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SIMULATION MODELING OF WATER PACKAGING PLANT COMPRISING OF FOUR UNITS WITH PROTECTIVE MAINTENANCE AND DETERIORATION

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Abstract

In this paper, we have tried to provide a stochastic model by simulation analysis of a drinking water packaging system comprising of four units as used for process of Clarification, Flocculation, Filtration and Disinfection. In this system protective maintenance is applied to main unit and deterioration takes place after repairing on passing through complete non performing stage in the same unit and the other units are provided perfect repair. The system is analyzed using Regenerative Point Graphical Technique (RPGT) is done. Here we have considered that since all subunits are connected in parallel topology and initially working at full capacity. The main unit A may go through two types of failures one is direct and second one is through partial failure mode, but complementary units can fail directly. A person is provided for protective maintenance of main unit who will inspect and repair the subunits when a need arises. Protective maintenance is applied to the main unit on partial failure before attaining of complete non performing stage. The server which is appointed to repair the units and founds always the main unit cannot be restored to its original capacity means goes to a degraded/ deteriorated state. Some special cases are taken into consideration to study the effect of variation in failure/repair *rates on the parameters like average time of operation and repair time upon which the profit of system depends. To explain performance in of plant/ system in better way bar graphs/curve diagrams is also plotted.*

Keywords: Simulation, Protective Maintenance, Deterioration, ATSF, Availability, Fuzzy Logic, Working Period of Server, Expert's Visits, Performance.

2010 AMS classification: 97M10

1. Introduction

Here we have analyzed working of a system comprising four units as mentioned above. In this system whole operational behavior is based upon working of main unit having parallel sub units so that it is operational in full capacity as well as in a state of reduced capacity. Nandal and Anand (2018) have presented a research article paper to study the comparison between two reliability models and given analysis. In last few years' researcher have tried to study behavioral analysis many processing industries with a number of considerations. Kumar et al. (2019) have given mathematical modeling of paper mill and analyzed the behavior under various conditions. Kumari et al. (**2021)** have studied working of thresher machine used in agriculture and given profit analysis. Goyal and Goel (2016) discussed the behavioural Analysis of four unit's framework with PM and deterioration in single using RPGT. Profit optimization is also discussed with the assistance of graphs and tables. Tsung-Jung **(2021)** have published a paper on hybrid artificial-bee colony algorithm and simplified swarm optimization to solve problem regarding allocation of redundant units. Kumar et al. (2018) studied a bread-making system comprising five distinct sub-systems such as Mixer, Oven, Tunnels, Divider & Proofer and evaluated some useful facts about working of industry under steady-state. The model is presented for a validated on real SW data set. Aggrawal et al.

(2021) studied the profit analysis of a Water Treatment RO Plant is agreed out by utilizing the same technique used by us. In the present paper arithmetical analysis is accepted out for calculating the performance measures. Gao et al. (2019) considered mechanism of a planar slider crank having two clearance joints to study the reliability sensitivity analysis and optimization design using the Monte Carlo method. Tahir et al. (2019) demonstrated a model to interpret warm capacity and demand response improve the part of variable manageable force sources.

2. Working of system

Some basic assumptions are to be taken into consideration that the protective maintenance is not provided to other subunits except main unit which can perform in a low performance stage stated as deteriorated state. Also it is assumed that the rates of repair and downfall of subunits remain same which may not be practical in every time. Based upon the above said assumptions and notations let we try to understand the working of system. Some notation is used in this study as working state of unit is shown by capital alphabets and non-working state is shown by small alphabets. On spot repair of main unit is available in the industry. The expert does two kind of repair that first one is protective maintenance which is not cent percent accurate i.e. the unit after this is not good as new one on complete failure, in the other kind of repair the units B, C and D is taken fully repaired. The exponential probability distribution is used as the rates of downfall of system and repair of units in both type protective maintenance as well as repair of other units. There is no correlation between the all type of repair and failure rates of units nothing can fail when the system is in failed state. There is no concept of waiting time as server is ready for his duty at all time. Unit A can fail completely as well as through partial failure but unit B, C and D have complete failure only. A Transition Diagram can be drawn to understand the working of system and interconnected units as given below.

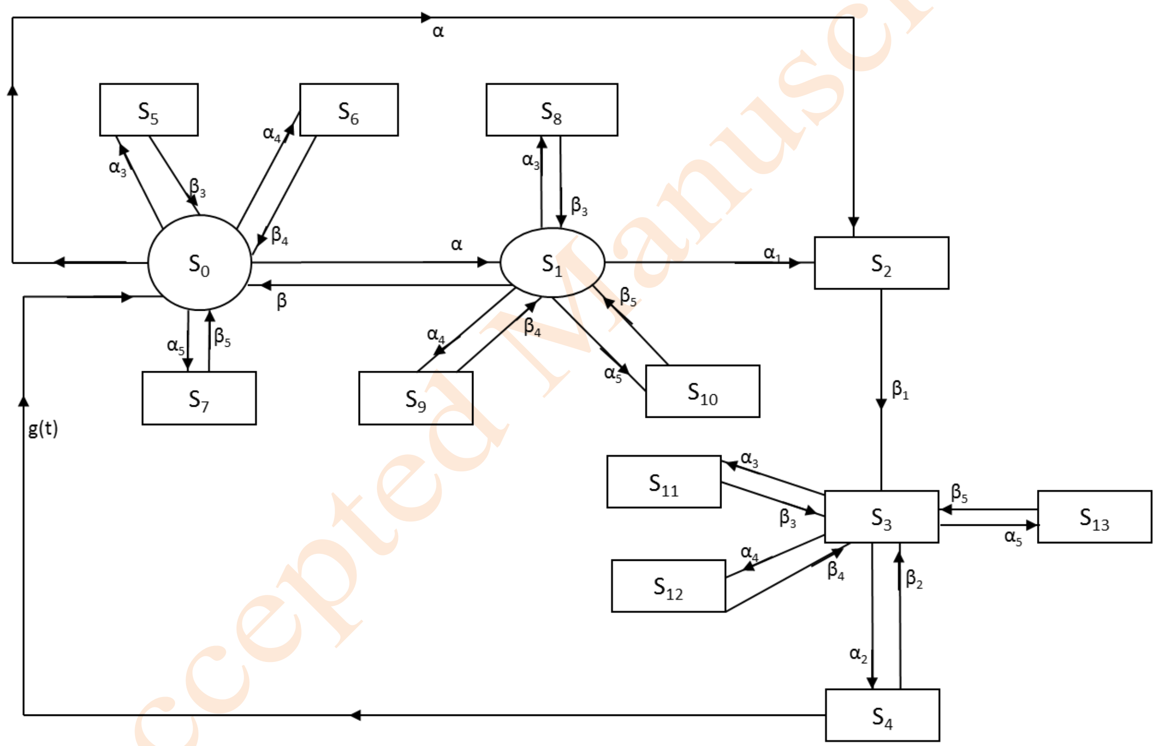

Figure 1: Transition Diagram

In the above given flow diagram for the transition of system through a number of stages we have used symbols prescribed as follows. Here suffixes A_1 stage represent the deteriorated state of unit A after the repair and $\bar{A}$ represents a stage which is not up to the mark i.e. partially working state.

S_0	=	ABCD	S_1	=	$\bar{A}$BCD	S_2	=	aBCD
S_3	=	A_1BCD	S_4	=	a_1BCD	S_5	=	AbCD
S_6	=	ABcD	S_7	=	ABCd	S_8	=	$\bar{A}$bCD
S_9	=	$\bar{A}$BcD	S_{10}	=	$\bar{A}$BCd	S_{11}	=	A_1bCD
S_{12}	=	A_1BcD	S_{13}	=	A_1BCd			

1. α is rate at which the main unit goes Partial/initial failure, β is the rate of preventive maintenance
2. $\lambda_1, \lambda_2 \lambda_3, \lambda_4 \lambda_5$ Failure rates of Unit A from $\bar{A}$ to a., $\bar{A}_1$ to a_1 and other units B, C and D, respectively.
3. $w_1,\ w_2 w_3,\ w_4\ w_5$ Repair rates of unit A from a to $\bar{A}$. a_1 to $\bar{A}_1$.B, C and D, respectively.

Table 1: Linear Path showing Primary, Secondary and Tertiary Circuits from different states:

i	Primary Circuits	Secondary Circuits	Tertiary Circuits
0	[0,1,0]	[1,8,1], [1,9,1],[1,10,1]	None
	[0,5,0]	None	None
	[0,6,0]	None	None
	[0,7,0]	None	None
	[0,1,2,3,4,0]	[1,8,1], [1,9,1] [1,10,1], [3,11,3]	None

		[3,12,3], [3,13,3]	
	[0,2,3,4,0]	[3,11,3], [3,12,3] [3,13,3]	None
1	[1,8,1]	None	None
	[1,9,1]	None	None
	[1,10,1]	None	None
	[1,2,3,4,0,1]	[3,11,3], [3,12,1],[3,1,3,1],[0,5,0] [0,6,0], [0,7,0]	None
	[1,0,1]	[,5,0], [0,6,0] [0,7,0]	None
2	[2,3,4,0,1,2]	[3,11,3], [3,12,3],[3,1,3,1], [0,5,0] [0,6,0], [0,7,0],[1,8,1], [1,9,1] [0,5,0]	None
	[2,3,4,0,2]	[1,10,1],[3,11,3], [3,12,3],[3,13,1], [0,6,0], [0,7,0]	None
3	[3,4,3]	None	None
	[311,3]	None	None
	[3,12,3]	None	None
	[3,13,3]	None	None
	[3,4,0,1,2,3]	[0,5,0], [0,6,0] [0,7,0], [1,8,1] [1,9,1], [1,10,1]	None
	[3,4,0,2,3]	[0,5,0], [0,6,0] [0,7,0]	None
4	[4,3,4]	[3,11,3], [3,12,3],[3,13,1]	None
		[0,5,0], [0,6,0] [0,7,0], [1,8,1]	None
	[4,0,1,2,3,4]	[1,9,1], [1,10,1][3,11,3],	None

	[4,0,2,3,4]	[3,12,3][3,13,3][0,5,0], [0,6,0] [0,7,0], [3,11,3] [3,12,3], [3,13,3]	None
5	[5,0,5]	[0,6,0], [0,7,0][0,1,0]	None
6	[6,0,6]	[0,5,0], [0,7,0] [0,1,0]	None [1,8,1], [1,9,1] [1,10,1]
7	[7,0,7]	[0,5,0], [0,6,0][0,1,0]	None
8	[8,1,8]	[1,9,1], [1,10,1] [1,0,1]	None [0,5,0], [0,6,0] [0,7,0]
9	[9,1,9]	[1,8,1], [1,10,1] [1,0,1]	None [0,5,0], [0,6,0] [0,7,0]
10	[10,1,10]	[1,8,1], [1,9,1] [1,0,1]	None [0,5,0], [0,6,0] [0,7,0]
11	[11,3,11]	[3,12,3], [3,13,3][3,4,3]	None
12	[12,3,12]	[3,11,3], [3,13,3][3,4,3]	None

13	[13,3,13]	[3,11,3], [3,12,3][3,4,3]	None

From above table we see that primary circuits are maximum and secondary and tertiary circuits are minimum at state $S_{0,}$ there for this is our base state, now we will find transition probabilities from all states to that base state.

$q_{i,j}[t]$ **:** It represents the Prob. Dist. Function for the system to go from state I to state j in the time interval [0,t].

$p_{i,j}$ **:** It represents the probability of transition of system for steady state from a regenerative state 'i' to a regenerative state 'j' which is determined or calculated with the help of Laplace transformation in which we can take parameter 's' used in integration as zero.

Table 2: Probabilities of Transition

$q_{i,j}^{[t]}$	$P_{ij} = q^*_{i,j}{}^{[t]}$
$q_{0,1}= \alpha e^{-(\alpha+\lambda_3+\lambda_4+\lambda_5)t}$	$P_{0,1}= \alpha/\alpha + \lambda_3 + \lambda_4 + \lambda_5 + \lambda$
$q_{0,5}= \lambda_3 e^{-(\alpha+\lambda_3+\lambda_4+\lambda_5)t}$	$P_{0,5}= \alpha/\alpha + \lambda_3 + \lambda_4 + \lambda_5 + \lambda$
$q_{0,6}= \lambda_4 e^{-(\alpha+\lambda_3+\lambda_4+\lambda_5+\lambda)t}$	$P_{0,6}= \lambda_4/\alpha + \lambda_3 + \lambda_4 + \lambda_5 + \lambda$
$q_{0,7}= \lambda_5 e^{-(\lambda_3+\lambda_4+\lambda_5+\alpha+\lambda)t}$	$P_{0,7}= \lambda_5/\lambda_3 + \lambda_4 + \lambda_5 + \alpha + \lambda$
$q_{0,2}=\lambda e^{-(\lambda_3+\lambda_4+\lambda_5+\alpha+\lambda)t}$	$P_{0,2}= \lambda/\lambda_3 + \lambda_4 + \lambda_5 + \alpha + \lambda$
$q_{1,0}= \beta e^{-(\beta+\lambda_3+\lambda_4+\lambda_5+\lambda_1)t}$	$P_{1,0}= \beta/\beta + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_1$
$q_{1,2}= \lambda_1 e^{-(\beta+\lambda_3+\lambda_4+\lambda_5+\lambda_1)t}$	$P_{1,2}= \lambda_1/\beta + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_1$
$q_{1,8}= \lambda_3 e^{-(\beta+\lambda_3+\lambda_4+\lambda_5+\lambda_1)t}$	$P_{1,8}= \lambda_3/\beta + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_1$

$q_{1,9}= \lambda_4 e^{-(\beta+\lambda_3+\lambda_4+\lambda_5+\lambda_1)t}$	$P_{1,9}= \lambda_4/\beta + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_1$
$q_{1,10}= \lambda_5 e^{-(\beta+\lambda_3+\lambda_4+\lambda_5+\lambda_1)t}$	$P_{1,10}= \lambda_5/\beta + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_1$
$q_{2,3}= w_1 e^{-w_1 t}$	$P_{2,3}=1$
$q_{3,3}= \lambda_5 e^{-(\lambda_3+\lambda_4+\lambda_5+\lambda_2)t}$	$P_{3,3}=\lambda_5/\lambda_3 + \lambda_4 + \lambda_2 + \lambda_5$
$q_{3,4}= \lambda_2 e^{-(\lambda_3+\lambda_4+\lambda_5+\lambda_2)t}$	$P_{3,4} = \lambda_2/\lambda_3 + \lambda_3 + \lambda_2 + \lambda_5$
$q_{3,11}= \lambda_3 e^{-(\lambda_3+\lambda_2+\lambda_4+\lambda_5)t}$	$P_{3,11}= \lambda_3/\lambda_3 + \lambda_2 + \lambda_4 + \lambda_5$
$q_{3,12}= \lambda_4 e^{-(\lambda_3+\lambda_2+\lambda_4+\lambda_5)t}$	$P_{3,12}= \lambda_4/\lambda_3 + \lambda_2 + \lambda_4 + \lambda_5$
$q_{4,0}= g[t]e^{-w_3[t]}$	$p_{4,0}= g^*[w_3]$
$q_{4,3}= w_3 e^{-w_3 t}\overline{g[t]}$	$p_{4,3}= 1-g^*[w_3]$
$q_{5,0}= w_3 e^{-w_3 t}$	$P_{5,0}= 1$
$q_{6,0}= w_4 e^{-w_4 t}$	$P_{6,0}= 1$
$q_{7,0}= w_5 e^{-w_5 t}$	$P_{7,0}= 1$
$q_{8,1}= w_3 e^{-w_3 t}$	$P_{8,1} = 1$
$q_{9,1}= w_4 e^{-w_4 t}$	$P_{9,1}= 1$
$q_{10,1}= w_5 e^{-w_5 t}$	$P_{10,1}= 1$
$q_{11,3}= w_3 e^{-w_3 t}$	$P_{11,3}= 1$
$q_{12,3}= w_4 e^{-w_4 t}$	$P_{12,3}= 1$
$q_{13,3}= w_5 e^{-w_5 t}$	$P_{13,3}= 1$

Table 3: Average Sojourn Time at various stages

$R_i[t]$	$\mu_i=R_i^*[0]$
$R_0^{(t)}= e^{-(\alpha+\lambda+\lambda_3+\lambda_4+\lambda_5)t}$	$\mu_0 = 1/(\alpha + \lambda + \lambda_3 + \lambda_4 + \lambda_5)$
$R_1^{(t)}= e^{-(\lambda_1+\lambda_3+\lambda_4+\lambda_5)t}$	$\mu_1= 1/(\lambda_1 + \lambda_3 + \lambda_4 + \lambda_5)$
$R_2^{(t)}= e^{-w_1 t}$	$\mu_2= 1/w_1$
$R_3^{(t)}= e^{-(\lambda_2+\lambda_3+\lambda_4+\lambda_5)t}$	$\mu_3= 1/(\lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)$
$R_4^{(t)}= e^{-w_3 t}\overline{g(t)}$	$\mu_4= [1-g^* w_3]/w_3$
$R_5^{(t)}= e^{-w_3 t}$	$\mu_5= 1/w_3$
$R_6^{(t)}= e^{-w_4 t}$	$\mu_6= 1/w_4$
$R_7^{(t)}= e^{-w_5 t}$	$\mu_7= 1/w_5$
$R_8^{(t)}= e^{-w_3 t}$	$\mu_8= 1/w_3$
$R_9^{(t)}= e^{-w_4 t}$	$\mu_9= 1/w_4$
$R_{10}^{(t)}= e^{-w_5 t}$	$\mu_{10}= 1/w_5$
$R_{11}^{(t)}= e^{-w_3 t}$	$\mu_{11}= 1/w_3$
$R_{12}^{(t)}= e^{-w_4 t}$	$\mu_{12}= 1/w_4$
$R_{13}^{(t)}= e^{-w_5 t}$	$\mu_{13}= 1/w_5$

Now by the use of some notations as

L_1= [0,1,0] L_2 = [0,5,0] L_3 = [0,6,0] L_4 = [0,7,0] L_5 = [1,8,1] L_6= [1,9,1]

L_7 = [1,10,1] L_8 = [3,4,3] L_8 = [3,4,3] L_9 = [3,11,3] L_{10} = [3,12,3] L_{11} = [3,13,3]

Path Probabilities from the maximum stay state '0' to a number of stages through which system passes are represented as $V_{0,i}$, i= 0 to 13

$V_{0,0} = 1$,

$V_{0,1} = p_{0,1} = \alpha/[\alpha+\lambda_3+\lambda_4+\lambda_5+\lambda]$

$V_{0,2} = p_{0,1}p_{1,2}/[1-p_{1,8}p_{8,1}][1-p_{1,9}p_{9,1}][1-p_{1,10}p_{10,1}]+p_{0,2}$

$= \alpha\lambda/[\lambda+\lambda_3+\lambda_4+\lambda_5+\alpha][w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6]\div[w_1+\lambda_2+\lambda_4+\alpha][w_1+\lambda_2+\lambda_5+\alpha]$

$[w_1+\lambda_2+\lambda_4+\lambda_5]/[w_1+\lambda_2+\lambda_4+\lambda_5+\alpha]^3+\lambda/[\lambda+\lambda_1+\lambda_4+\lambda_5+\alpha]$

$V_{0,3} = p_{0,2}p_{2,3}+p_{0,1}p_{1,2}p_{2,3}/[1-p_{1,6}p_{6,1}][1-p_{1,8}p_{8,1}]$

$= \lambda_1\lambda_2/[\lambda_1+\lambda_4+\lambda_5+\alpha+\lambda][w_1+\beta+\lambda_4+\lambda_5+\lambda_3]\div[w_1+\lambda_2+\lambda_4+\lambda_6][w_1+\lambda_2+\lambda_5+\beta]$

$[w_1+\lambda_2+\lambda_4+\lambda_5]/[w_1+\lambda_2+\lambda_4+\lambda_5+\beta]^3[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\beta][\lambda_4+\lambda_5+\beta]$

$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4+\lambda/[\lambda_1+\lambda+\lambda_4+\lambda_5+\beta]\div[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\beta]$

$/[\lambda_3+\lambda_4+\lambda_5+\beta^4$

$V_{0,4} = p_{0,2}p_{2,3}+p_{0,1}p_{1,2}p_{2,3}/[1-p_{1,6}p_{6,1}][1-p_{1,8}p_{8,1}]$

$= \lambda_1\lambda_2/[\lambda_1+\lambda_4+\lambda_5+\alpha+\lambda][w_1+\lambda_2+\lambda_4+\lambda_5+\beta]\div[w_1+\lambda_2+\lambda_4+\alpha][w_1+\lambda_2+\lambda_5+\beta]$

$[w_1+\lambda_2+\lambda_4+\lambda_5]/[w_1+\lambda_2+\lambda_4+\lambda_5+\beta]^3[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\beta][\lambda_3+\lambda_4+\beta][\lambda_4+\lambda_5+\alpha]$

$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4+\lambda/[\lambda_1+\lambda+\lambda_4+\lambda_5+\beta]\div[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\lambda_6][\lambda_3+\lambda_4+\beta][\lambda_4+\lambda_5+\beta]$

$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4\lambda_3/[\lambda_3+\lambda_4+\lambda_5+\beta]$

$V_{0,5} = \lambda_3/[\lambda+\lambda_3+\lambda_5+\lambda_4+\alpha]$,

$V_{0,6} = \lambda_4/[\lambda+\lambda_3+\lambda_5+\lambda_4+\alpha]$

$V_{0,7} = \lambda_5/[\lambda+\lambda_3+\lambda_4+\lambda_5+\alpha]$

$V_{0,8} = [0,1,8] = p_{0,1}p_{1,8}= \alpha\lambda_3/[\lambda+\lambda_3+\lambda_4+\lambda_5+\alpha][\beta+\lambda_2+\lambda_4+\lambda_5+\alpha]$

$V_{0,9} = [0,1,9] = p_{0,1}p_{1,9} = \alpha\lambda_4/[\lambda+\lambda_1+\lambda_3+\lambda_5+\alpha][\beta+\lambda_3+\lambda_4+\lambda_5+\alpha]$

$V_{0,10} = [0,1,10] = p_{0,1}p_{1,10} = \alpha\lambda_5/[\lambda+\lambda_3+\lambda_4+\lambda_5+\alpha][\beta+\lambda_3+\lambda_4+\lambda_5+\alpha]$

$V_{0,11} = p_{0,2}p_{2,3}+p_{0,1}p_{1,2}p_{2,3}/[1-p_{1,6}p_{6,1}][1-p_{1,8}p_{8,1}]$

$= \alpha\lambda_3/[\lambda_1+\lambda_4+\lambda_5+\alpha+\lambda][\beta+\lambda_2+\lambda_4+\lambda_5+\lambda_6]\div[\beta+\lambda_2+\lambda_4+\lambda_6][\beta+\lambda_2+\lambda_5+\lambda_6]$
$[\beta+\lambda_2+\lambda_4+\lambda_5]/[\beta+\lambda_2+\lambda_4+\lambda_5+\alpha]^3[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\alpha]$
$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4+\lambda/[\lambda_1+\lambda+\lambda_4+\lambda_5+\alpha]\div[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\alpha]$
$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4\lambda_4/[\lambda_3+\lambda_4+\lambda_5+\alpha]$

$V_{0,12} = p_{0,2}p_{2,3}+p_{0,1}p_{1,2}p_{2,3}/[1-p_{1,6}p_{6,1}][1-p_{1,8}p_{8,1}]$
$= \alpha\lambda_4/[\lambda_1+\lambda_4+\lambda_5+\alpha+\lambda][\beta+\lambda_2+\lambda_4+\lambda_5+\lambda_6]\div[\beta+\lambda_2+\lambda_4+\alpha][\beta+\lambda_2+\lambda_5+\alpha]$
$[\beta+\lambda_2+\lambda_4+\lambda_5]/[w_1+\lambda_2+\lambda_4+\lambda_5+\alpha]^3[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\alpha]$
$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4+\lambda/[\lambda_1+\lambda+\lambda_4+\lambda_5+\alpha]\div[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\alpha]$
$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4\lambda_5/[\lambda_3+\lambda_4+\lambda_5+\alpha+\beta]$

$V_{0,13} = p_{0,2}p_{2,3}+p_{0,1}p_{1,2}p_{2,3}/[1-p_{1,6}p_{6,1}][1-p_{1,8}p_{8,1}]$
$= \alpha\lambda_5/[\lambda_1+\lambda_4+\lambda_5+\alpha+\lambda][\beta+\lambda_2+\lambda_4+\lambda_5+\lambda_6]\div[\beta+\lambda_2+\lambda_4+\alpha][\beta+\lambda_2+\lambda_5+\lambda_6]$
$[w_1+\lambda_2+\lambda_4+\lambda_5]/[w_1+\lambda_2+\lambda_4+\lambda_5+\alpha]^3[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\alpha]$
$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4+\lambda/[\lambda_1+\lambda+\lambda_4+\lambda_5+\alpha]\div[\lambda_3+\lambda_4+\lambda_5][\lambda_3+\lambda_5+\alpha][\lambda_3+\lambda_4+\alpha][\lambda_4+\lambda_5+\alpha]$
$/[\lambda_3+\lambda_4+\lambda_5+\alpha]^4\alpha/[\lambda_3+\lambda_4+\lambda_5+\alpha]$

ATSF[T_0]: For computing profit function and other parameters, In the RPG Technique for, the average time for a system spent in regenerative un-failed state [initial state ‘0’], before going through any type of failed state are: ‘i’ = 0,1,2,3,4 so we have taken the value of ξ = ‘0’.

$$\text{ATSF}\ [T_0] = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr[sff]}i\right)\right\}\mu i}{\Pi_{m_1\neq\xi}\left\{1\text{-}V_{\overline{m_1m_1}}\right\}}\right\}\right]\div\left[1\text{-}\sum_{sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr[sff]}\xi\right)\right\}}{\Pi_{m_2\neq\xi}\left\{1\text{-}V_{\overline{m_2m_2}}\right\}}\right\}\right]$$

$T_0 = [0,0]\mu_0+[0,1]\mu_1\div 1\text{-}[0,1,0]= [p_{0,0}\mu_0+p_{0,1}\mu_1]\div[1\text{-}p_{0,1}p_{1,0}]$

$=1/[\lambda+\lambda_1+\lambda_4+\lambda_5+\alpha]+\lambda_1/[\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda][\beta+\lambda_2+\lambda_4+\lambda_5+\alpha]\div 1$

$\lambda_1\beta[\lambda+\lambda_1+\lambda_4+\lambda_5+\alpha][\beta+\lambda_2+\lambda_4+\lambda_5+\lambda_6]$

$= [\beta+\lambda_2+\lambda_4+\lambda_5+\alpha]+\lambda_1\div[\beta+\lambda_2+\lambda_4+\lambda_5+\alpha][\lambda+\lambda_1+\lambda_4+\lambda_5+\alpha]-\lambda_1\beta$

4. Availability of the System:

It is the time for which the system is available in the regenerative state in the working state and can be computed by formula listed below by taking fraction of total time in which system in upstate to the total time. Here we take j = 0,1,2,3,4, i = 0 to 10, ξ = '0'. Now availability time the system is available is given by

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

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

$=$

$[V_{3,0}\mu_0+V_{3,1}\mu_1+V_{3,3}\mu_3]\div[V_{3,0}\mu_0+V_{3,1}\mu_1+V_{3,2}\mu_2+V_{3,3}\mu_3+V_{3,4}\mu_4+V_{3,5}\mu_5+V_{3,6}\mu_6+V_{3,7}\mu_7$
$+V_{3,8}\mu_8+V_{3,9}\mu_9+V_{3,10}\mu_{10}+V_{3,11}\mu_{11}+V_{3,12}\mu_{12}+V_{3,13}\mu_{13}]$

$= \lambda_3 g^*[w_3]/[\lambda_3+\lambda_4+\lambda_5+\alpha]\div 1-\lambda_1\beta/[\lambda+\lambda_1+\lambda_4+\lambda_5+\alpha][\beta+\lambda_2+\lambda_4+\lambda_5+\alpha][\lambda+\lambda_1+\lambda_4+\beta]$

Busy Period of the Server: Since the expert repairman visits whenever need is created at any time. It can be calculated for a regenerative state as server is busy at stages for suffix 'j' =1,2,3,4,5,6,7,8,9,10 and we take ξ = '0' is computed the total fraction of time for which the repairman is busy to the total time he/she is available given as:

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

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

$B_0= [V_{3,1}\mu_1+V_{3,2}\mu_2+V_{3,4}\mu_4+V_{3,5}\mu_5+V_{3,6}\mu_6+V_{3,7}\mu_7+V_{3,8}\mu_8+V_{3,9}\mu_9+V_{3,10}\mu_{10}+V_{3,11}\mu_{11}$

$+V_{3,12}\mu_{12}+V_{3,13}\mu_{13}]\div[V_{3,0}\mu_0+V_{3,1}\mu_1+V_{3,2}\mu_2+V_{3,3}\mu_3+V_{3,4}$

$\mu_4+V_{3,5}\mu_5+V_{3,6}\mu_6+V_{3,7}\mu_7+V_{3,8}\mu_8+V_{3,9}\mu_9+V_{3,10}\mu_{10}+V_{3,11}\mu_{11}+V_{3,12}\mu_{12}+V_{3,13}\mu_{13}]$

$=N_1 \div D_1$Where $N_1= \beta/[\beta+w_3+w_4+w_5]+2\beta[\alpha+2\lambda\beta+\alpha w_3+w_4+\alpha w_5]$

$D_1 = [\alpha+\lambda_1+\lambda_3+\lambda_{4+}\lambda_5]+[2\alpha+\lambda_1+ \lambda_4+ \lambda_5]$

Some special Cases: Considering the different values of Preventive Maintenance factor and the repair rates. The replacing of unit by new unit is given by $g[t] = we^{-wt}$

So that $g^*[w] = L[we^{-wt}] == w_3L[e^{-wt}]== w_3 1/[w_3+w_3] = 1/2$

Putting these values, we got

ATSF [T_0]: - $[\alpha+2\beta]/[[4\alpha+\beta][5\lambda]-\beta\alpha]=[w+5\lambda]/[20\lambda^2+4\lambda w]=[w+5\lambda]/4\lambda[5\lambda+w]$

Table 4: ATSF

T_0	$\beta = 0.90$	$\beta = 0.92$	$\beta = 0.95$
$\alpha = 0.05$	0.8120	0.8392	0.8516
$\alpha = 0.10$	0.7655	0.7890	0.8005
$\alpha = 0.15$	0.7132	0.7415	0.7780

Here we have considered the repair rates [w_r] and failure rates [λ_r] as constant to be happened for steady states condition.

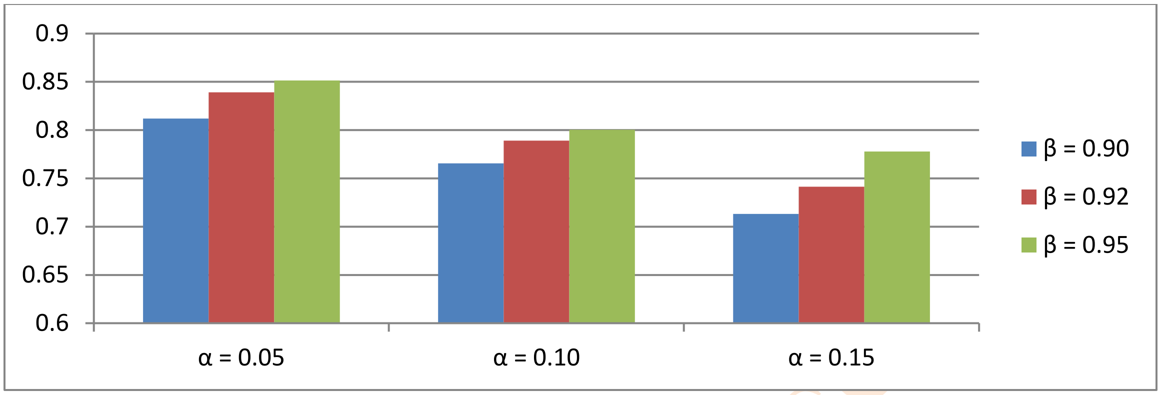

Fig. 2: ATSF

This shows that **Average time to system failure** is inversely proportional to failure rate 'λ'

4. Availability of System

$A_0 = N \div D$ where $N = 3\lambda\beta^2+4\alpha\beta+\alpha$, $D = 5\alpha\beta^2+2\beta\alpha^2+6\alpha\beta+2\alpha$

Table 5: Availability of System

A_0	$\beta = 0.90$	$\beta = 0.92$	$\beta = 0.95$
α =0.005	0.9882	0.9885	0.9889
α = 0.007	0.9814	0.9819	0.9823
α = 0.009	0.9801	0.9803	0.9807

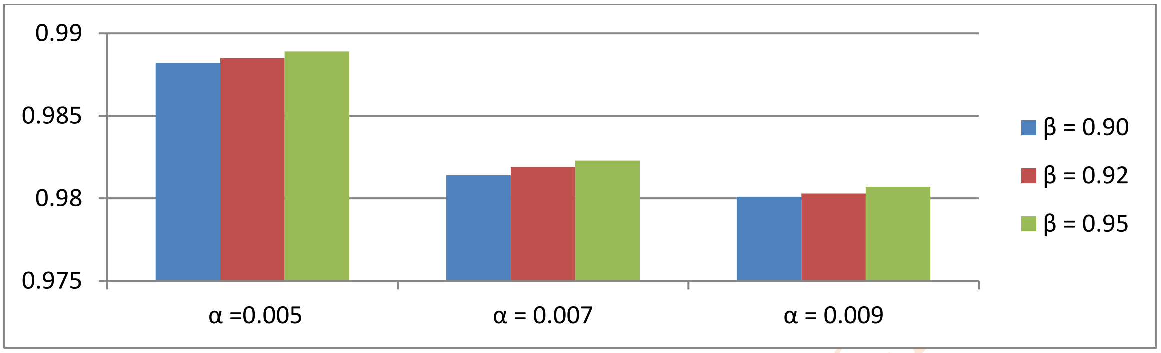

Fig. 3: Availability of System

This bar diagram shows the behavior of Availability [A_0] Vs the repair rate 'w' of unit of system for different values of failure rate 'λ'. It can be seen from table values that availability increases with increase in repair rate and with decrease in failure rate

5. Performance of system

Considering impact of preventive maintenance and different failure and repair rates on all the parameters mentioned above, finally we have to find the performance of the system under study. This can be done by using the Performance function as P0 = C1T0+C2A0-C3B0-C4V0

=C1 [[β+5α]/4α[5α+β]]+C2 [[3αβ^2+4αβ+α]/[5αβ^2+2βα^2+6αβ+2α]]-C3[[α+β][α+α+2β]]-C4[2α-β+5α]

Table 6: Performance/Output Function

[P_0]	β = 0.85	β = 0.90	β = 0.95
α = 0.05	0.8728	0.9392	0.9518
α = 0.08	0.8155	0.8390	0.8745
α = 0.10	0.7532	0.7815	0.8240

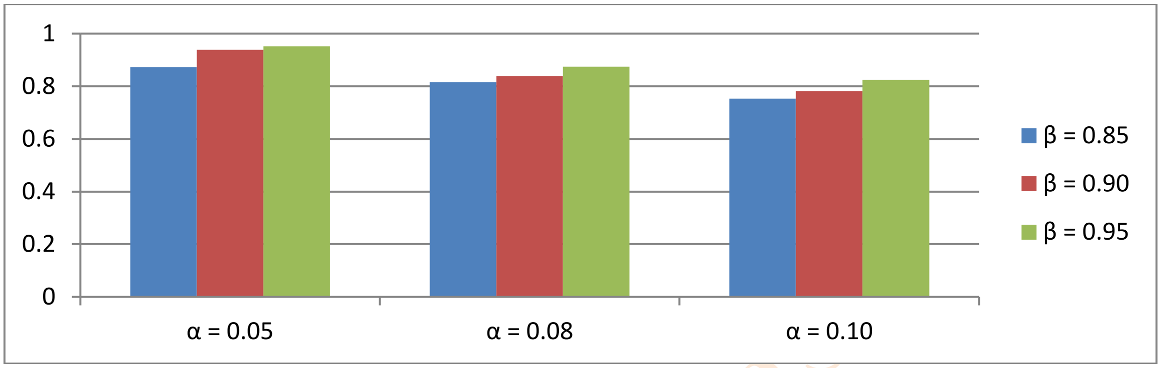

Fig. 4: Performance/Output Function

6. Conclusions

We arrive at a conclusion that Protective Maintenance plays a vital role in optimization of performance of system. The research design and methodology used in this paper are replicable to other industries with the assumption and limitations considered in this paper, and research results obtained in this paper are useful for similar manufacture businesses, giving optimized throughput as a result of this reliability study.

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