Cost-Benefit Analysis of Sulphated Juice Pump in a Sugar Plant using RPGT

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Abstract

This paper's goal is to use RPGT to calculate the reliability characteristics for the sulphated juice pump in a sugar mill with two units. A and B are the two subunits of a sulphated juice pump. Both units have parts, thus if any of those parts stop working, subunits "A" and "B" will also stop working as a result, which will lead to the failure of the sulphated juice subsystem. The generated conclusions are validated using numerical examples. Behavior analysis of the structure is carried out, which can assist supervision in supporting the system's an assortment of elements. To measure up to and reach an ending, tables and graphs are generated.

Keyword: Reliability, Availability, Busy Period, System parameters, RPGT

1. Introduction

A sugar mill's operation can be broken down into a number of sub-systems that each carry out a variety of tasks, including weighing juice mills that prepare cane juice, boilers that boil cane juice, crystallization, sulphation, purification, grading packing, and others. A sugar mill is separated into a number of sub-systems since it is difficult to study the system parameters of a sugar mill as a whole. In this case, we used RPGT to model and perform a Cost-Benefit scrutiny of a sulphated juice pump in a sugar mill by attendant failure. A and B are the two subunits of a sulphated juice pump. Both units have parts, thus if any of those parts stop working, subunits "A" and "B" will also stop working as a result, which will lead to the failure of the sulphated juice subsystem. Because unit "A" is more sensitive than unit "B," a standby unit is given to unit "A." Both the units 'A' (its standby unit) and 'B' are repaired by a single server 'M' who is available 24 hours a day, 7 days a week.Assuming constant failure repair of units ‘A’ & ‘B’ and server ‘M’ and transition rates a state diagram using Markov method representing the stable states and transition rates is constructed. RPGT is used to assess mean sojourn times and state probabilities. Utilizing RPGT, four system parameters are modeled. To investigate the impact of system parameters for failure and repair rates, cost-benefit analysis is used. The creation of tables and graphics is followed by analysis. Using Markov Regenerative modeling, Singh and Goyal [2013] addressed the activities psychotherapy of a biscuit manufacturing unit. The modeling is used to determine a repairable mechanical biscuit manufacturing plant's repairable mechanical biscuit shaping system's availability and transient behavior. According to Garg, Kumar, and Singh (2009), a matrix method was used to analyze the ease of use of a cattle feed factory. This plant has seven sequentially arranged subsystems. The transition graphic is created by birth-death process in the mathematical model. The ease of use study of the milling structure in a rice milling facility is discussed in Tewari and Kumar's [2016] work. Kumar [2014] talked about the system at this facility has four subsystems, each of which is in one of three states: fully operational, decreased capacity, and failed. The ease of use analysis of a built-up plant was studied by Rajbala and Garg in 2019. Rajbala and Garg [2019] talked about the behavior analysis of the facility that makes alloy wheels. Rajbala and Kumar [2021] converse an article on the coordination consistency and accessibility analysis. The dependability technology theory and its applications have been discussed by Kumar and Garg (2019). A bread-making system's behavior analysis was researched by Kumar et al. in 2018. The Cost-Benefit analysis of a cold standby framework with precedence for PM that consists of two indistinguishable units by server stoppage was carry out by Kumar et al. in 2019 using RPGT. Two units make up the current paper, solitary of which is available online and the other is stored in cold standby mode. Both online and cold standby units are identical in scenery and only encompass two modes: excellent and completely failed. Rajbala and others EAEP manufacturing plant system modeling and analysis have been studied as of [2019]. In the urea nourishment sector, activities analysis has subsisted do research by Kumar et al. [2017]. The mathematical modeling and profit analysis of an edible oil refinery plant were looked at by Kumar et al. in 2017. The behavioral psychiatry of a wash unit in a paper mill were explored by Kumar et al. in 2019. Krishna et al. [2018] paper examined Analysis of the cost-benefits of a 3:4: excellent structure plant. Kumari et al. [2021] premeditated the controlled tribulations via PSO. Kumari et al. [2021] converse the profit psychiatry of an cultivation combine plant in fixed state via RPGT.

2. Assumption and Notations

- There is one repairman whose availability is 24/7 after joining the system and specialist server is christening on need basis.
- The distributions of disappointment and repair period are stable, different and statistically independent.
- The system is examined under steady state circumstances.
- In the event that the main unit malfunctions, the organization is considered degraded, and the malfunctioning unit is promptly repaired.
- Repair rates are general, independent, and diverse for working units.
- The facility never damages the units; that is, the repairs are flawless.

m_1, m_2, m_3:- Repair rates

h_1, h_2, h_3:- Failure rates

3. Transition Diagram

Considering all expectations & notations transition diagram of organization is specified in Figure 1

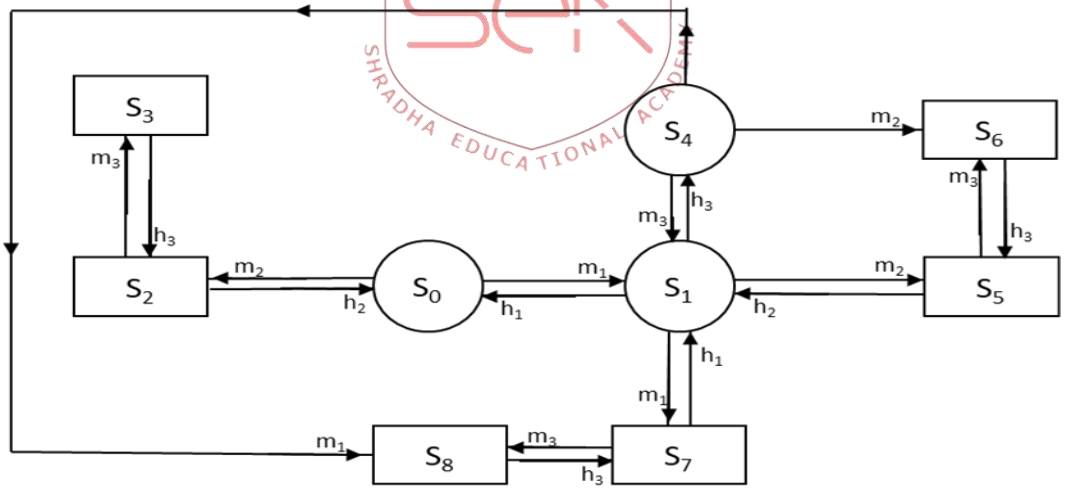

Figure 1: Transition Diagram

S_0 = A(A)B, S_1 = aAB, S_2 = A(A)b, S_3 = A(A)bM,
S_4 = aABM, S_5 = aAb, S_6 = aAbM, S_7 = aaB,
S_8 = aaBM,

4. Model Description

A subsystem for the sulphated juice pump in a sugar mill is made up of two subunits: unit "A" with a cold standby unit of equal capacity and unit "B" with subunits connected in series such that if one of the subunits malfunctions, both units "A" or "B" will also malfunction. Since Unit "A" is more crucial, a cold standby unit is included in the system to improve availability and other system metrics. Although it is commonly believed that servers never fail, a server maintenance facility is also available to maintain system parameters at their optimal levels. Since servers occasionally experience downtime for unknown reasons, they require service/treatment units or similar replacements in order to function as intended. Upon the loss of main unit "A," the cold redundant unit, when in good condition, is displayed in a straightforward bracket and is instantly brought online aid of a perfect control over system. The structure enters state S_1 from state S_0 when online unit "A," with a failure rate of m_1, fails. In this condition, the system once again operates at efficiency because cold standby unit be in online mode. After a failed unit is repaired, with a repair rate of h_1, rejoins state S_0.If unit "B" fails in state S_0 at a velocity of m_2, returns to state S0 after its repair (repair rates h_2), however if the server "m" fails in state S_2 at a rate of m_3, the system enters state S_3 after its repair (repair rates h_3), returning to state S_2. If unit "A" fails at rates in state S_1, the system state S_7 after unit "A" is repaired at rate h_1. If the server fails (failure rate is m_3), the system joins the failed state S_8. After it is repaired or treated, the system rejoins the state S_7 and continues fixing the failed unit. Additionally, in state S_1, if unit "B" breaks at rate m_2, the system enters state S_5. After unit "B" is repaired, the system returns to state S_1, staying in state S_5. When the server is repaired as the top priority, the system returns to the state S_5 if the server fails at a rate of m_3. When a server fails in state S_1, the system joins state S_4, where it continues to operate at full capacity while the server is being repaired. When the server is repaired, the system rejoins state S_1, state S_4 if online unit "A" is online at rate m_1, state S_8, and state S_4 if online unit "B" is online at rate m_1.

5. Transition Probabilities

$q_{i,j}(t)$

$q_{0,1}(t) = m_1 e^{-(m_1+m_2)t}$; $q_{0,2}(t) = m_2 e^{-(m_1+m_2)t}$; $q_{1,0}(t) = h_1 e^{-(m_1+m_2+m_3+h_1)t}$
$q_{1,4}(t) = m_3 e^{-(m_1+m_2+m_3+h_1)t}$; $q_{1,5}(t) = m_2 e^{-(m_1+m_2+m_3+h_1)t}$
$q_{1,7}(t) = m_1 e^{-(m_1+m_2+m_3+h_1)t}$; $q_{2,0}(t) = h_2 e^{-(h_2+m_3)t}$; $q_{2,3}(t) = m_3 e^{-(h_2+m_3)t}$
$q_{3,2}(t) = h_3 e^{-h_3 t}$; $q_{4,1}(t) = h_3 e^{-(m_1+m_2+h_3)t}$; $q_{4,6}(t) = m_2 e^{-(m_1+m_2+h_3)t}$
$q_{4,8}(t) = m_1 e^{-(m_1+m_2+h_3)t}$; $q_{5,1}(t) = h_2 e^{-(m_3+h_2)t}$; $q_{5,6}(t) = m_3 e^{-(m_3+h_2)t}$
$q_{6,5}(t) = h_3 e^{-h_3 t}$; $q_{7,1}(t) = h_1 e^{-(m_3+h_1)t}$; $q_{7,8}(t) = m_3 e^{-(m_3+h_1)t}$, $q_{8,7}(t) = h_3 e^{-h_3 t}$

$p_{ij} = q^*_{i,j}(t)$

$p_{0,1} = m_1/(m_1 + m_2)$; $p_{0,2} = m_1/(m_1+m_2)$; $p_{1,0} = m_1/(m_1 + m_2 + m_3 + h_1)$
$p_{1,4} = m_3/(m_1 + m_2 + m_3 + h_1)$; $p_{1,5} = m_2/(m_1 + m_2 + m_3 + h_1)$
$p_{1,7} = m_1/(m_1 + m_2 + m_3 + h_1)$; $p_{2,0} = h_2/(h_2 + m_3)$; $p_{2,3} = m_3/(h_2+m_3)$
$p_{3,2} = 1$; $p_{4,1} = f_3/(m_1+m_2+h_3)$; $p_{4,6} = m_2/(m_1+m_2+h_3)$; $p_{4,8} = m_1/(m_1+m_2+h_3)$
$p_{5,1} = h_2/(m_3+h_2)$; $p_{5,6} = m_3/(m_3+h_2)$; $p_{6,5} = 1$; $p_{7,1} = h_1/(h_1+m_3)$
$p_{7,8} = m_3/(h_1+m_3)$; $p_{8,7} = 1$; $p_{2,0}+p_{2,3} = 1$; $p_{4,1} + p_{4,6} + p_{4,8} = 1$
$p_{5,1} + p_{5,6} = 1$; $p_{7,1} + p_{7,8} = 1$

6. Mean Sojourn Times

$R_i(t)$

$R_0(t) = e^{-(m_1+m_2)t}$; $R_1(t) = e^{-(m_1+m_2+m_3+h_1)t}$; $R_2(t) = e^{-(h_2+m_3)t}$; $R_3(t) = e^{-h_3 t}$
$R_4(t) = e^{-(m_1+m_2+h_3)t}$; $R_5(t) = e^{-(m_3+h_2)t}$; $R_6(t) = e^{-h_3 t}$; $R_7(t) = e^{-(h_1+m_3)t}$; $R_8(t) = e^{-h_3 t}$

$\mu_i = R_i^*(0)$

$\mu_0 = 1/(m_1 + m_2)$; $\mu_1 = 1/(m_1 + m_2 + m_3 + h_1)$; $\mu_2 = 1/(h_2 + m_3)$; $\mu_3 = 1/h_3$
$\mu_4 = 1/(m_1+m_2+h_3)$; $\mu_5 = 1/(m_3+h_2)$; $\mu_6 = 1/h_3$; $\mu_7 = 1/(h_1+m_3)$; $\mu_8 = 1/h_3$

7. Evaluation of Path Probabilities

Applying RPGT, path probabilities of accessible states commencing initial state to different vertices are as under

$V_{0,0} = 1$
$V_{0,1} = p_{0,1}/(1 - p_{1,4} p_{4,1})[1 - \{(p_{1,5} p_{5,1}/(1 - p_{5,6} p_{6,5})\}][1 - \{(p_{1,7} p_{7,1}/(1 - p_{7,8} p_{8,7})\}]$
$V_{0,2} =$ …….Continuous
$V_{1,0} = p_{1,0}/\{(1 - p_{0,2} p_{2,0})/(1 - p_{2,3} p_{3,2})\}$
$V_{1,1} = 1$
$V_{1,2} =$ …….Continuous

8. Modeling System Parameters

MTSF (T_0): Regenerative un-failed position to which the method can transit (preliminary state '0'), sooner than incoming any unsuccessful state are: 'i' = 0,1,4 pleasing 'ξ' = '0'

$$\text{MTSF} = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}i\right)\right\}\mu i}{\Pi_{m_{1\neq\xi}}\left\{1\text{-}V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[1\text{-}\sum_{sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr(sff)}\xi\right)\right\}}{\Pi_{m_{2\neq\xi}}\left\{1\text{-}V_{\overline{m_2 m_2}}\right\}}\right\}\right]$$

Availability of the System (A_0): Regenerative position at which the structure is to be had be ‘i’ = 0,1,4; ‘ξ’ = ‘1’

$$A_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\Pi_{m_{1\neq\xi}}\left\{1\text{-}V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_{2\neq\xi}}\left\{1\text{-}V_{\overline{m_2 m_2}}\right\}}\right\}\right]$$

$$A_0 = \left[\sum_j V_{\xi,j}\,, f_j, \mu_j\right] \div \left[\sum_i V_{\xi,i}\,, f_j, \mu_i^1\right]$$

Busy Period of the Server: Regenerative circumstances where attendant is full of activity are1 ≤ j ≤ 8; ξ = ‘0’,

$$B_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\},nj}{\Pi_{m_{1\neq\xi}}\left\{1\text{-}V_{\overline{m_1 m_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_{2\neq\xi}}\left\{1\text{-}V_{\overline{m_2 m_2}}\right\}}\right\}\right]$$

$$B_0 = \left[\sum_j V_{\xi,j}\,, n_j\right] \div \left[\sum_i V_{\xi,i}\,, \mu_i^1\right]$$

Expected Number of Inspections by the repair man: Regenerative state where repair man does this job j = 1,4 taking ‘ξ’ = ‘0’,

$$V_0 = \left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}}{\Pi_{k_{1\neq\xi}}\left\{1\text{-}V_{\overline{k_1 k_1}}\right\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{k_{2\neq\xi}}\left\{1\text{-}V_{\overline{k_2 k_2}}\right\}}\right\}\right]$$

$$V_0 = \left[\sum_j V_{\xi,j}\right] \div \left[\sum_i V_{\xi,i}\,, \mu_i^1\right]$$

9. Analytical Example with Particular Cases: RPGT and Data Analysis Results

Behavior Analysis: Fix; $h = h_1 = h_2 = h_3; m = m_2 = m_3 = m_1$

Table 1: MTSF

T_0	m = 0.50	m = 0.55	m = 0.60
h = 0.10	7.034	7.803	8.716
h = 0.15	5.048	5.928	6.901
h = 0.20	3.060	3.901	4.633

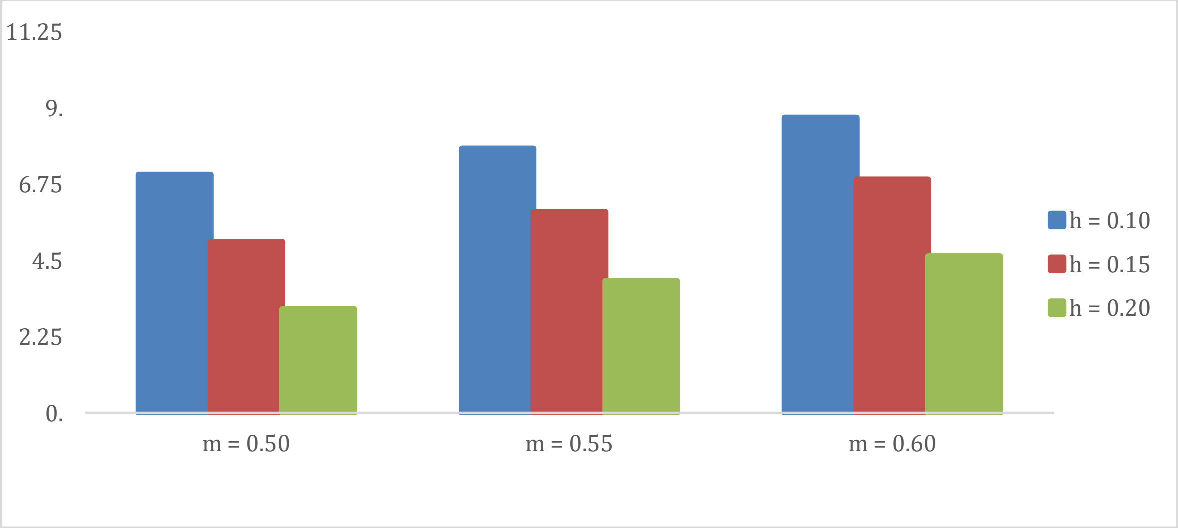

Figure 2: MTSF

Table 1 and Fig. 2 demonstrate that when machine failure rates rise, MTSF declines more quickly. The disappointment rate remnants constant and the MTSF are not increased with the rate of repair.

Table 2: Availability of System (A_0)

A_0	m = 0.50	m = 0.55	m = 0.60
h = 0.10	0.563	0.670	0.707
h = 0.15	0.312	0.467	0.620
h = 0.20	0.156	0.230	0.317

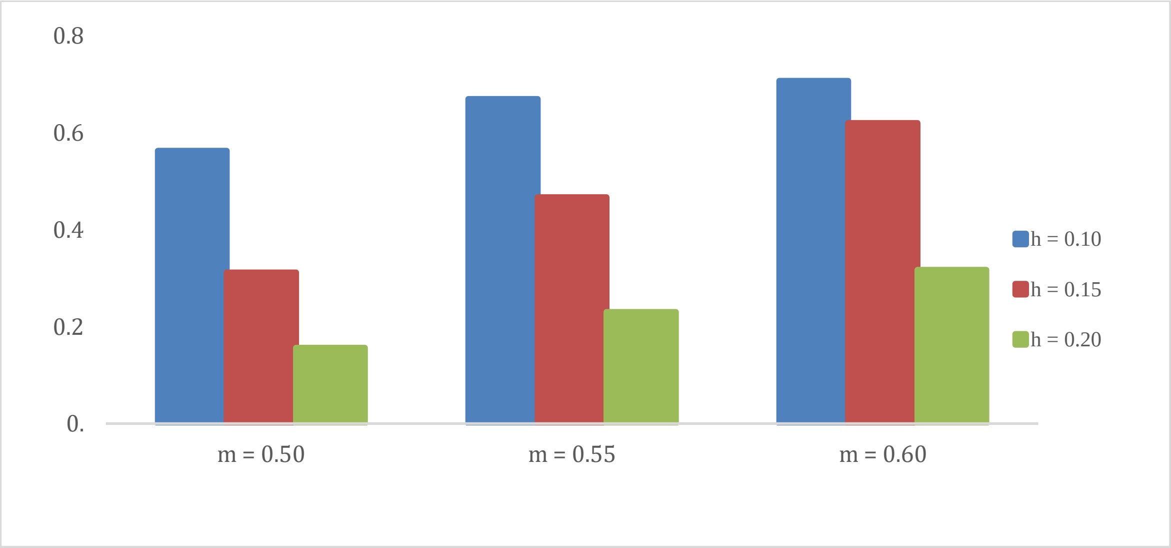

Fig. 3: Availability of System

The trends of increasing disappointment and repair rates are depicted in Table 2 and Figure 3. When the failure value is higher, Availability of system is lowest, and vice versa for repair value.

Table 3: Server of Busy Period (B_0)

B_0	m = 0.50	m = 0.55	m = 0.60
h = 0.10	0.443	0.402	0.367
h = 0.15	0.502	0.456	0.425
h = 0.20	0.601	0.500	0.462

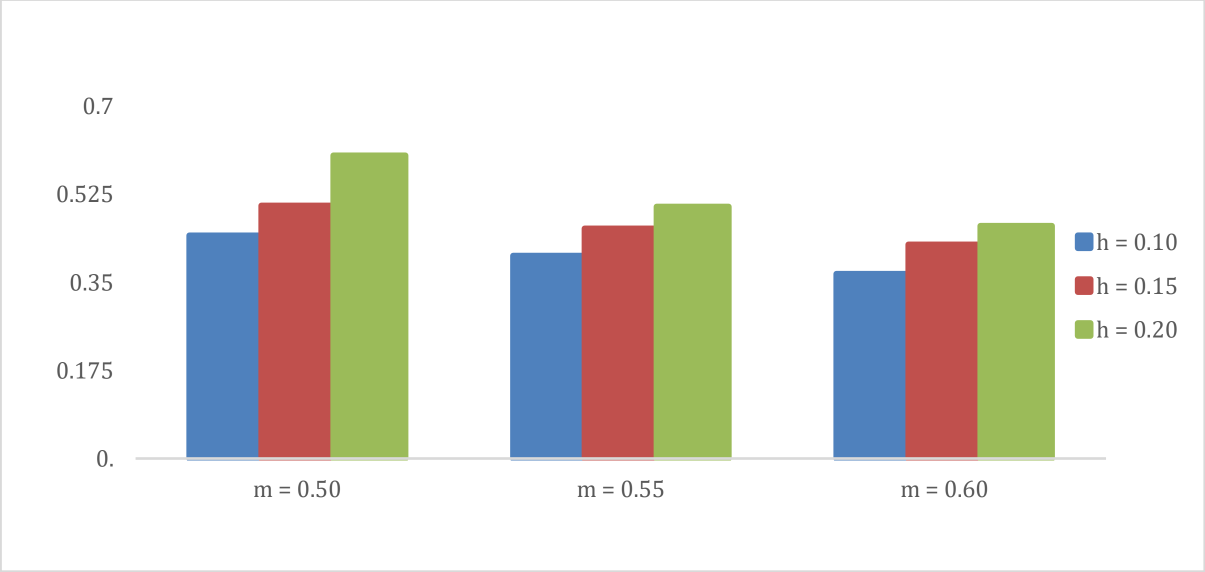

Figure 4: Server of Busy Period

Table 3 and Fig. 4 show that busy period value increases with breakdown rates in addition to decreases with revamp rates, respectively. These tendencies are in line with observations made in real-world scenarios. On supplementary hand, repair rates peak occasion should have lowest possible value.

Table 4: Expected Number of server's visits (V_0)

V_0	m = 0.50	m = 0.55	m = 0.60
h = 0.10	0.355	0.337	0.320
h = 0.15	0.359	0.347	0.336
h = 0.20	0.364	0.354	0.359

Table 4 and Figure 5 showed that the expected fraction of repairman inspections is directly associated with the subsystem disappointment and repair rates.

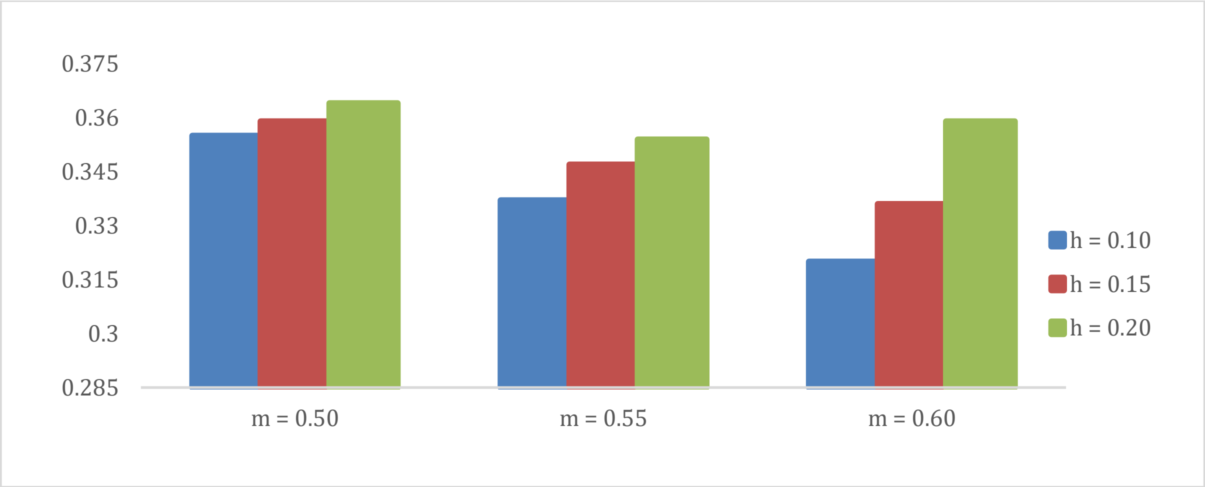

Fig. 5: Expected Number of Server's Visits

Profit Function (P_0): The system can be done by utilized PF

$P_0 = D_1A_0 - D_2B_0 - D_3V_0,$

$D_1 = 1200; D_2 = 100; D_3 = 200$

Table 5: Profit Function

P_0	m = 0.50	m = 0.55	m = 0.60
h = 0.10	560.3	697.06	747.70
h = 0.15	252.4	445.40	634.30
h = 0.20	54.228	155.20	262.40

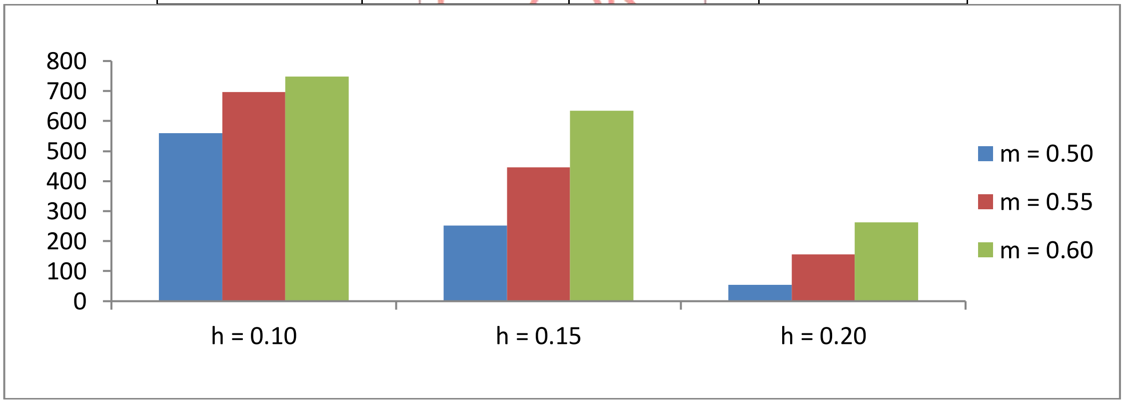

Fig. 6: Profit Function

The settings for P_0, according to the analytical and graphical discussion. When unit disappointment rates are at their lowest and repair rates are at their highest, the maximum profit value is 747.70. The system cannot reach production after a limit, i.e. a recession occurs. A degraded state is a state of the system in which the system or units perform a function continuously up to a satisfactory but lower (lower) limit than specified due to its required functions.

10. Conclusion

The system's availability, the profit function, and the anticipated number of repairman inspections are all observed to decrease with an rise in breakdown rate and to rise by the revamp rate, based on the analytical and figure discussions. Increased repair rates result in a decrease in the MTSF breakdown and busiest period of the server. By defiance of gravity repair rate and sinking disappointment rate, plant's effectiveness and steadiness can survive enhanced. The system cannot reach production after a limit, i.e. a recession occurs. A degraded state is a state of the classification in which the system or units perform a function continuously up to a satisfactory but lower (lower) limit than specified due to its required functions. The system's availability, the profit function, and the anticipated number of repairman inspections are all observed to decrease by a boost in malfunction rate, based on the analytical and figure discussions. Increased repair rates result in a decrease in the MTSF breakdown and the busiest period of the server. Decision-makers can choose which input variables to priorities for optimization by determining which ones have the biggest effects on the output variable. This has the potential to improve the industry's effectiveness and profitability while also raising the standard of the finished good. According to another claim, when a degraded unit is inspected before it completely fails, we can determine whether it can be repaired or whether it needs to be replaced with a new unit, which makes the system more functional and profitable. By using these insights, processing parameters may be optimized, raw material quality can be raised, and industrial efficiency and profitability can eventually rise.

REFRENCES

1. Singh, P., Goyal. A.: "Behavior analysis of a biscuit making plant using Markov Regenerative modeling", International Journal on theoretical and applied research in mechanical engineering, Vol2, Issue-3, 2103.
2. Kumar, A., Garg, D., and Goel, P. (2017), "Mathematical modeling and profit analysis of an edible oil refinery industry", Airo International Research journal, XIII, 1-14.
3. Kumar, A., and Garg, D. (2019), "Reliability technology theory and application", Lap Lambert Academic Publishing in Germany, ISBN 978-613-9-47665-7.
4. Kumar, A., Goel, P., Garg, D., and Sahu, A. (2017)," System behavior analysis in the urea fertilizer industry", Book: Data and Analysis [978-981-10-8526-0], Communications in computer and information Science (CCIS), Springer, 3-12.
5. Kumari, S., Khurana, P., Singla, S., Kumar, A. (2021) Solution of constrained problems using particle swarm optimiziation, International Journal of System Assurance Engineering and Management, pp. 1-8.
6. Kumari S, Khurana P, Singla S (2021) Behavior and profit analysis of a thresher plant under steady state. International Journal of System Assurance Engineering and Man., 1-12.
7. Rajbala and Deepika Garg, "Behaviour analysis of alloy wheel plant", International journal of engineering and advanced technology (IJEAT), vol 9(2), pp 319-327, 2019, ISSN 2249-8958.
8. Rajbala, Kumar, A. Article on the system reliability and availability analysis using RPGT- A general approach, Galaxy international interdisciplinary research journal, vol. 9(5), pp. 371-375, (2021).
9. Kumar, A., Garg, D., and Goel, P. (2019), "Mathematical modeling and behavioral analysis of a washing unit in paper mill", International Journal of System Assurance Engineering and Management, 1(6), 1639-1645.
10. Kumar, A., Garg, D., and Goel, P. (2019), "Cost -Benefit analysis of a cold standby system with priority for preventive maintenance", Journal of Advance and Scholarly Researches in Allied Education, 16(4), 253-258.
11. Kumar, A., Goel, P. and Garg, D. (2018), "Behaviour analysis of a bread making system", International Journal of Statistics and Applied Mathematics, 3(6), 56-61.
12. Kumar, A., Garg, D., Goel, P., Ozer, O. (2018), "Cost -Benefit analysis of 3:4:: good system", International Journal of Advance Research in Science and Engineering, 7(2), 851-862.
13. Garg, D., Kumar, K., Singh, j.: "Availability analysis of a cattle feed plant using matrix method", International Journals of engineering, Volume 3, Issue-2. (2009).
14. Kumar.: "availability analysis of thermal power plant boiler air circulation system using Markov approach", Decision Science letters, pp 65-72 (2014).
15. Rajbala, Arun Kumar and Deepika Garg, "Systems Modeling and Analysis: A Case Study of EAEP Manufacturing Plant", International Journal of Advanced Science and Technology, vol 28(14), pp 08-18, 2019.