankets can be made using warp and/or weft knitting processes.

Assumptions

- Model based on initial analysis.
- Faults in the system are immediately apparent or become known without the need for additional detection measures.
- After every maintenance or replacement, the system is restored to its original condition.
- A master technician is always available to service in the Raschel machine in loomtax.
- The time until a failure occurs follows an exponential distribution and the time for other processes follows a general distribution.
- A related software fault cured by computer operator hired from outside.

Notations

O	operative unit
λ	constant failure rate of operative unit
$\lambda_{11}/\lambda_{12}/\lambda_{13}$	Failure rate due to occurrence of software, minor and major faults
a/b	Probability that a fault is repairable or non-repairable
$i(t)/I(t)$	$p.d.f./c.d.f.$ of time of inspection of the unit
$h_1(t)/H_1(t)$	$p.d.f./c.d.f.$ of time to replacement of unit

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$k_1(t)/K_1(t)$ $p.d.f./c.d.f.$ of time of maintenance of unit

$g_1(t)/G_1(t)$ $p.d.f./c.d.f.$ of time of repair of unit

$g_2(t)/G_2(t)$ $p.d.f./c.d.f.$ of time of repair of unit

$u_1(t)/U_1(t)$ $p.d.f./c.d.f.$ of time of update of unit

$F_i/F_{rp}/F_m/F_r/F_u$ Failed unit under inspection/replacement/maintenance/repair/update

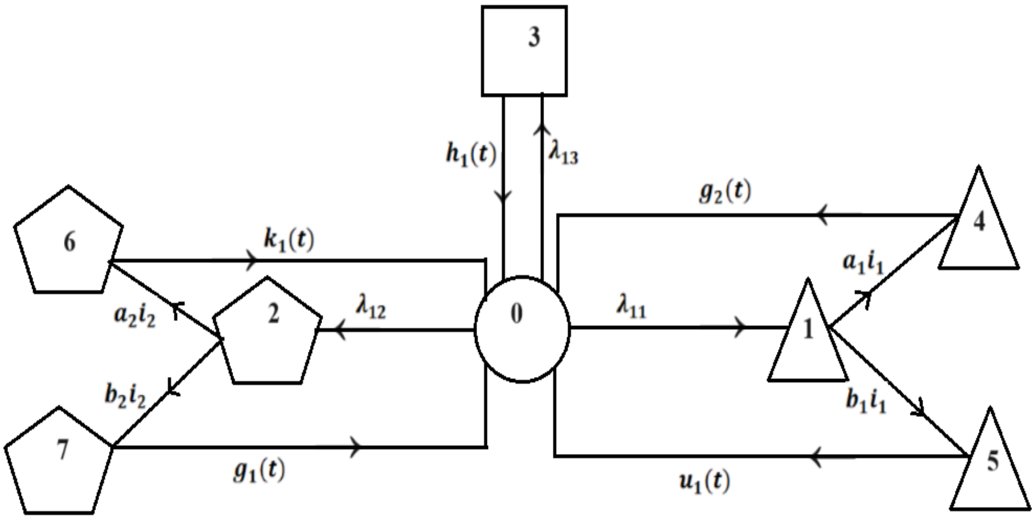

Figure 1 Transition diagram

Model Description

Different stages of the loomtex models according to Semi Markov process and Regenerative Point Technique are as follows:

Stage 0: Initial Operative stage.

Stage 1: Machine works but some software faults like chip update etc. and work properly after update and repair.

Stage 2: Machine is partially working due to some minor fault like vibration, wire burnt etc. and work properly after repair and maintenance.

Stage 3: Machine is not working due to major fault like motor burnt, ring damage etc. after replacement it works properly.

Stage 4: Machine works imperfectly, after repair it work properly.

Stage 5: Machine works imperfectly, after update it works properly.

Stage 6: Machine work imperfectly, after maintenance it work properly.

Stage 7: Machine works imperfectly, after repair it work properly.

Transition Probabilities and mean sojourn Times:

The transition probability of the raschel machine in loomtax

$p_{01} = \frac{\lambda_{11}}{\lambda_{11}+\lambda_{12}+\lambda_{13}}$, $p_{02} = \frac{\lambda_{12}}{\lambda_{11}+\lambda_{12}+\lambda_{13}}$, $p_{03} = \frac{\lambda_{13}}{\lambda_{11}+\lambda_{12}+\lambda_{13}}$,

$p_{14} = a_1^* i_1^*(0)$, $p_{15} = b_1^* i_1^*(0)$, $p_{26} = a_2^* i_2^*(0)$, $p_{27} = b_2^* i_2^*(0)$, $p_{30} = h_1^*(0)$,

$p_{40} = g_2^*(0)$, $p_{50} = u_1^*(0)$, $p_{60} = k_1^*(0)$, $p_{70} = g_1^*(0)$,

$$p_{01} + p_{02} + p_{03} = p_{14} + p_{15} = p_{26} + p_{27} = p_{30} = p_{40} = p_{50} = p_{60} = p_{70} = 1$$

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

$$m_{ij} = \int_0^\infty t\, dQ_{ij}(t) = -q_{ij}^{*'}(0)$$

Then,

$m_{01} + m_{02} + m_{03} = \mu_0$, $m_{14} + m_{15} = \mu_1$, $m_{26} + m_{27} = \mu_2$, $m_{30} = \mu_7$, $m_{40} = \mu_3$, $m_{50} = \mu_4$, $m_{60} = \mu_5$, $m_{70} = \mu_6$

The mean sojourn time (μ_1) in the regenerative state i are obtained as:

$\mu_0 = \frac{1}{\lambda_{11}+\lambda_{12}+\lambda_{13}}$, $\mu_1 = -i_1^{*'}(0)$, $\mu_2 = -i_2^{*'}(0)$, $\mu_3 = -g_2^{*'}(0)$, $\mu_4 = -u_1^{*'}(0)$, $\mu_5 = -k_1^{*'}$, $\mu_6 = -g_1^{*'}(0)$, $\mu_7 = -h_1^{*'}(0)$

Other Measure of System Effectiveness:

Using probabilistic arguments for regenerative processes, various recursive relations are solved to drive important measures of the system effectiveness that are given below:

Mean Time to System Failure:

$\phi_0 = Q_{01}Ⓢ\,\phi_1 + Q_{03}+Q_{02}Ⓢ\,\phi_2$

$\phi_1 = Q_{15}Ⓢ\,\phi_5 + Q_{14}Ⓢ\,\phi_4$

$\phi_2 = Q_{26}Ⓢ\,\phi_6 + Q_{27}Ⓢ\,\phi_7$

$\phi_4 = Q_{40}Ⓢ\,\phi_0$

$\phi_5 = Q_{50}Ⓢ\,\phi_0$

$\phi_6 = Q_{60}Ⓢ\,\phi_0$

$\phi_7 = Q_{70}Ⓢ\,\phi_0$

$(T_0) = \mu_0 + p_{01}[\mu_1 + \mu_4 p_{15} + \mu_3 p_{14}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}]/1 - p_{01}p_{15}p_{50} - p_{02}p_{26}p_{60} - p_{02}p_{27}p_{70} - p_{01}p_{14}p_{40}.$

Expected Up-Time of the System:

$UT_0 = q_{01}© UT_1 + M_0 + q_{02}© UT_2 + q_{03}© UT_3$

$UT_1 = q_{15}© UT_5 + q_{14}© UT_4$

$UT_2 = q_{26}© UT_6 + q_{27}© UT_7$

$UT_3 = q_{30}© UT_0$

$UT_4 = q_{40}© UT_0$

$UT_5 = q_{50}© UT_0$

$UT_6 = q_{60}© UT_0$

$UT_7 = q_{70}© UT_0$

$(N_1) = [\mu_0]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

Expected Down-Time of the System:

$DT_0 = q_{01}© DT_1 + q_{02}© DT_2 + q_{03}© DT_3$

$DT_1 = q_{15}© DT_5 + q_{14}© DT_4$

$DT_2 = q_{26} © DT_6 + q_{27} © DT_7$

$DT_3 = q_{30} © DT_0 + M_3$

$DT_4 = q_{40} © DT_0$

$DT_5 = q_{50} © DT_0$

$DT_6 = q_{60} © DT_0$

$DT_7 = q_{70} © DT_0$

$(DT_0) = [\mu_1 p_{01} + \mu_2 p_{02}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

Busy Period of Technician (Inspection Time Only):

$BI_0 = q_{01} © BI_1 + q_{02} © BI_2 + q_{03} © BI_3$

$BI_1 = M_1 + q_{15} © BI_5 + q_{14} © BI_4$

$BI_2 = M_2 + q_{26} © BI_6 + q_{27} © BI_7$

$BI_3 = q_{30} © BI_0$

$BI_4 = q_{40} © BI_0$

$BI_5 = q_{50} © BI_0$

$BI_6 = q_{60} © BI_0$

$BI_7 = q_{70} © BI_0$

$\boldsymbol{B}_1 = [\mu_3 p_{01} + \mu_4 p_{02}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

Busy Period of Technician (Maintenance Time Only):

$BM_0 = q_{01} © BM_1 + q_{02} © BM_2 + q_{03} © BM_3$

$BM_1 = q_{15} © BM_5 + q_{14} © BM_4$

$BM_2 = q_{26} © BM_6 + q_{27} © BM_7$

$BM_3 = q_{30} © BM_0$

$BM_4 = q_{40} © BM_0$

$BM_5 = q_{50} © BM_0$

$BM_6 = q_{60} © BM_0 + M_6$

$BM_7 = q_{70}© BM_0$

$\boldsymbol{B}_m = [\mu_6 p_{02} p_{26}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

Busy Period of Technician (Replacement Time Only):

$BP_0 = q_{01}© BP_1 + q_{02}© BP_2 + q_{03}© BP_3$

$BP_1 = q_{15}© BP_5 + q_{14}© BP_4$

$BP_2 = q_{26}© BP_6 + q_{27}© BP_7$

$BP_3 = q_{30}© BP_0 + M_3$

$BP_4 = q_{40}© BP_0$

$BP_5 = q_{50}© BP_0$

$BP_6 = q_{60}© BP_0$

$BP_7 = q_{70}© BP_0$

$\boldsymbol{B}_{rp} = [\mu_5 p_{03}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

Busy Period of Technician (Update Time Only):

$BU_0 = q_{01}© BU_1 + q_{02}© BU_2 + q_{03}© BU_3$

$BU_1 = q_{15}© BU_5 + q_{14}© BU_4$

$BU_2 = q_{26}© BU_6 + q_{27}© BU_7$

$BU_3 = q_{30}© BU_0$

$BU_4 = q_{40}© BU_0$

$BU_5 = q_{50}© BU_0 + M_5$

$BU_6 = q_{60}© BU_0$

$BU_7 = q_{70}© BU_0$

$\boldsymbol{B}_u = [\mu_7 p_{01} p_{15}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

Busy Period of Technician (Repair Time Only):

$BR_0 = q_{01}© BR_1 + q_{02}© BR_2 + q_{03}© BR_3$

$BR_1 = q_{15}© BR_5 + q_{14}© BR_4$

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$BR_2 = q_{26}© BR_6 + q_{27}© BR_7$

$BR_3 = q_{30}© BR_0$

$BR_4 = q_{40}© BR_0 + M_4$

$BR_5 = q_{50}© BR_0$

$BR_6 = q_{60}© BR_0$

$BR_7 = q_{70}© BR_0 + M_7$

$$\boldsymbol{B}_r = [\mu_1 p_{01}p_{14} + \mu_2 p_{02}p_{27}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$$

Profit Analysis:

The expected profit of the system is,

P=$C_0A_0 + C_1B_1 + C_2B_4 - C_3B_m - C_4B_{rp} - C_5B_r - C$

where

C_0 = revenue per unit uptime of the system

C_1 = revenue per unit downtime of the system

C_2 = cost per unit inspection of the failed unit

C_3 = cost per unit maintenance of the failed unit

C_4 = cost per unit replacement of the failed unit

C_5 = cost per unit repair of the system

C = cost of installation of the unit and miscellaneous cost

Particular Cases and Graphical Analysis:

The following particular cases are considered;

$k_1(t) = \alpha_1 e^{-\alpha_1(t)}$, $k_2(t) = \alpha_2 e^{-\alpha_2(t)}$, $h_1(t) = \gamma_1 e^{-\beta_1(t)}$,

$r_1(t) = \gamma_1 e^{-\gamma_1(t)}$, $i_1(t) = \delta_1 e^{-\delta_1(t)}$, $i_2(t) = \delta_2 e^{-\delta_2(t)}$

λ_{11}= 0.28, λ_{12}= 0.036, λ_{13}= 0.018, α_1= 0.0870, α_2= 0.0743, β_1= 1.123, γ_1= 0.027, a_1= 0.674, b_1= 0.326, a_2= 0.437, b_2= 0.563

Mean Time to system Failure = 11.6119

Expected up-time of the system = 0.1548

Expected Down-Time of the system = 0.3042

Busy Period of Technician (Inspection Time Only) = 0.2707

Busy Period of Technician (Maintenance Time Only) = 0.0564

Busy Period of Technician (Reset Time Only) = 0.2787

Busy Period of Technician (Replacement Time Only) = 0.3465

Graphical Analysis and Conclusion: -

The graph in fig. 2 illustrates the relationship between MTSF(T_0) and the rate of software faults(λ_{12}) across various rates of major faults(λ_{13}). It shows that downtime increases with an increase in the rate of minor faults and exhibits higher values at greater rates of major faults.

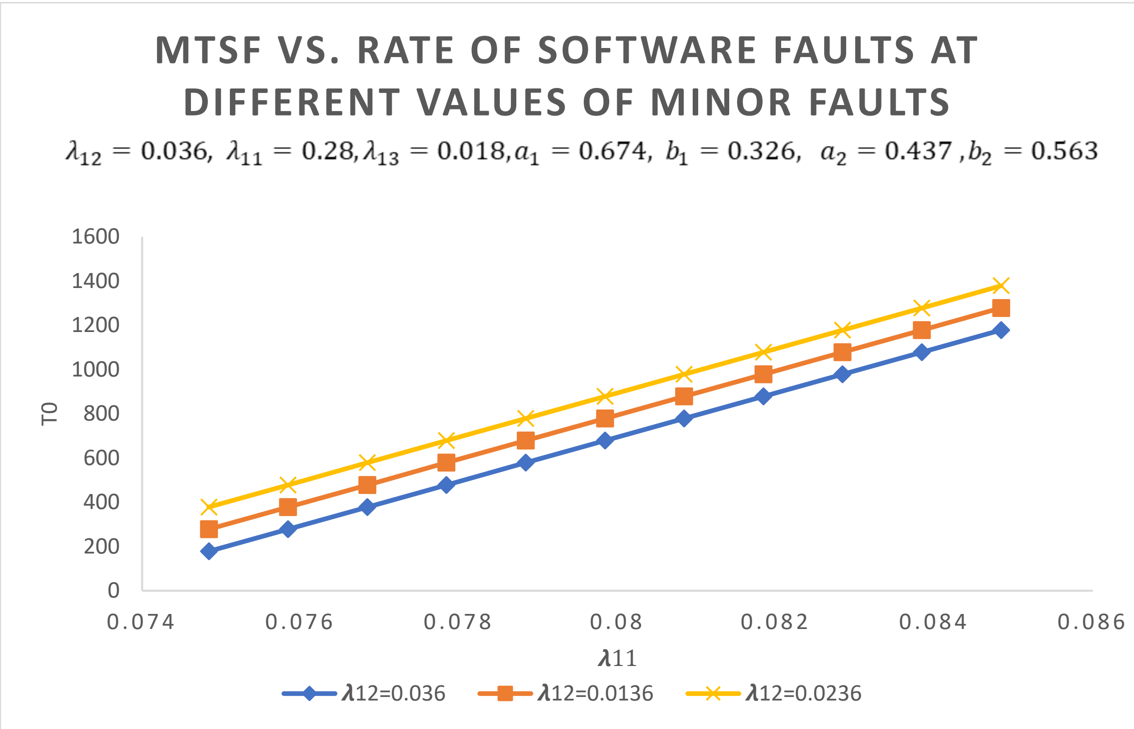

Figure 2

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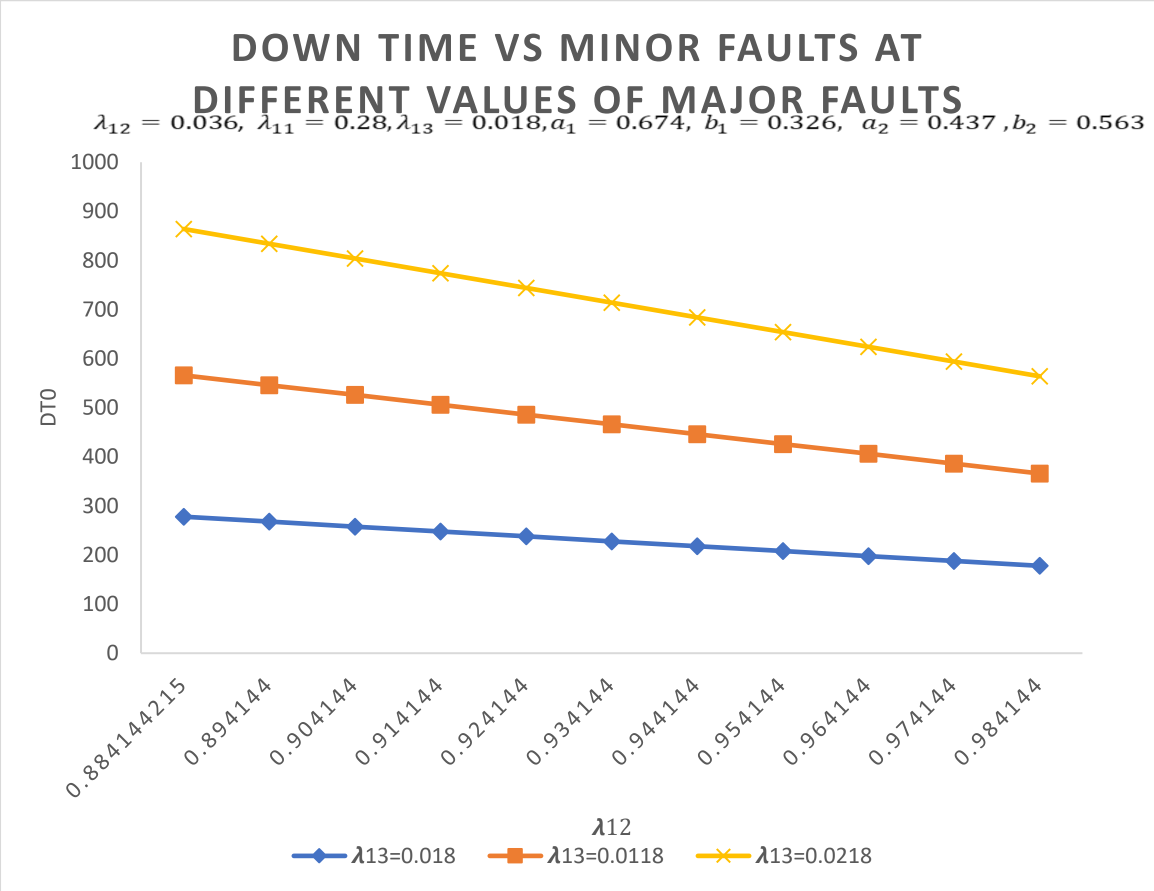

Figure 3

Fig. 3 presents a graph illustrating the relationship between Down Time(T_0) and the rate of occurrence of minor faults(λ_{12}), across various rates of occurrence of major faults(λ_{13}). The graph indicates that the down time decreases as the rates of occurrence of major and software faults increase.

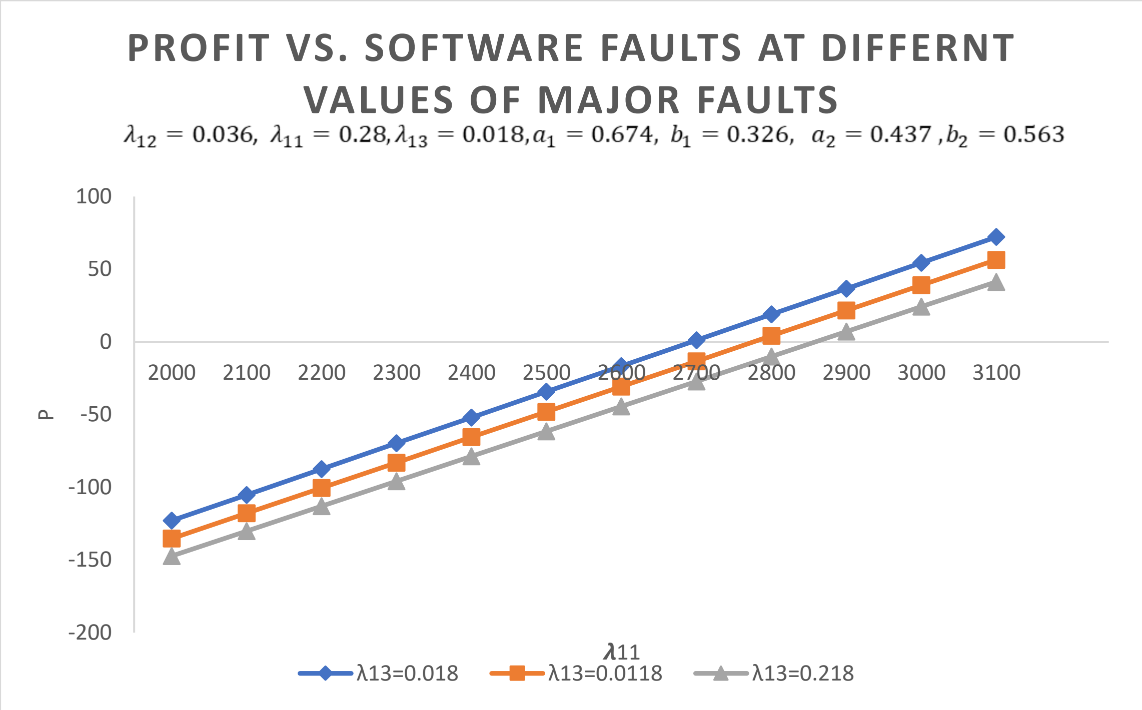

Figure 4

The graph in fig.4 shows the relation between profit (P) and rate of software fault (λ_{11}) rate at different value of major faults rates. It shows that some profit can be still obtained even when minor and software faults occur. Tie of master technician is also increases with increase of rate of minor and major faults.

The graph in fig.5 shows the relation between profit (P) and rate of major fault (λ_{12}) rate at different value of minor faults rates. It shows that some profit can be still obtained even when software faults occur. Tie of master technician is also increases with increase of rate of minor and major faults.

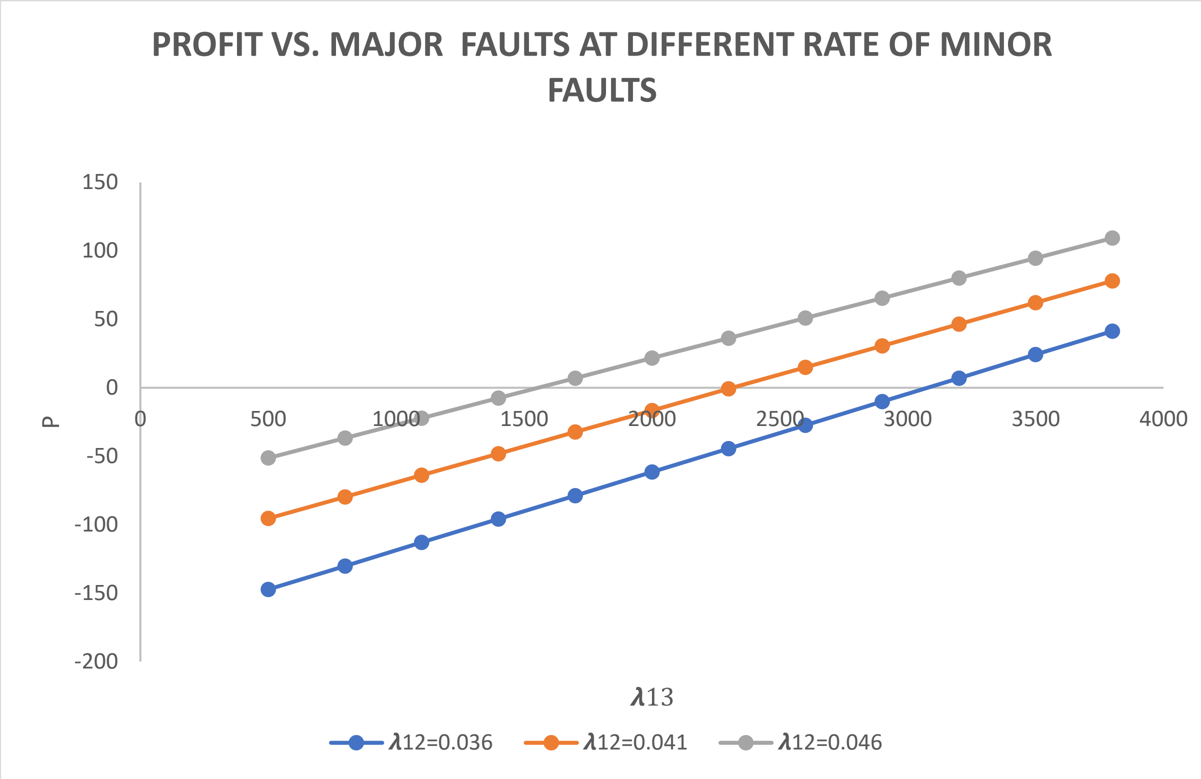

Figure 5

i. For $\lambda_{12} = 0.036$, the profit is $C_1 \leq or \geq Rs.1700$. Thus the machine give profit.
ii. For $\lambda_{12} = 0.041$, the profit is $C_2 \leq or \geq Rs.2300$. Thus the machine give profit.
iii. For $\lambda_{12} = 0.046$, the profit is $C_3 \leq or \geq Rs.3200$. Thus the machine give profit.

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