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MEASURES TO ENSURE THE RELIABILITY OF WATER SUPPLY IN THE MLDB SYSTEM USING REFRIGERATION

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Abstract

Various components work together to form a system's overall structure. Last but not least, how well each component functions affects how the system functions. Both a functioning and failing state are possible for a system built from components. Failure has a big effect on the way systems work in industry. So, in order to enhance system performance, it is essential to get rid of these errors. The aim of this research is to assess the scope of water supply concerns in the MLDB (Multi-Level Die Block) system at the Piston Foundry Plant.The MLDB system, which consists of a robotic key unit that works with the water supply, is the subject of this research. Robotic failure and a lack of water supply cause the system to fail.A reliability model is created in order to calculate MTSF (mean time to system failure), availability, busy times for repair, and profit evaluation. The abovementioned measurements were computed numerically and graphically using semi-Markov processes and the regenerating point technique. The results of this study are novel since no previous research has concentrated on the critical function of water delivery in the MLDB system in piston foundries. According to the discussion, the findings are both highly exciting and beneficial for piston manufacturing businesses who use the MLDB system. For companies that make pistons and use the MLDB system, the conclusions, according to the debate, are particularly beneficial.

Keywords: MLDB, MTSF, availability, semi-Markov process, regenerating point technique.

1. Introduction

Many study articles on reliability exist in the literature and many estimations such as reliability, availability, engagement length and other factors for standby system have been taken. Reliability principles have been utilised in different manufacturing and technological areas throught the last 45 years. Previously, researchers examined the various ways to standby systems such as: Srinivasan [10] gave an examination of warm standby system dependability for a repair facility. The stochastic standby system behaviour with repair time was handled by Kumar et al. [4]. Sharma and Kaur [8] conducted a cost-benefi analysis of a compressor standby system. A power plant system's cold standby unit was stochastically modelled by Sharma and Sharma[9].

Some authors provided an overview of the different reliability modelling methodologies used in die casting systems such as: High Pressure Grain structure and segregation in die casting of magnesium and aluminium alloys Characteristics mentioned by Laukli [5]. High pressure die cast AlSi9Cu3 (Fe) alloys are provided by Timelli [11] using constitutive and stochastic models to anticipate the impact of casting fl ws on the mechanical properties. Die Casting Process Modeling and Optimization for ZAMAK Alloy given by Sharma [7]. Existing epistemic uncertainty in die-casting is modelled for reliability and optimised by Yourui et al.[12]. Sensitivity study for the casting method provided by Kumar [3]. An Early Investigation of a Lightweight provided by Muller et al. [6] Die Casting Die Using a Modular Design Approach. High pressure die casting machine reliability analysis of two unit standby system offered by Bhatia and Sharma

[1]. The Casting Process Optimization Case Study: A Review of the Reliability Techniques used by Chaudhari and Vasudevan [2]. According to the discussion above, every researcher has addressed reliability analysis of the die casting method used in piston foundries. Research finding pertaining to the MLDB system in piston foundries have not been discovered. A few of them, though, have gathered and analysed real data. There are a variety of systems in piston foundry operations that must be analysed using real data at various rates and costs. Our efforts are closing this gap by gathering genuine data from a company called Federal-Mogul Powertrain, India Limited, which is based in Bahadurgarh, Punjab, near Patiala. Federal-Mogul is the world's leading maker of world-class pistons, piston rings and cylinder linears, with products for two-and three -wheelers, vehicles and tractors, among other applications.

The purpose of this research is to assess the MLDB system's water supply problems. For the MLDB system in the piston plant, a reliability model has been established. The MLDB system is an enhanced version of the die casting technology that was introduced to raise the piston foundry's output rate. For the operation of the MLDB system in the piston plant, there is one main unit, which is robotic and two sub-units. Water is supplied to the system via a fan (WSF). The system fails due to a lack of water supply. We create a novel reliability model to overcome the failure in water supply, which differ from the present approach in the piston plant. A main robotic unit that works with the water supply through a refrigeration(WSR) is required for the operation of this new model, the MLDB system. To run the entire system, both the robotic and the WSR units must be operational. Water supply from fan(WSF) is utillised as a cold standby unit for better working conditions. System failure occurs due to robotic failure and a lack of water supply.

For the model, there are a few assumptions that need to be made:

- S0 is the starting state of the system.
- The main unit, i.e. robotic, receives priority for repair.
- All failure and repair times were calculated using an exponential distribution.
- After each repair in the states, the system performs a new function.
- A repair man is dispatched as soon as a unit fails.

2. Methods

The following are the materials and methods that were used to complete this research:

Semi-Markov processes and regenerating point techniques are employed in order to tackle the challenges. Many system effectiveness metrics have been acquired, including mean time to system breakdown, system availability, busy period for repair and predicted number of repairs. The profit are also made. Using C++, Python and MS Excel programming, graphical analyses are created for a specifi situation.

3. Notations and States for the Model

$Rb \rightarrow$ Main unit of the MLDB system i.e. Robotic.

$O(Rb) \rightarrow$ Main unit of the MLDB system is in operating state.

$WSR \rightarrow$ Water supply refrigerator for the system.

$WSF \rightarrow$ Water supply fan for the system.

$O(WSR) \rightarrow$ Water supply refrigerator is in operating state.

$O(WSF) \rightarrow$ Water supply fan is in operating state.

$CS(WSF) \rightarrow$ WSF is in cold standby state.

$\lambda, \lambda_1, \lambda_2 \rightarrow$ Failure rates of the main unit i.e. Robotic, WSF and WSR respectively.

$Fr(Rb) \rightarrow$ Failures of the main unit i.e. Robotic under repair.

$Fr(WSR), Fr(WSF) \rightarrow$ Failures of the WSR and WSF are under repair respectively.

$FR(WSF), FR(WSR) \rightarrow$ Repair is continuing from previous state for WSF and WSR respectively.

$Fwr(WSF), Fwr(WSR) \rightarrow$ Failed WSF and WSR are waiting for repair respectively.

$G(t), g(t) \rightarrow$ c.d.f. and p.d.f of repair time for Robotic.

$G_1(t), g_1(t) \rightarrow$ c.d.f. and p.d.f of repair time for WSR.

$G_2(t), g_2(t) \rightarrow$ c.d.f. and p.d.f of repair time for WSF.

4. The System's Reliability Measures

4.1. Transition Probabilities

The various phases of the system are depicted in a transition diagram (see in **Fig.1**).

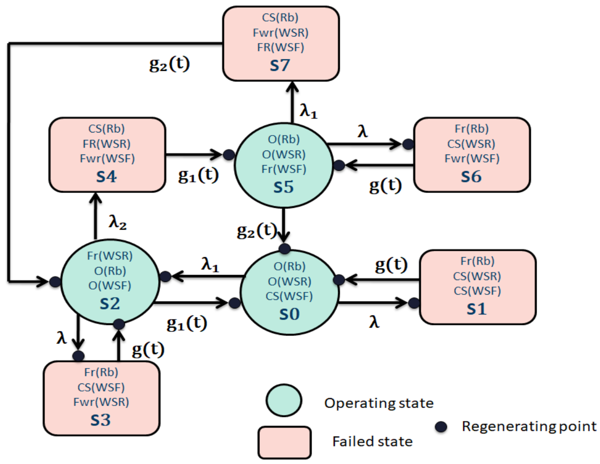

Figure 1: *State Transition Diagram*

The epochs of entry into states S0, S1, S2, S3, S5 and S6 are regenerative states, while the rest are non-regenerative stages. The operational states are S0, S2 and S5, while the failing states are S1, S3, S4, S6 and S7. The transition probabilities are:

$$dQ_{01}(t) = \lambda e^{-(\lambda+\lambda_1)t}dt \qquad dQ_{02}(t) = \lambda_1 e^{-(\lambda+\lambda_1)t}dt$$
$$dQ_{10}(t) = g_1(t)dt \qquad dQ_{20}(t) = g_1(t)e^{-(\lambda+\lambda_2)t}dt$$
$$dQ_{23}(t) = \lambda e^{-(\lambda+\lambda_2)t}\bar{G_1}(t)dt \qquad dQ_{24}(t) = \lambda_2 e^{-(\lambda+\lambda_2)t}\bar{G_1}(t)dt$$
$$dQ_{25}^{(4)}(t) = [\lambda_2 e^{-(\lambda+\lambda_2)t} © 1]g_1(t)dt \qquad dQ_{50}(t) = g_2(t)e^{-(\lambda+\lambda_1)t}dt$$
$$dQ_{56}(t) = \lambda e^{-(\lambda+\lambda_1)t}\bar{G_2}(t)dt \qquad dQ_{57}(t) = \lambda_1 e^{-(\lambda+\lambda_1)t}\bar{G_2}(t)dt$$
$$dQ_{52}^{(7)}(t) = [\lambda_1 e^{-(\lambda+\lambda_1)t} © 1]g_2(t)dt \qquad dQ_{72}(t) = g_2(t)dt$$
$$dQ_{45}(t) = g_1(t)dt \qquad dQ_{65}(t) = g(t)dt$$
$$dQ_{32}(t) = g(t)dt \tag{1}$$

The non-zero elements p_{ij} can be represented as below:

$$p_{01} = \frac{\lambda}{\lambda+\lambda_1} \qquad p_{02} = \frac{\lambda_1}{\lambda+\lambda_1}$$

$$p_{20} = g_1^*(\lambda + \lambda_2) \qquad p_{23} = \frac{\lambda[1 - g_1^*(\lambda + \lambda_2)]}{(\lambda + \lambda_2)}$$
$$p_{24} = p_{25}^{(4)} = \frac{\lambda_2[1 - g_1^*(\lambda + \lambda_2)]}{(\lambda + \lambda_2)} \qquad p_{50} = g_2^*(\lambda + \lambda_1)$$
$$p_{56} = \frac{\lambda[1 - g_2^*(\lambda + \lambda_1)]}{(\lambda + \lambda_1)} \qquad p_{57} = p_{52}^{(7)} = \frac{\lambda_1[1 - g_2^*(\lambda + \lambda_1)]}{(\lambda + \lambda_1)}$$
$$p_{10} = p_{32} = p_{65} = g^*(0) = 1 \qquad p_{45} = g_1^*(0) = 1$$
$$p_{72} = g_2^*(0) = 1 \tag{2}$$

It is also verifie that:

$$p_{01} + p_{02} = 1 \qquad p_{20} + p_{23} + p_{24} = 1$$
$$p_{20} + p_{23} + p_{25}^{(4)} = 1 \qquad p_{50} + p_{56} + p_{57} = 1$$
$$p_{50} + p_{56} + p_{52}^{(7)} = 1 \qquad p_{10} = p_{32} = p_{45} = p_{65} = p_{72} = 1 \tag{3}$$

When it (time) is calculated from the epoch of arriv al into state 'j', the unconditional mean time taken by the system to transit for each regeneration state 'i'is mathematically define as:

$$m_{ij} = \int_0^\infty t dQ_{ij}(t) = -q_{ij}^*(0) \tag{4}$$

it is also verifie that

$$m_{01} + m_{02} = \mu_0 \qquad m_{20} + m_{23} + m_{24} = \mu_2$$
$$m_{20} + m_{23} + m_{25}^{(4)} = K_1 \qquad m_{50} + m_{56} + m_{57} = \mu_5$$
$$m_{50} + m_{56} + m_{52}^{(7)} = K_2 \qquad m_{10} = \mu_1$$
$$m_{32} = \mu_3 \qquad m_{45} = \mu_4$$
$$m_{65} = \mu_6 \qquad m_{72} = \mu_7 \tag{5}$$

wher e

$$m_{01} = \int_0^\infty t\lambda e^{-(\lambda+\lambda_1)t} dt \qquad m_{02} = \int_0^\infty t\lambda_1 e^{-(\lambda+\lambda_1)t} dt$$
$$m_{20} = \int_0^\infty g_1(t) t e^{-(\lambda+\lambda_2)t} dt \qquad m_{23} = \int_0^\infty \lambda t e^{-(\lambda+\lambda_2)t} \bar{G_1}(t) dt$$
$$m_{24} = \int_0^\infty \lambda_2 t e^{-(\lambda+\lambda_2)t} \bar{G_1}(t) dt \qquad m_{25}^{(4)} = \int_0^\infty t[\lambda_2 e^{-(\lambda+\lambda_2)t} ©1] g_1(t) dt$$
$$m_{50} = \int_0^\infty g_2(t) t e^{-(\lambda+\lambda_1)t} dt \qquad m_{56} = \int_0^\infty \lambda t e^{-(\lambda+\lambda_1)t} \bar{G_2}(t) dt$$
$$m_{57} = \int_0^\infty \lambda_1 t e^{-(\lambda+\lambda_1)t} \bar{G_2}(t) dt \qquad m_{52}^{(7)} = \int_0^\infty t[\lambda_1 e^{-(\lambda+\lambda_1)t} ©1] g_2(t) dt$$
$$m_{10} = m_{32} = m_{65} = \int_0^\infty t g(t) t dt \qquad m_{45} = \int_0^\infty t g_1(t) t dt$$
$$m_{72} = \int_0^\infty t g_2(t) t dt \qquad K_1 = \int_0^\infty \bar{G_1}(t) dt$$
$$K_2 = \int_0^\infty \bar{G_2}(t) dt \tag{6}$$

The mean sojour n time (μ_i) in the regenerativ e state 'i'is define as the period of time spent in that state befor e transitioning to any other state:

$$\mu_i = E(T_i) = \int_0^\infty P(T_i > t) \tag{7}$$

As we get

$$\mu_0 = \frac{1}{\lambda+\lambda_1} \qquad \mu_2 = \frac{1-g_1^*(\lambda+\lambda_2)}{\lambda+\lambda_2}$$
$$\mu_5 = \frac{1-g_2^*(\lambda+\lambda_1)}{\lambda+\lambda_1} \qquad \mu_1=\mu_3=\mu_6=-g^*(0)$$
$$\mu_4 = -g_1^*(0) \qquad \mu_7 = -g_2^*(0) \tag{8}$$

4.2. Mean Time To System Failure

The failed states of the system are considered absorbing to determine the mean time to system failure (MTSF) of the system. The following recursive relation for $\phi_i(t)$ is obtained with probabilities arguments:

$$\phi_0(t) = Q_{01}(t) + Q_{02}(t)Ⓢ\phi_2(t)$$
$$\phi_2(t) = Q_{20}(t)Ⓢ\phi_0(t) + Q_{23}(t) + Q_{24}(t) \tag{9}$$

Taking Laplace Stieltje Transforms(L.S.T) of these relations in equations(9) and solving for $\phi_o^{**}(s)$ we obtain

$$\phi_o^{**}(s) = \frac{N(s)}{D(s)} \tag{10}$$

where

$$N(s) = Q_{01}^{**}(s) + Q_{02}^{**}(s)[Q_{23}^{**}(s) + Q_{24}^{**}(s)] \tag{11}$$
$$D(s) = [1 - Q_{02}^{**}(s)Q_{20}^{**}] \tag{12}$$

Now the mean time to system failure (MTSF) , when the system started at the beginning of state S0 is

$$T = \lim_{s\longrightarrow 0} \frac{1-\phi_o^{**}(s)}{s} \tag{13}$$

Using L' Hospital rule and putting the value of $\phi_o^{**}(s)$ from equation(13), we have

$$T_0 = \frac{N}{D} \tag{14}$$

where

$$N = \mu_0 + \mu_2[p_{02}] \tag{15}$$
$$D = 1 - p_{02}p_{20} \tag{16}$$

4.3. Availability Analysis

Let $A_i(t)$ be the probability that the system is in the up state at instant t, given that the system entered the regenerative state i at t=0. The following recursive relations are satisfie by the availability $A_i(t)$:

$$A_0(t) = M_0(t) + q_{01}(t)©A_1(t) + q_{02}(t)©A_2(t)$$
$$A_1(t) = q_{10}(t)©A_0(t)$$
$$A_2(t) = M_2(t) + q_{20}(t)©A_0(t) + q_{23}(t)©A_3(t) + q_{25}^{(4)}(t)©A_5(t)$$
$$A_3(t) = q_{32}(t)©A_2(t)$$
$$A_5(t) = M_5(t) + q_{50}(t)©A_0(t) + q_{56}(t)©A_6(t) + q_{52}^{(7)}(t)©A_2(t)$$
$$A_6(t) = q_{65}(t)©A_5(t) \tag{17}$$

where

$$M_0(t) = e^{-(\lambda+\lambda_1)t} \qquad M_2(t) = e^{-(\lambda+\lambda_2)t}\bar{G_1}(t)$$
$$M_5(t) = e^{-(\lambda+\lambda_1)t}\bar{G_2}(t) \tag{18}$$

Taking Laplace Transformation of the above equation(18) and letting s ⟶ 0, we get

$$M_0^*(0) = \mu_0 \qquad M_2^*(0) = \mu_2$$
$$M_5^*(0) = \mu_5 \tag{19}$$

Taking Laplace transform of the above equations(17) and solving them for

$$A_0^*(s) = \frac{N_1(s)}{D_1(s)} \tag{20}$$

where

$$N_1(s) = M_0^*(s)[1 - q_{23}^*(s)q_{32}^*(s) - q_{56}^*(s)q_{65}^*(s) - q_{25}^{(4)*}(s)q_{52}^{(7)*}(s) + q_{23}^*(s)q_{32}^*(s) - q_{56}^*(s)q_{65}^*(s)] + M_2^*(s)q_{02}^*(s)[1 - q_{56}^*(s)q_{65}^*(s)] + M_5^*(s)q_{02}^*(s)q_{25}^{(4)*}(s) \tag{21}$$

$$D_1(s) = [1 - q_{56}^*(s)q_{65}^*(s) - q_{23}^*(s)q_{32}^*(s) + q_{23}^*(s)q_{32}^*(s)q_{56}^*(s)q_{65}^*(s) - q_{25}^{(4)*}(s)q_{52}^{(7)*}(s)] - q_{01}^*(s)q_{10}^*(s)[1 - q_{56}^*(s)q_{65}^*(s) - q_{23}^*(s)q_{32}^*(s) + q_{23}^*(s)q_{32}^*(s)q_{56}^*(s)q_{65}^*(s) - q_{25}^{(4)*}(s)q_{52}^{(7)*}(s)] - q_{02}^*(s)q_{20}^*(s) + q_{02}^*(s)q_{20}^*(s)q_{56}^*(s)q_{65}^*(s) - q_{02}^*(s)q_{50}^*(s)q_{25}^{(4)*}(s) \tag{22}$$

In steady state, system availability is given as

$$A_0 = \lim_{s\longrightarrow 0} sA_0^*(s) = \frac{N_1}{D_1} \tag{23}$$

where

$$N_1 = \mu_0[1 - p_{23} - p_{56} + p_{23}p_{56} - p_{25}^{(4)}p_{52}^{(7)}] + \mu_2[p_{02}(1 - p_{56})] + \mu_5[p_{02}p_{25}^{(4)}] \tag{24}$$

$$D_1 = \mu_0[1 - p_{23} - p_{56} + p_{23}p_{56} - p_{25}^{(4)}p_{52}^{(7)}] + \mu_1 p_{01}[1 - p_{23} - p_{56} + p_{23}p_{56} - p_{25}^{(4)}p_{52}^{(7)}] + K_1 p_{02}[1 - p_{56}] + K_2 p_{02}p_{25}^{(4)} + \mu_6[p_{02}p_{23}p_{56}] \tag{25}$$

4.4. Busy Period Analysis of the Repair man

Let $BR_i(t)$ be the probability that the repair man is busy at time t given that the system entered regenerative state i at i=0. The recursive relation for $BR_i(t)$ are as follows:

$$BR_0(t) = q_{01}(t)©BR_1(t) + q_{02}(t)©BR_2(t)$$
$$BR_1(t) = W_1(t) + q_{10}(t)©BR_0(t)$$
$$BR_2(t) = W_2(t) + q_{20}(t)©BR_0(t) + q_{23}(t)©BR_3(t) + q_{25}^{(4)}(t)©BR_5(t)$$
$$BR_3(t) = W_3(t) + q_{32}(t)©BR_2(t)$$
$$BR_5(t) = W_5(t) + q_{50}(t)©BR_0(t) + q_{56}(t)©BR_6(t) + q_{52}^{(7)}(t)©BR_2(t)$$
$$BR_6(t) = W_6(t) + q_{65}(t)©BR_5(t) \tag{26}$$

where

$$W_1(t) = \bar{G}(t) \qquad W_2(t) = e^{-(\lambda+\lambda_2)t}\bar{G_1}(t) \qquad W_3(t) = \bar{G}(t)$$
$$W_5(t) = e^{-(\lambda+\lambda_1)}\bar{G_2}(t)dt \qquad W_6(t) = \bar{G}(t) \tag{27}$$

Taking Laplace Transfor mation of the abo ve equation(27) and letting s$\longrightarrow$ 0, we get

$$W_1^*(0) = \mu_1 \qquad W_2^*(0) = \mu_2 \qquad W_3^*(0) = \mu_3$$
$$W_5^*(0) = \mu_5 \qquad W_6^*(0) = \mu_6 \tag{28}$$

Taking Laplace transfor m of the abo ve equations(26) and solving them for

$$BR_0^*(s) = \frac{N_2(s)}{D_1(s)} \tag{29}$$

wher e

$$N_2(s) = W_1^*(s)q_{01}^*(s)[1 - q_{23}^*(s)q_{32}^*(s) - q_{56}^*(s)q_{65}^*(s) + q_{23}^*(s)q_{32}^*(s)q_{56}^*(s)q_{65}^*(s)] + W_2^*(s)q_{02}^*(s)[1 - q_{56}^*(s)q_{65}^*(s)] + W_3^*(s)q_{02}^*(s)[q_{23}^*(s) - q_{56}^*(s)q_{65}^*(s)] + W_5^*(s)q_{02}^*(s)q_{25}^{(4)*}(s) + W_6^*(s)q_{02}^*(s)q_{25}^{(4)*}(s)q_{56}^*(s) \tag{30}$$

The value of $D_1(s)$ is alr eady define in equation(22).

System total fraction of the time when it is under repair in steady state is giv en by

$$BR_0 = \lim_{s \longrightarrow 0} sBR_0^*(s) = \frac{N_2}{D_1} \tag{31}$$

wher e

$$N_2 = \mu_1[p_{01}(1 - p_{23} - p_{56} + p_{23}p_{56} - p_{25}^{(4)}p_{52}^{(7)})] + \mu_2[p_{02}(1 - p_{56})] + \mu_3[p_{02}(p_{23} - p_{56})] + \mu_5[p_{02}p_{25}^{(4)}] + \mu_6[p_{02}p_{56}p_{25}^{(4)}] \tag{32}$$

The value of D_1 is alr eady define in equation(25).

4.5. Expected Number of Repairs

Let $ER_i(t)$ be the expected no. of repairs in (0,t] giv en that the system enter ed regenerativ e state i at i=0. The recursiv e relations for $ER_i(t)$ are as follo ws:

$$\begin{aligned}
ER_0(t) &= Q_{01}(t)Ⓢ[1 + ER_1(t)] + Q_{02}(t)Ⓢ[1 + ER_2(t)] \\
ER_1(t) &= Q_{10}(t)ⓈER_0(t) \\
ER_2(t) &= Q_{20}(t)ⓈER_0(t) + Q_{23}(t)Ⓢ[1 + ER_3(t)] + Q_{25}^{(4)}(t)Ⓢ[1 + ER_5(t)] \\
ER_3(t) &= Q_{32}(t)ⓈER_2(t) \\
ER_5(t) &= Q_{50}(t)ⓈER_0(t) + Q_{56}(t)Ⓢ[1 + ER_6(t)] + Q_{52}^{(7)}(t)ⓈER_2(t) \\
ER_6(t) &= Q_{65}(t)ⓈER_5(t)
\end{aligned} \tag{33}$$

Taking L.S.T.of abo ve relations and obtain the value of $VR_0^{**}(s)$, we get

$$ER_0^{**}(s) = \frac{N_3(s)}{D_1(s)} \tag{34}$$

wher e

$$N_3(s) = (Q_{01}^{**}(s) + Q_{02}^{**}(s))[1 - Q_{23}^{**}(s)Q_{32}^{**}(s) - Q_{56}^{**}(s)Q_{65}^{**}(s) - Q_{25}^{(4)**}(s)Q_{52}^{(7)**}(s) + Q_{23}^{**}(s)Q_{32}^{**}(s) - Q_{23}^{**}(s)Q_{32}^{**}(s) - Q_{56}^{**}(s)Q_{65}^{**}(s)] + (Q_{23}^{**}(s) + Q_{25}^{(4)**}(s)) [1 - Q_{56}^{**}(s)Q_{65}^{**}(s) + Q_{56}^{**}(s)Q_{25}^{(4)**}(s)] \tag{35}$$

The value of $D_1(s)$ is alr eady define in equation(22).

For system steady state, the number of repairs per unit time is given by

$$ER_0 = \lim_{s \longrightarrow 0} sER_0^{**}(s) = \frac{N_3}{D_1} \tag{36}$$

where

$$N_3 = [1 - p_{23} - p_{56} + p_{23}p_{56} - p_{25}^{(4)}p_{52}^{(7)}] + p_{02}(1 - p_{20})[1 - p_{56} + p_{56}p_{25}^{(4)}] \tag{37}$$

The value of D_1 is already define in equation(25).

5. Profi Analysis

The profi incurred by the system model in steady state is calculated as follows:

$$P = Z_0 A_0 - Z_1 BR_0 - Z_2 ER_0 - Z_3 \tag{38}$$

where

P = Profit
Z_0 = Revenue per unit up time.
Z_1 = Cost per unit up time for which the repair man is busy for repair.
Z_2 = Cost per repair.
Z_3 = Installation Cost.

6. Particular Cases

For the particular case, the failure rates and repair rates are exponentially distributed as follows:

$$g(t) = \alpha e^{-\alpha t} \qquad g_1(t) = \alpha_1 e^{-\alpha_1 t}$$
$$g_2(t) = \alpha_2 e^{-\alpha_2 t}$$

As we get,

$$\begin{aligned}
p_{01} &= \frac{\lambda}{\lambda + \lambda_1} & & \\
p_{02} &= \frac{\lambda_1}{\lambda + \lambda_1} & p_{20} &= \frac{\alpha_1}{\lambda + \lambda_2 \alpha_1} \\
p_{23} &= \frac{\lambda}{(\lambda + \lambda_2 + \alpha_1)} & p_{24} = p_{25}^{(4)} &= \frac{\lambda_2}{(\lambda + \lambda_2 + \alpha_1)} \\
p_{50} &= \frac{\alpha_2}{\lambda + \lambda_1 + \alpha_2} & p_{56} &= \frac{\lambda}{(\lambda + \lambda_1 + \alpha_2)} \\
p_{57} = p_{52}^{(7)} &= \frac{\lambda_1}{(\lambda + \lambda_1 + \alpha_2)} & p_{10} = p_{32} = p_{65} = p_{45} = p_{72} &= 1 \\
\mu_0 &= \frac{1}{\lambda + \lambda_1} & \mu_2 &= \frac{1}{(\lambda + \lambda_2 + \alpha_1)} \\
\mu_5 &= \frac{1}{\lambda + \lambda_1 + \alpha_2} & \mu_1 = \mu_3 = \mu_6 &= \frac{1}{\alpha} \\
\mu_4 = K_1 &= \frac{1}{\alpha_1} & \mu_7 = K_2 &= \frac{1}{\alpha_2}
\end{aligned} \tag{39}$$

Based on the facts received i.e.,

Table 1: *Information Gathered*

Description	Notation	Rate(/hr)
Failure Rate of robotic	λ	0.001378336 / hr
Failure Rate of WSF	λ_2	0.000117273 / hr
Repair Rate of robotic	α	0.20271061 / hr
Repair Rate of WSF	α_2	0.005767389 / hr

The remaining values are assumed and are listed in Table 2:

Table 2: *Assumed Values*

Description	Notation	Rate(/hr)
Failure Rate of WSR	λ_1	0.000018325 / hr
Repair Rate of WSR	α_1	0.003728205 / hr
Revenue per unit uptime(per month)	Z_0	$Rs.$10, 80, 000
Cost per unit uptime, when repair man is busy for repair(per month)	Z_1	$Rs.$12, 466
Cost per reapir(per month)	Z_2	$Rs.$18, 350

Various measures of system effectiveness are shown in Table 3:

Table 3: *Results*

Description	Notation	Rate(/hr)
Mean Time to System Failure	T_0	714.866577 / hrs
Availability of the system	A_0	0.909847
Busy period of Repair man	BR_0	0.21322
Expected no. of Repairs	ER_0	0.002053
Profi	P	$Rs.$14, 21, 955

7. Graphical Representation

This study has prepared graphs for the MTSF (as shown in Figure.2), Profi as a result of failure rate of main unit(λ)(Figure 3.) and revenue (uptime of the system per unit) (Z_0) for various estimates of repair man cost for busy work in (Z_1) is shown in Figure 4.

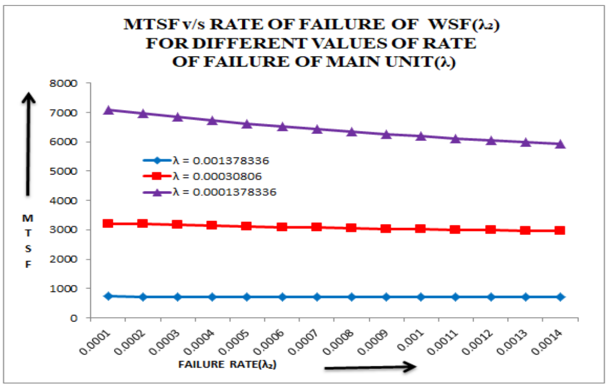

Figure 2: *MTSF v/s Failure Rate*

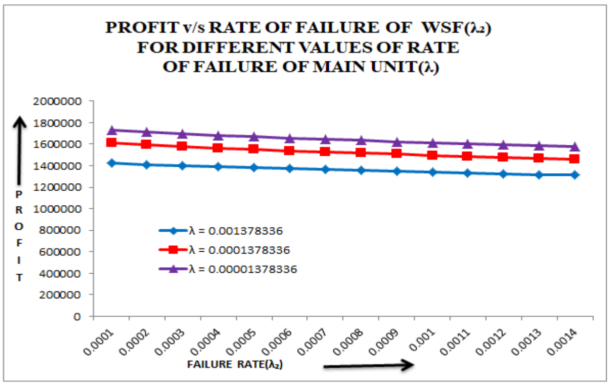

Figure 3: *Profit v/s Failure Rate*

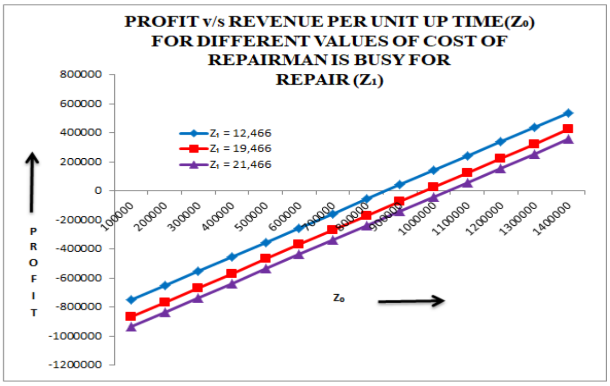

Figure 4: *Profit v/s Revenue*

8. Discussion

Discussion for the FAILURE RATE v/s MTSF and PROFIT v/s FAILURE RATE in the **Table 4.**

Table 4: *Results*

Variation	Effect
λ / λ_1 increasing (↑)	MTSF decreases (↓)
λ / λ_1 increasing (↑)	Profi decreases (↓)

As shown in above table, the behaviour of MTSF and Profi w.r.t. rate of failure of Main unit for the different values of the rate of failure of WSF. It clear from the table that MTSF and Profi gets decreased with increase in values of rate of failure of Main unit i.e. λ. Also MTSF and Profi decreases as failure rate of WSF i.e. λ_1 increases.

Discussion for the PROFIT v/s REVENUE in the **Table 5.** as below:

Table 5: *Results*

Variation	Effect
Z_0 increasing (↑)	Profi increases (↑)
$Z_1 = 12,466$; Profi $>=<$ according as z_0	when Z_0 is $>=< 8,00,000$
$Z_1 = 19,466$; Profi $>=<$ according as z_0	when it Z_0 $>=< 9,25,525$
$Z_1 = 21,466$; Profi $>=<$ according as z_0	when it Z_0 $>=< 9,98,980$

Above table depicts the behaviour of the profi w.r.t. revenue per unit uptime of the system (Z_0) for different values of cost of repair man is busy under repair (Z_1). The graph exhibits that there is inclination in the trend of profi increases with increases in the values of Z_0. Also, following conclusion can be drawn from the discussion for Profi v/s Revenue :

For $Z_1 = 12,466$, the profi is positive or zero or negative according as Z_0 is $>=<$ 8,00,000. Hence, for this case the revenue per unit up time should be fixed equal or greater than 8,00,000.

Similarly, discussion for other values of Z_1.

9. Conclusion

The conclusion is based on data from Federal-Mogul Powertrain. By using various parameters in the existing model at piston plant, the numerical value of profi is calculated as Rs. 10,45,838 and profi for current research is Rs. 14,21,955. From numerical values it has been shown that profi for new model is greater as compare to existing model, when referigerator facility is used. The finding of this study are novel since no previous research has highlighted the critical function of water supply for the MLDB system in piston foundries. The discussion reveal that the results analysed are quite interesting and beneficia for piston manufacturing businesses who use the MLDB system. In the same way, system designers might apply the escommended strategy to their own sectors. The generated equations can be used to figu e out how practical different mechanism-type systems are.

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