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Profit analysis of one-unit loomtex system with three types of faults with A master technician and A computer operator

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Abstract
This paper investigates the reliability and availability of a Raschel machine used at Shiv Shakti Loomtex Pvt ltd, Panipat operated by a master technician. Machine faults are categorized as minor, major and software faults based on the associated repair or replacement time and costs. Minor faults and software lead to system downtime, whereas major faults cause complete machine failure. Following a failure, a technician evaluates the reparability of the faults before taking corrective action and in case of software faults an expert of computer will come resolve the solution. Using regenerative point techniques, various metrics of system effectiveness are derived. Graphical analyses are employed to evaluate system performance, providing insights into its reliability and associated costs. This study offers valuable recommendations for optimizing the reliability and cost-efficiency of warping machines.

Keywords: Raschel Machine, MTSF, Expected uptime, Markov process and 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 warp-knitted fabric business has emerged as a result of the remarkable advancements in textile technology and machinery, which aim to serve consumers with unique and innovative products. The warp-knitted fabric sector has grown rapidly in the last several years, making it a formidable competitor to woven materials in many markets. Fabrics that are knitted are among the most widespread in the apparel industry. Knitted items cover the human body in a variety of ways, including socks, hats, gloves, undergarments, and outerwear. Of all the methods used to make textiles, warp knitting is the most adaptable and multipurpose. Produced in either flat or non-flat form, it can have open or closed structures, and its composition can be elastic, non-elastic, or a combination of the two. Additionally, warp knitting fabrics that are tubular or multi-layered can be manufactured with widths that surpass six meters. Tricot and Raschel machines are the two main categories of warp knitting machines. Lace fabrics are one kind of fabric that may be made with a Raschel machine. Warp knitting machines are used to create lace, a fabric type. A versatile textile fabric that may be made using a variety of techniques; it is thin and mesh-like. 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 operational unit failure rate is unchanged
$\lambda_{11}/\lambda_{12}/\lambda_{13}$ Rate of failure as a result of software, minor & severe error
a/b The likelihood that a defect can be fixed or cannot be fixed
$i(t)/I(t)$ $p.d.f./c.d.f.$ Around the time of the unit's examination
$h_1(t)/H_1(t)$ $p.d.f./c.d.f.$ when the device will need to be replaced
$k_1(t)/K_1(t)$ $p.d.f./c.d.f.$ amount of time spent on unit maintenance
$g_1(t)/G_1(t)$ $p.d.f./c.d.f.$ 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

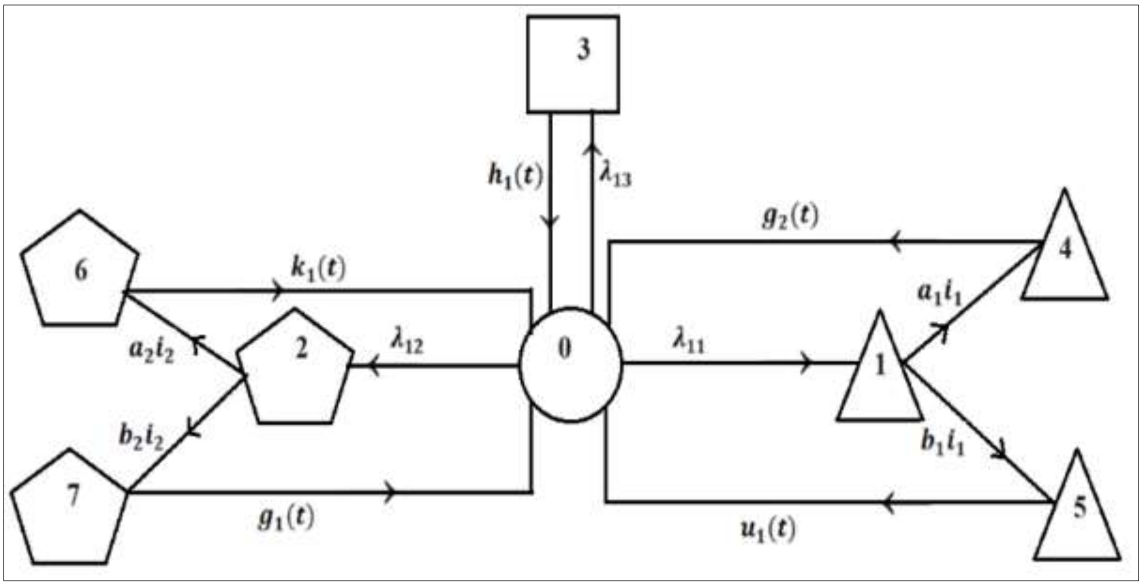
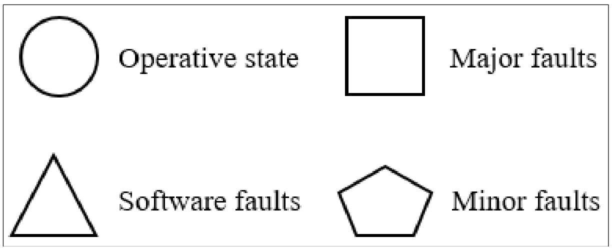


Fig 1: Transition diagram



Model Description

Following are the many loomtex model stages as outlined by the Semi-Markov method and the Regenerative Point Technique:

- **Stage 0:** Initial operational stage.
- **Stage 1:** The machine is functional but experiences minor software issues, such as chip updates. It resumes normal operation after updates and repairs.
- **Stage 2:** The machine operates partially due to minor faults like vibrations or burnt wires. Proper functionality is restored after repairs and maintenance.
- **Stage 3:** The machine is non-functional due to major issues like a burnt motor or damaged ring. It requires replacement to resume operation.
- **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

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

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

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

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

Mathematically, the aforementioned system's unconditional mean transit time for any regeneration state j, counting from the epoch of admission into state i, is expressed as.

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

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:

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

Other Measure of System Effectiveness
The following essential metrics of the system's effectiveness are driven by solving numerous recursive relations using probabilistic justifications for regeneration processes:

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)

$BI_0 = q_{01}© BI_1 + q_{02}© BI_2 + q_{03}© BI_3$
$BI_1 = M_1 + q_{15}© BI_5 + q_{14}© BI_4$
$BI_2 = M_2 + q_{26}© BI_6 + q_{27}© BI_7$
$BI_3 = q_{30}© BI_0$
$BI_4 = q_{40}© BI_0$
$BI_5 = q_{50}© BI_0$
$BI_6 = q_{60}© BI_0$
$BI_7 = q_{70}© BI_0$
$B_1 = [\mu_3 p_{01} + \mu_4 p_{02}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

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)

$BP_0 = q_{01}© BP_1 + q_{02}© BP_2 + q_{03}© BP_3$
$BP_1 = q_{15}© BP_5 + q_{14}© BP_4$
$BP_2 = q_{26}© BP_6 + q_{27}© BP_7$
$BP_3 = q_{30}© BP_0 + M_3$
$BP_4 = q_{40}© BP_0$
$BP_5 = q_{50}© BP_0$
$BP_6 = q_{60}© BP_0$
$BP_7 = q_{70}© BP_0$
$B_{rp} = [\mu_5 p_{03}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

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)

$BR_0 = q_{01}© BR_1 + q_{02}© BR_2 + q_{03}© BR_3$
$BR_1 = q_{15}© BR_5 + q_{14}© BR_4$
$BR_2 = q_{26}© BR_6 + q_{27}© BR_7$
$BR_3 = q_{30}© BR_0$
$BR_4 = q_{40}© BR_0 + M_4$
$BR_5 = q_{50}© BR_0$
$BR_6 = q_{60}© BR_0$
$BR_7 = q_{70}© BR_0 + M_7$
$B_r = [\mu_1 p_{01} p_{14} + \mu_2 p_{02} p_{27}]/\mu_0 + p_{01}[\mu_1 + \mu_3 p_{14} + \mu_4 p_{15}] + p_{02}[\mu_2 + \mu_5 p_{26} + \mu_6 p_{27}] + \mu_7 p_{03}$

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 generated per unit of system uptime
C_1 = revenue loss per unit of system downtime
C_2 = cost incurred per unit inspection of a failed unit
C_3 = cost incurred per unit maintenance of a failed unit
C_4 = cost incurred per unit replacement of a failed unit
C_5 = cost incurred per unit repair of the system
C = installation cost of the unit, including miscellaneous expenses.

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 System Uptime = 0.1548
Expected System Downtime = 0.3042
Technician's Busy Period (Inspection Time Only) = 0.2707
Technician's Busy Period (Maintenance Time Only) = 0.0564
Technician's Busy Period (Reset Time Only) = 0.2787
Technician's Busy Period (Replacement Time Only) = 0.3465

Graphical Analysis and Conclusion

The correlation between MTSF(T_0) and the software fault rate (λ_{12}) for different major fault rates (λ_{13}). is shown in figure 2. It demonstrates that the downtime grows as the rate of small faults increases and shows larger values as the rate of severe faults increases.

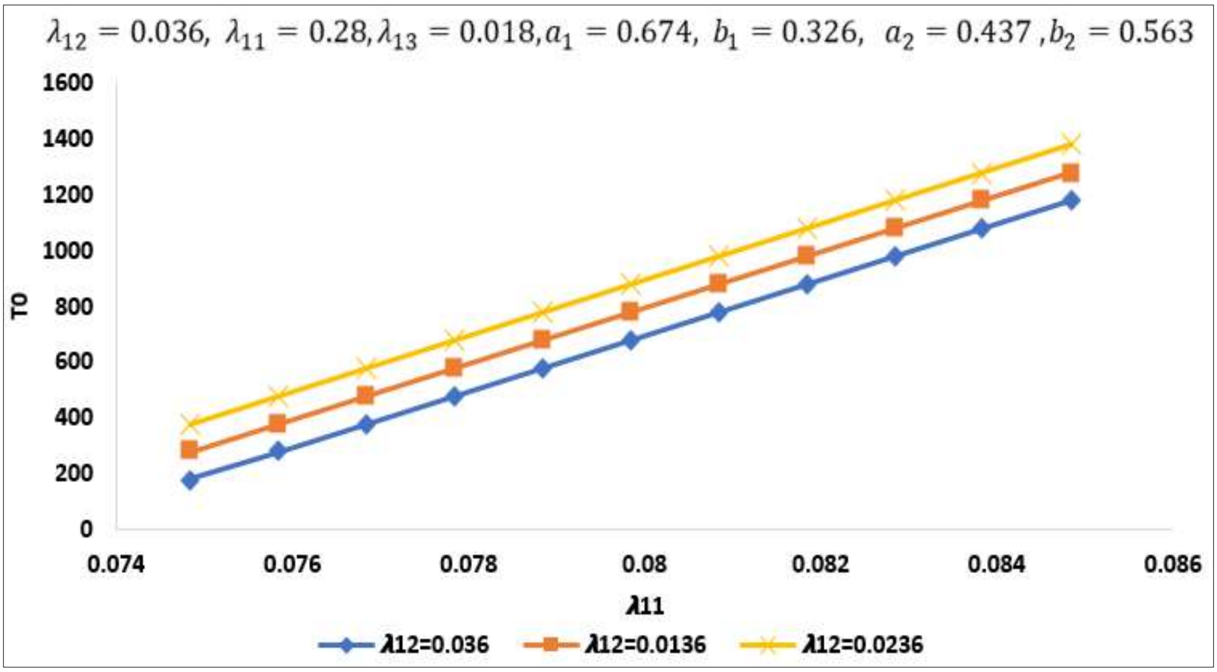


Fig 2: MTSF vs. Software Failure Rate for Various Minor Failure Values

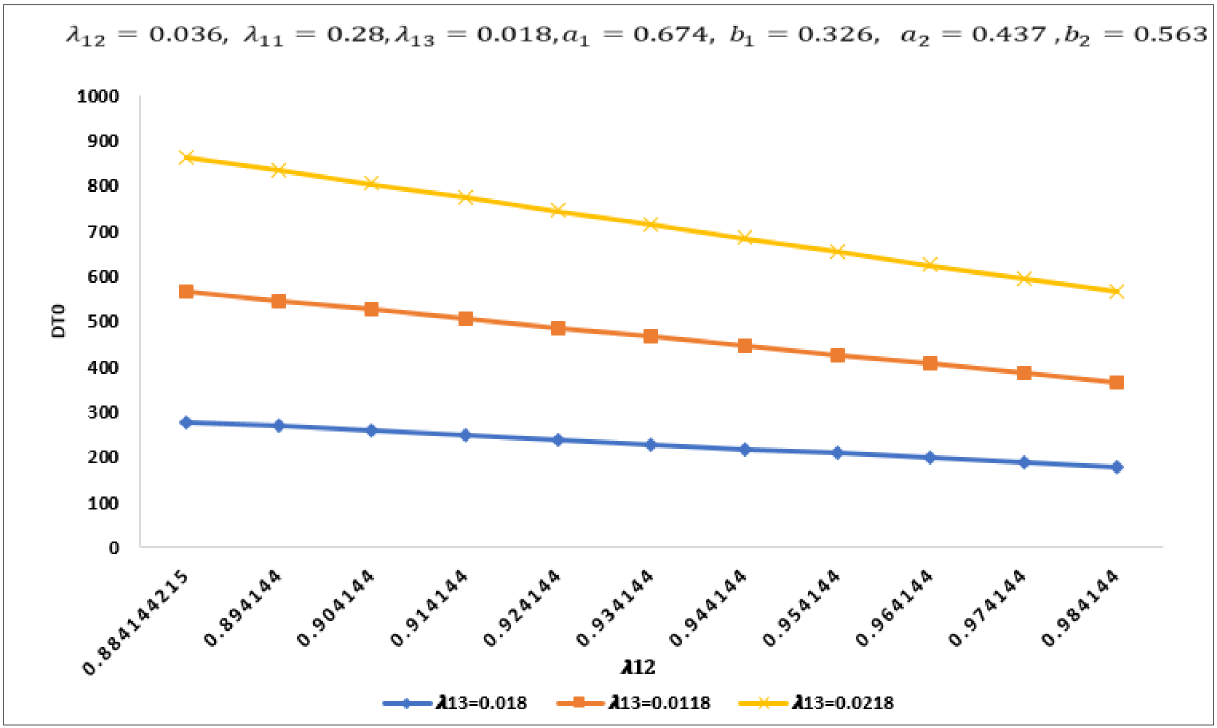


Fig 3: Down time vs minor faults at different values of major faults

Figure 3 shows a graph that shows how different rates of major fault occurrence (λ_{13}) relate to the link between Down Time (T_0) and the rate of occurrence of minor faults (λ_{12}). As the frequency of both hardware and software failures rises, the graph shows that the amount of time systems are down drops.

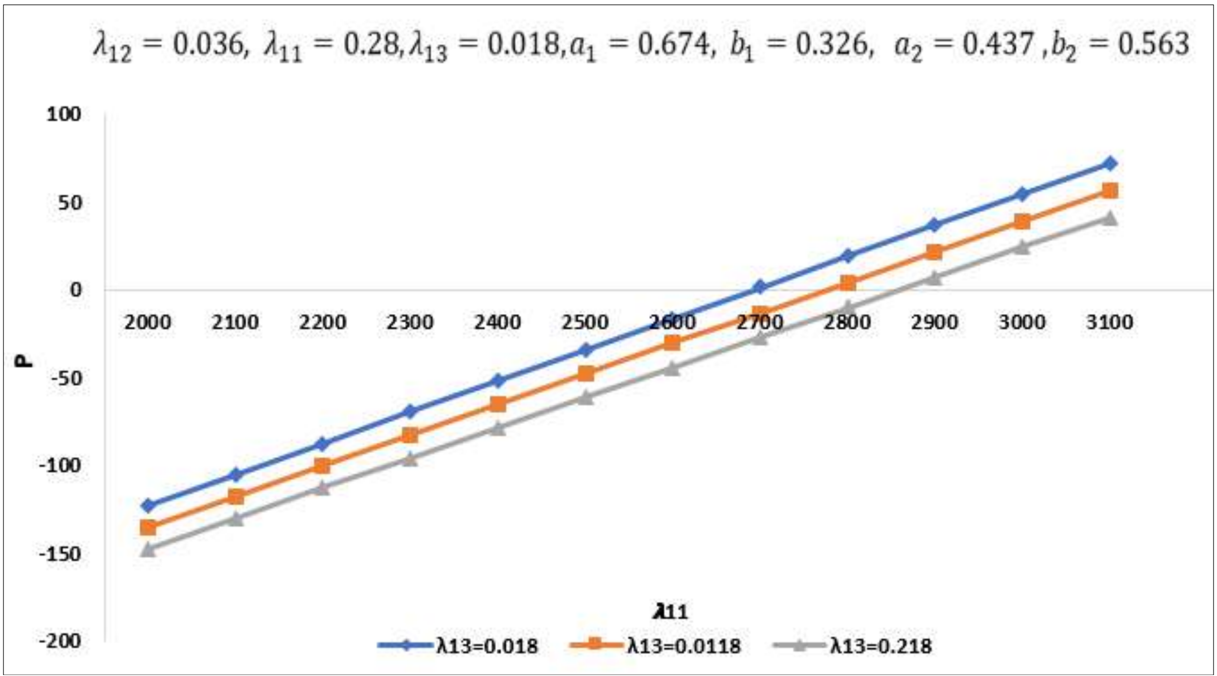


Fig 4: Profit vs. software faults at different values of major faults

Figure 4 displays the relationship between profit (P) and software fault rate (λ_11) for various significant fault rates. It demonstrates that even with small software errors, a profit may be made. The rate of both minor and major defects also raises the tie of the master technician.

Profit (P) and the rate of major fault (λ_12) rate at different values of minor fault rates are shown in the graph in figure 5. In spite of software errors, it demonstrates that a profit may be made. An increase in the number of both small and major defects also raises the tie of the master technician.

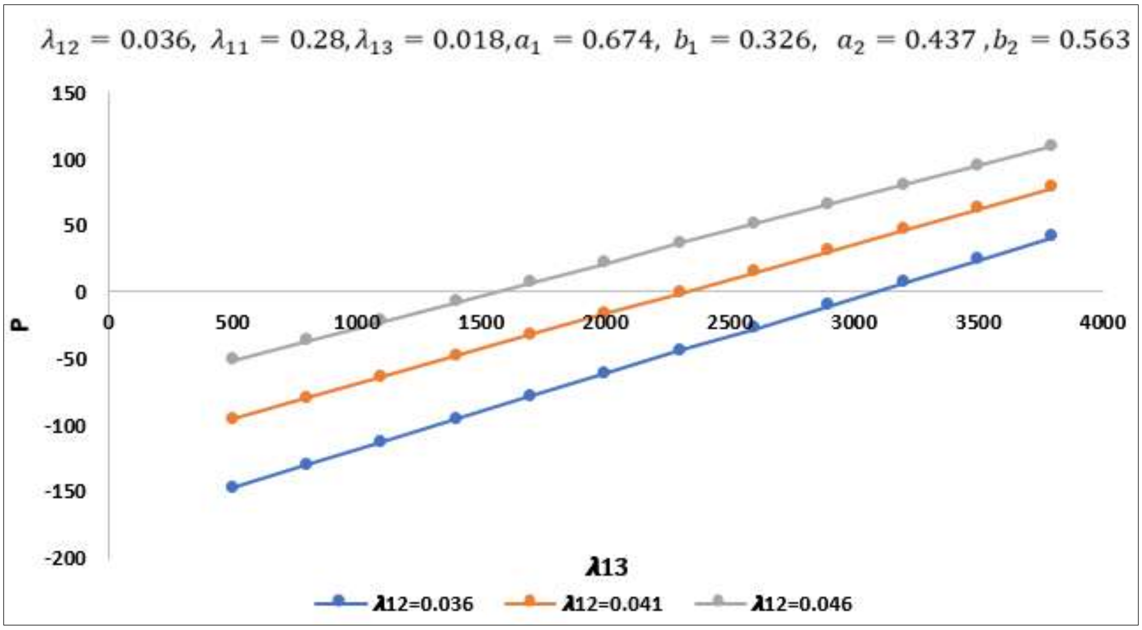


Fig 5: profit vs. Major faults at different rate of minor faults

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

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