Sensitivity Analysis of System of Three Units Having Standby Units and Having Degradation in Main Unit

Shakuntla Singla and Diksha Mangla

January 3, 2023

Sensitivity Analysis of System of Three Units having Standby Units and having Degradation in Main Unit

Shakuntla Singla[1], Diksha Mangla[2]

[1]Associate Professor, Department of Mathematics and Humanities, MMEC, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, India

[2]Research Scholar, Department of Mathematics and Humanities, MMEC, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, India

Email: shakus25@gmail.com[1]; dikshamangla1995@gmail.com[2]

Abstract: Here, a stochastic model is created utilizing a single repair facility for a standby system with three identical units. A server is a type of repair facility that responds right away to system problems that arise during system operation. For failure and repair times of the system with various parameters, the most significant monotonically declining lifetime Lindley distribution is used. The primary unit in this study is quite expensive and has two different sorts of deteriorated states in which it can run before changing to D. For random values of the shape parameter related to failure and repair times, the reliability measures' behavior has been graphically depicted. Graphs and tables are employed in order to demonstrate system behavior.

Keywords: - Preventive Maintenance, Circuits, Degradation, Regenerative Point Graphical Technique (RPGT).

1. Introduction

Here we have considered a system of three units A, B, and D in which Unit 'D' is the main working unit having two types of degradation. After the first degradation, the main unit has an efficiency of working up to 70%, and in the second type of degradation, the working capacity is again reduced to 50-55%. Also, there is a provision or facility for a standby unit to the unit 'A' denoted by (A). Now the capacity of the standby unit is not up to the mark i.e., the capacity of (A) is also in a reduced state. The failure of unit 'B' has only one type of failure i.e., unit 'B' completely fails. In unit 'A' fails, the system has to replace unit 'A' with a standby unit available at once call i.e., there is no concept of waiting time for replacing the main unit 'A'. The repair of units 'D' is at two times one at stage D_1 (First Degraded State) and second time at stage D_2 (Second Degraded State). The repair for unit "B' is perfect since it is available in the industry, so there is no issue of repair of units and replacement by standby unit. The failure and repair rates for the units are expressed by exponential functions and the P. D. F. of these functions is statistically independent. As in an earlier study, we have studied a three-unit system having increasing failure and repair rates. In this study the main unit has a very high cost and can be operated in two types of degraded states after the second degraded state, it can be changed to D (i.e., after a perfect repair).

The repairmen have to appear in the system at first call and the repair is done at no time loss. For study of system, we take probability density functions as $q_{i,i,j}$ (t) which is a function time variable 't' and probability distribution function of $q_{i,j}$ are represented by $p_{i,j}$ (using Laplace Transforms) of the functions for steady state condition. In Laplace transform, the variable's' can be taken as α_i or β_i or according to conditions/ situations. Komal et al. (2009) described the reliability, availability, and maintainability analysis presents some strategies to carryout structure alteration. Benefit analysis of the agribusiness harvester plants in a stable condition using RPGT was discussed by Kumari et al. in 2021. In their 2018 study, Kumar et al. focused on the investigation of a bakery and an edible petroleum treatment plant. In a series framework with a span portion, Bhunia et al. (2010) presented GA to address concerns with unshakable quality stochastic augmentation. The review found a solution to the problem of streamlining stochastic unshakable quality in light of the series framework's chance imperatives. Jieong et al. (2009) used GA, or a half-and-half calculation, to address multi-objective streamlining problems. The fundamental objective of the paper by Kumar et al. (2019) focuses on the investigated examination of the washing element in the paper company consuming RPGT, while Kumar et al. (2017) analyzed the urea compost industry for system parameters. The mist group of a coal-fired thermal impact shrub was optimized by Malik et al. in 2022. Dual categories of deficiencies—simple and hard as for the time in which these happen for disengagement and expulsion following their recognition—have been reported in Anchal et al(2021) .'s analysis of the SRGM classic using variance condition. Assuming any necessary to complete the superior of the complicated mechanical systems.

2. Assumption & Notation used in this study: -

Here we have taken $\alpha \rightarrow$ the Failure Rate from S_0 to S_1 and A to (A)

$\alpha_2 \rightarrow$ Failure Rate: B to b, $\alpha_3 \rightarrow$ Failure Rate: - D to D_1 (First Degraded State)

$\alpha_4 \rightarrow$ Failure Rate: - D_1 to D_2 (Second Degraded State), $\alpha_5 \rightarrow$ Failure Rate: - D_2 to d

$\beta \rightarrow$ the Repair Rate from S_1 to S_0 and (A) to A, $\beta_2 \rightarrow$ Repair Rate: - b to B

$\beta_3 \rightarrow$ Repair Rate: - D_1 to D, $\beta_4 \rightarrow$ Repair Rate: - D_2 to D_1, $\beta_5 \rightarrow$ Repair Rate: - d to D.

3. Transition Diagram

Circle, ellipse and rectangle in transition diagram in Figure 1 represent full, reduce and failed states respectively.

S_0 = ABD,	S_1 = (A)BD,	S_2 = ABD$_1$,	S_3 = ABD$_2$,
S_4 = (A)BD$_1$,	S_5 = (A)BD$_2$,	S_6 = (A)bD,	S_7 = AbD,
S_8 = (A)bD$_1$,	S_9 = AbD$_1$,	S_{10} = AbD$_2$,	S_{11} = (A)bD$_2$,
S_{12} = (A)Bd,	S_{13} = ABd		

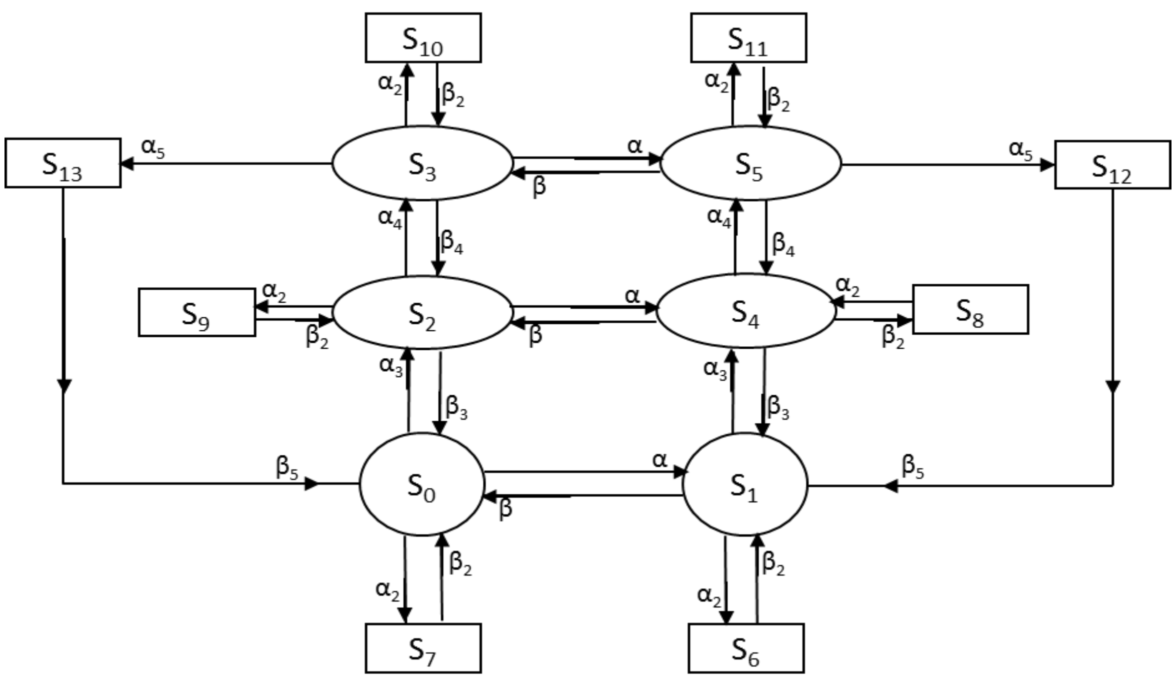

Figure 1: Transition Diagram

4. Transition Probabilities

$q_{i,j}(t)$: p. d. f. from state 'i' to state 'j' in (0, t]

$\mathbf{p_{i,j}} = q_{i,j}^{*}(0)$; Steady state probability, where '*' indicates Laplace transformation.

Table 1: Transition Probabilities

$q_{i,j}^{(t)}$	$P_{ij} = q^*_{i,j}{}^{(t)}$
$q_{0,1} = \alpha e^{-kt}$	$P_{0,1} = \alpha/k$
$q_{0,2} = \alpha_3 e^{-kt}$	$P_{0,2} = \alpha_3/k$
$q_{0,7} = \alpha_2 e^{-kt}$	$P_{0,7} = \alpha_2/k$
$q_{1,0} = \beta e^{-lt}$	$P_{1,0} = \beta/l$
$q_{1,4} = \alpha_3 e^{-lt}$	$P_{1,4} = \alpha_3/l$
$q_{1,6} = \alpha_2 e^{-lt}$	$P_{1,6} = \alpha_2/l$
$q_{2,0} = \beta_3 e^{-mt}$	$P_{2,0} = \beta_3/m$
$q_{2,3} = \alpha_4 e^{-mt}$	$P_{2,3} = \alpha_4/m$
$q_{2,4} = \alpha e^{-mt}$	$P_{2,4} = \alpha/m$
$q_{2,9} = \alpha_2 e^{-mt}$	$P_{2,9} = \alpha_2/m$
$q_{3,2} = \beta_4 e^{-nt}$	$P_{3,2} = \beta_4/n$
$q_{3,5} = \alpha e^{-nt}$	$P_{3,5} = \alpha/n$
$q_{3,10} = \alpha_2 e^{-nt}$	$P_{3,10} = \alpha_2/n$
$q_{3,13} = \alpha_5 e^{-nt}$	$P_{3,13} = \alpha_5/n$
$q_{4,1} = \beta_3 e^{-rt}$	$P_{4,1} = \beta_3/r$
$q_{4,2} = \beta e^{-rt}$	$P_{4,2} = \beta/r$
$q_{4,5} = \alpha_2 e^{-rt}$	$P_{4,5} = \alpha_2/r$
$q_{4,8} = \alpha_4 e^{-rt}$	$P_{4,8} = \alpha_4/r$
$q_{5,3} = \beta e^{-st}$	$P_{5,3} = \beta/s$
$q_{5,4} = \beta_4 e^{-st}$	$P_{5,4} = \beta_4/s$
$q_{5,11} = \alpha_2 e^{-st}$	$P_{5,11} = \alpha_2/s$
$q_{5,12} = \alpha_5 e^{-st}$	$P_{5,12} = \alpha_5/s$
$q_{i,1} = \beta_2 e^{-\beta_2 t}$ i=6 to11	$p_{i,1} = 1$
$q_{12,1} = \beta_5 e^{-\beta_5 t}$	$p_{12,1} = 1$

$q_{13,0} = \beta_5 e^{-\beta_5 t}$	$p_{13,0} = 1$

k= $\alpha + \alpha_2 + \alpha_3$, l= $\beta + \alpha_2 + \alpha_3$, m= $(\alpha + \beta_3 + \alpha_2 + \alpha_4)$, n=$(\beta_4 + \alpha + \alpha_2 + \alpha_5)$,

$$r = (\beta_3 + \beta + \alpha_2 + \alpha_4), s = \beta + \beta_4 + \alpha_2 + \alpha_5$$

4.1 Mean Sojourn Times (μ):

μ_i : MST in state i, $\mu_i = \int_0^\infty R_i\,(t)dt$

μ_i^1 : waiting time for repair in regenerative state 'i' at t=0.

Table 2: Mean Sojourn Times

$R_i(t)$	$\mu_i = R_i^*(0)$
$R_0^{(t)} = e^{-kt}$	$\mu_0 = 1/k$
$R_1^{(t)} = e^{-lt}$	$\mu_1 = 1/l$
$R_2^{(t)} = e^{-mt}$	$\mu_2 = 1/m$
$R_3^{(t)} = e^{-nt}$	$\mu_3 = 1/n$
$R_4^{(t)} = e^{-rt}$	$\mu_4 = 1/r$
$R_5^{(t)} = e^{-st}$	$\mu_5 = 1/s$
$R_i^{(t)} = e^{-\beta_2 t}$, i=6 to11	$\mu_6 = 1/\beta_2$
$R_{12}^{(t)} = e^{-\beta_5 t}$	$\mu_{12} = 1/\beta_5$
$R_{13}^{(t)} = e^{-\beta_5 t}$	$\mu_{13} = 1/\beta_5$

5. Path Probabilities:

Transition probabilities from vertex '0' to other vertices of system (using the table q_i (t), p_i* (0) and sojourn times μ_i, we get

$V_{0,0} = 1$ (verified), $V_{0,1} = p_{0,1} = [\alpha/k]$, $V_{0,2} = p_{1,2} = [\alpha_3/k]$

$V_{0,3} = = [2\alpha_2\alpha_4^2(1+\alpha_3)(\beta\ \beta_5)]/[lkn^2]$

$V_{0,4} = [\alpha_4^2\alpha_4(3+2\alpha_2)(1+\beta_4)]/[(k+\alpha^2+2\beta_3)(5+4\alpha_2+3\beta^2)]$

$V_{0,5} = [(\alpha_2\alpha_5\ \beta\ \beta_4)(2\beta+3\alpha^2)]/[(3\alpha_4+\alpha_2+\beta)(\beta_4+\alpha_2+4\alpha_3+k)^2(\alpha_2+\alpha_3)]$

$V_{0,6} = [(\alpha\alpha_2)/kl]/[(\alpha_3+\beta)/l]$, $V_{0,7} = p_{1,7} = [\alpha_2/k]$

$V_{0,8} = (0,1,4,8)/[(1-L_3)(1-L_4)]= (p_{0,1}p_{1,4}p_{4,8})/[(1-p_{1,6}p_{6,1})(1-p_{1,4}p_{4,1})]$

$= [(2\alpha+3\beta_4+\alpha^2+2\beta)/(1+\alpha_2+\beta)^2(4\alpha_2+3\alpha_5)^3]$

$V_{0,9} = (0,2,9)/[(1-L_4)(1-L_2)]= (p_{0,2}p_{2,9})/[(1-p_{0,7}p_{7,0})(1-p_{2,4}p_{4,2})]$

$= [(\alpha_3\alpha_2)/km]/[(\alpha+\alpha_3)k\{(r/3\alpha_3\}]$

$V_{0,10} = (2\alpha_2+\alpha_2+\alpha_4\alpha_2^2)/(\beta+2\alpha_4+\alpha_3+4\beta_4)^2(3\alpha+\beta_4)]$, $V_{0,11} = (s+\beta)/(\beta_4+\alpha_2+3\alpha+\alpha_5)^2$

$V_{0,12} = (0,1,4,5,12)/[(1-L_3)(1-L_5)]+(0,2,3,5,12)/[(1-L_1)]$

$= (2\alpha^2+\beta_4+3\alpha+\alpha_5)/(3\alpha+\beta_4)(3\beta_2+3\alpha_5+4\alpha)^2$

$V_{0,13} = (0,2,3,13,)/[(1-L_1)(1-L_5)(1-L_3)]= (p_{0,2}\ p_{2,3}\ p_{3,13})/[(1-p_{0,7}\ p_{7,0})(1-p_{2,4}\ p_{4,2})(1-p_{2,9}\ p_{9,2})]$

$= (2\alpha+\beta_4+\beta_2+5\alpha_3)/(\alpha^2+\beta_4+9\beta_2+\beta\alpha_5)$

Evaluation or calculating the various parameters involved in the sensitivity analysis of the system are as here we are considering the exponential functions as the failure rates and repair rates of the system using RPGT as a tool which is most commonly used to derive the expression for parameters as average or mean time in which system remains failed between various states, available time of system and profit function of system.

After calculating the path probabilities from vertex '0'to different vertices, now it is required to calculate the various type of parameters involved in sensitivity analysis of system, examples are average time for which system remain in good state, the availability of system and time period of repairman for repair of units. The waiting time for replacement of redundant nit is take as zero i.e. the standby units are available at instant.

6. Results

6.1 ATSF (T_0): The good states to which system may go through out from the base state 'i' = 0, are given by 'i' = 1, 2, 3, 4, 5, then ATSF is

$$\text{ATSF } (T_0) = \left[\sum\nolimits_{i,sr}\left\{\frac{\left\{\text{pr}\left(\xi\xrightarrow{\text{sr(sff)}}\text{i}\right)\right\}\mu\text{i}}{\prod_{m_{1}\neq\xi}\left\{1\text{-}V_{\overline{m_1m_1}}\right\}}\right\}\right] \div \left[1\text{-}\sum\nolimits_{sr}\left\{\frac{\left\{\text{pr}\left(\xi\xrightarrow{\text{sr(sff)}}\xi\right)\right\}}{\prod_{m_{2}\neq\xi}\left\{1\text{-}V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

$= [(0,0)\mu_0]+[\{(0,0)\mu_1\}/(1-L_3)]+[\{(0,2)\mu_2\}/(1-L_1)]/[\{1-(0,1,0)\}/(1-L_3)(1-L_4)]$

$= [\mu_0+\{(p_{0,1}\mu_1)/(1-L_3)\}+\{(p_{0,2}\mu_2)/(1-L_1)\}]/[1-\{(p_{0,1}p_{1,0})/(1-L_3)(1-L_4)\}]$

$= [\beta(\alpha_2+\alpha_3+\alpha)^2]+[(2\alpha_2+\beta_3+\alpha_4)/(3\alpha^2+3\beta+\beta\alpha_4+\alpha_2^3)]$

Now, as we know system is not available at all the times, we get all the states for which system is available in working state. From the transition diagram we find that in up states, system is working fully or partially in states S_i, 0, 1, 2, 3, 4, 5 out of total 13 states.

6.2 Availability (A_0) **of the System:** The working states are at vertices j = 0, 1, 2, 3, 4, 5 and using fuzzy logic, we get

$$A_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\Pi_{m_1\neq\xi}\{1\text{-}V_{\overline{m_1m_1}}\}}\right\}\right]\div\left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_2\neq\xi}\{1\text{-}V_{\overline{m_2m_2}}\}}\right\}\right]$$

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

$= (\sum V_{0,i}f_i\mu_i)\div(\sum V_{0,j}f_j\mu_j)$, Where $1\leq i\leq 5$, $f_i = 1$ and $1\leq j\leq 13$, $f_j = 0$, for $i\neq j$.

$=1/k+[\alpha/k(\beta_3+\alpha_2+\alpha+\alpha_4)]+[2\alpha_2\alpha_4^2(1+\alpha_3)(\beta\beta_5)]/[(\alpha_2+\alpha_3+\beta)(\alpha_2+\alpha_3+\alpha)$

$(\alpha+\alpha_2+\alpha_5+\beta_4)^2][1/n]+[\{\alpha_4^2\alpha_4(3+2\alpha_2)(1+\beta_4)(r+\alpha^2+\beta_3)(5+4\alpha_2+3\beta^2)\}/r]+[\{(\alpha_2\alpha_5\beta\beta_4)(2\beta+3\alpha^2)\}/\{(3\alpha_4+\alpha_2+\beta)(\beta_4+2\alpha_2+5\alpha_3+\alpha)^2(\alpha_2+\alpha_3)\}]/s=$

$(3\alpha_2+5\beta+\alpha_2^2\beta_4+4\alpha)/[3\alpha_4+(\beta+\beta4)^2+3\alpha_2^2\beta+4\alpha\beta_2)]$

6.3 Busy Period of Server/Repairman (B_0): The server is busy for states $1\leq j\leq 13$ and taking initial state ξ = '0', the proportion of time for which server is repairing of faulty units.

$$B_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\},nj}{\Pi_{m_1\neq\xi}\{1\text{-}V_{\overline{m_1m_1}}\}}\right\}\right]\div\left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_2\neq\xi}\{1\text{-}V_{\overline{m_2m_2}}\}}\right\}\right]$$

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

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

$= (\sum V_{0,i}f_i\mu_i)\div(\sum V_{0,j}f_j\mu_j)$, Where $0\leq i\leq 5$, $f_i = 1$ and $1\leq j\leq 13$, $f_j = 0$, for $i\neq j$.

$B_0=N2\div D2$

Where, $N_2 = [\alpha/kl]+[\alpha_3/k(\beta_3+\alpha_2+\alpha_3+\alpha)]+[2\alpha 2\alpha_4^2(1+\alpha_3)\{\beta\beta_5/(\alpha_2+\alpha_3+\beta)(\alpha_2+\alpha_3+\alpha)s^2] + [\alpha_2^2\alpha_4(3+\alpha_2)(1+\beta_4)/(k+\alpha^2)(5+4\alpha_2-\beta^2)r]+[(\alpha_2\alpha_5+\beta\beta_4)(2\beta+3\alpha^2)/(3\alpha_4+\alpha_2+\beta)] + [(\beta_4+2\alpha_2+5\alpha_3+\alpha)^2(\alpha_2+\alpha_3)/s]$

$D_2 = [1+\{\alpha_2/k\}]+[(2\alpha+3\beta_4+\alpha^2+2\beta)/(\alpha_2+1+\beta)^2(4\alpha_2+3\alpha_5)^3]+[(s+\beta)/(n+2\alpha)^2]+(3\alpha+2\alpha^2+\beta_4+\alpha_5)+[(2\alpha+\beta_4+\beta_2+5\alpha_3)/(\alpha^2+\beta_4+9\beta_2+3\alpha_5)] +[(2\alpha^2+\beta_4+3\alpha+\alpha_5)/(3\alpha+\beta_1)(\beta_2+3\alpha_5+4\alpha)^2]$

For standby units and repaired unit working analysis, we have to specify some particular value to failure and repair rates of unit and consider the behavior of other units.

6.4 Profit Function : $C_1T_0 + C_2A_0 - C_3B_0 + \Upsilon$

Where ϒ factor depends upon the working condition of system 'D' materials of units.

6.5 Particular/ Special Cases

Let α_i, i = 1, 2, 3 as some constant failure rate 'α' and β_i, 'i' = 1, 2, 3 as some constant repair rates 'β'. These can take hypothetical values and does not imply that it may happen/ exist in real situation of an industry, using these values of repair and failure rates, we get the above mentioned parameters.

Average time of System Failure (T_0): $= (1+3\alpha)+[\alpha/\{3\alpha(2\alpha+\beta)\}]/(2\alpha/3\alpha)+$ $[\alpha/\{3\alpha(3\alpha+\beta)\}]/\{(\beta+2\alpha)/(3\alpha+\beta)\} +[1-\{\alpha\beta/3\alpha(2\alpha+\beta)\}+(2\alpha/3\alpha)$

Availability of System (A_0): - $A_0 = (3\alpha+5\beta+\alpha_2\beta+4\alpha)/(3\alpha+4\beta^2+3\alpha^2\beta+\alpha\beta)$

Busy Period of Server (B_0): - $B_0 = [\alpha^2(2\alpha+\beta)]+[4\alpha\beta/(\alpha+2\beta)(\alpha+3\beta)]+[\alpha\beta^2(\alpha+2\beta)^2]$

Profit Function: $= [C_1\{\beta k^2\}+\{(2\alpha_2+\beta_3+\alpha_4)/(3\alpha^2+3\beta+\beta\alpha_4+\alpha_2^3)\}]+[C_2(3\alpha_2+5\beta+\alpha_2^2\beta_4+4\alpha)$ $/\{3\alpha_4+(\beta+\beta4)^2+3\alpha_2^2\beta+4\alpha\beta_2)\}]+C_3[[\alpha/kl]+[\alpha_3/sm]+[2\alpha2\alpha_4^2(1+\alpha_3)\{\beta\beta_5/lks^2]$ $+[\alpha_2^2\alpha_4(3+\alpha_2)(1+\beta_4)/(k+\alpha^2)(5+4\alpha_2- \beta^2)r]+[(\alpha_2\alpha_5+\beta\beta_4)(2\beta+3\alpha^2)/(3\alpha_4+\alpha_2+\beta)]$ $+[(\beta_4+2\alpha_2+5\alpha_3+\alpha)^2(\alpha_2+\alpha_3)/s]]/[[1+\{\alpha_2/k\}]+[(2\alpha+3\beta_4+\alpha^2+2\beta)/(\alpha_2+1+\beta)^2(4\alpha_2+3\alpha_5)^3]$ $+[(s+\beta)/(\beta_4+\alpha_2+3\alpha+\alpha_5)^2]+(3\alpha+2\alpha^2+\beta_4+\alpha_5)+[(2\alpha+\beta_4+\beta_2+5\alpha_3)/(\alpha^2+\beta_4+9\beta_2+3\alpha_5)]$ $+[(2\alpha^2+\beta_4+3\alpha+\alpha_5)/(3\alpha+\beta_1)(\beta_2+3\alpha_5+4\alpha)^2]]$

Table 3: ATSF

α ↓\ β→	0.85	0.88	0.90
0.15	6.925	7.215	**9.24**
0.17	4.215	5.86	7.245
0.20	4.005	4.91	6.95

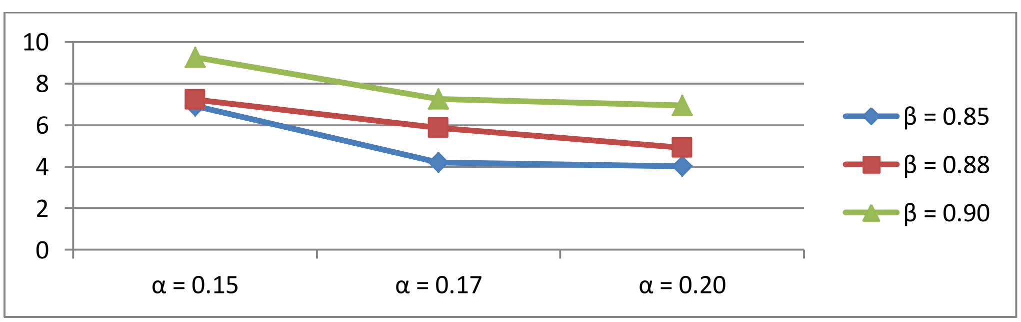

Figure 2: ATSF Graph

Table 4: A_0

α ↓\ β→	0.85	0.88	0.90
0.15	**0.855**	0.76	0.645

0.17	0.61	0.505	0.435
0.20	0.48	0.405	0.31

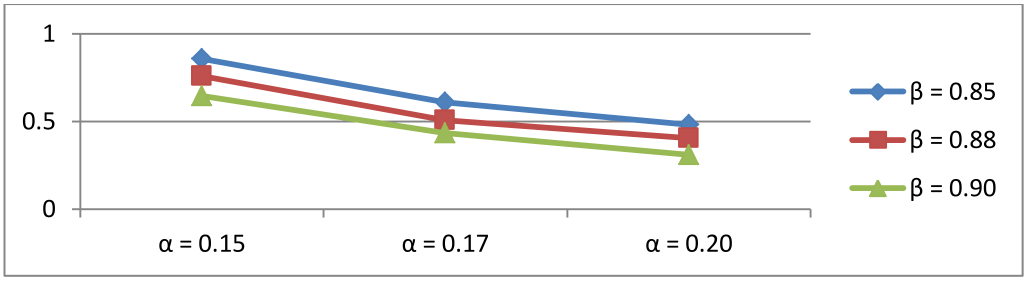

Figure 3: A_0 Graph

Profit Function of System can be understood using following table and graph

Table 5: Profit Function

α ↓\ β→	0.85	0.88	0.90
0.15	8.55	6.05	5.96
0.17	11.215	10.32	9.315
0.20	**13.96**	12.245	11.68

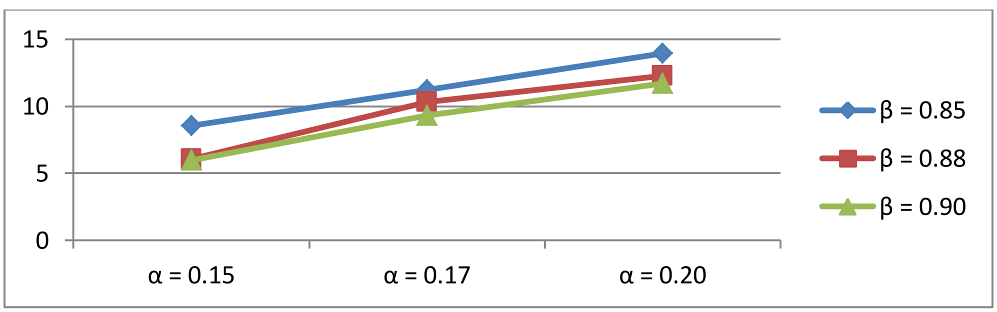

Figure 4: Profit Function Graph

7. Conclusion

Table 3 and figure 2 shows the behavior of the ATSF vs. the repair rate of the unit of the framework for various values of disappointment rate. It is determined that ATSF increases with rise in the values of repair rate and losses with rise in disappointment rate. Table 4 and figure 3 shows the performance of the Accessibility vs. Reparation rate of the unit of the framework for numerous values of the disappointment rate. It is determined that Accessibility rises with rise in values of the Reparation rate & reductions with the rise in disappointment rates. The optimum values of system parameters and profit are highlighted in table 5 and graph 4, which are also practically observed in industry corresponding to increasing failure & repair rates of units, similar results may be derived for other industries.

References:

1) Komal, S., P. and Kumar, D. (2009). RAM analysis of the press unit in a paper plant using genetic algorithm and lambda-tau methodology. *In Proceeding of the 13th online International Conference (WSC '08), (Springer Book Series),* 127–137.
2) Kumar, A. Garg, D. and Goel, P. (2019). Mathematical modelling and behavioural analysis of a washing unit in paper mill. *International Journal of System Assurance Engineering and Management*, 10, 1639-1645.
3) Jieong, S., Hasegawa, S., Shimoyama, and Obayashi, S. (2009). Development and investigation of efficient GA/PSO-hybrid algorithm applicable to real-world design optimization. *IEEE Computational Intelligence Magzine,* 4, 36-44.
4) 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.
5) Anchal, Majumder A, Goel P (2021) Irregular Fluctuation of Successive SW Release Models. *Design Engineering,* 7, 8954-8962.
6) Bhunia, A. K., Sahoo, L., and Roy, D. (2010). Reliability stochastic optimization for a series system with interval component reliability via genetic algorithm. *Applied Mathematics and Computation*, 216(3), 929-939
7) Malik, S., Verma, S., Gupta, A., Sharma, G., and Singla, S. (2022). Performability evaluation, validation and optimization for the steam generation system of a coal-fired thermal power plant. *Methods*, 9, 1-14.
8) Kumari S, Khurana P, Singla S (2021) Behaviour and profit analysis of a thresher plant under steady state. *International Journal of System Assurance Engineering and Man.*, 1-12.
9) Kumar, A., Goel, P., Garg, D., and Sahu A. (2017). System behaviour analysis in the urea fertilizer industry. *Book: Data and Analysis communications in computer and information Science*, 1, 3-12.