International Journal of Engineering, Science & Mathematics
Vol. 13 Issue 01, January 2024,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gate as well as in Cabell's Directories of Publishing Opportunities, U.S.A

AVAILABILITYANALYSIS OF FOUR UNIT SYSTEM WITH PREVENTIVE MAINTENANCE AND DEGRADATION IN ONE UNIT IN REPAIR AND FAILURE RATES

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DOI:ijesm.102232.11459

Abstract: This paper discusses Availability Analysis of Four Unit System with Preventive Maintenance and Degradation. In One Unit, and a single permanent repairman who is 24x7 available using the Regenerative Point Graphical Technique (RPGT). Initially, all the units A, B, C & D are working at full capacity in which unit A may have two types of failures one is direct and second one is through partial failure mode, but unit B, C and D can fail directly. We analysis of a System comprising four units with Preventive Maintenance and Degradation in main unit is done. Various systems are assembly of a number of units. A four unit system is used in a number of process industries such as Utensil Industry and Cloth Industry and many more others. If a single unit fails then the whole system fails. Various path probabilities mean sojourn time is discussed by drawing tables for increasing failure/repair rates and graphs.

Keywords:-Availability, Mean time to system Failure, Busy period of the server

1. Introduction:

This article discusses a system with four units, one of which has flawless repair using the Regenerative Point Graphical Technique (RPGT) and the other of which has preventive maintenance applied before full failure and degeneration in one unit post-failure. At first, all four units—A, B, C, and D—are operating at maximum capacity. Unit A may experience a direct failure or a partial failure mode, but units B, C, and D may have a direct failure. Preventive maintenance is performed on a system consisting of four units, and the primary unit undergoes degradation. Multiple pieces are assembled to form different systems. Many process industries, like the cloth and utensil industries, among many others, use four unit systems. The system fails as a whole if one unit malfunctions. In light of the significance of a single unit within the larger system, we have examined a system consisting of four subunits in this chapter, with the primary single unit undergoing preventive maintenance and the first unit experiencing degradation upon complete failure. A transition diagram of the system is created by accounting for different scenarios and path probabilities. From this diagram, a table for primary, secondary, and tertiary cycles is created. The behavior of a bread plant was examined by Kumar et al. in [2018]. In order to do a sensitivity analysis on a cold standby framework made up of two identical units with server failure and prioritized for preventative maintenance, Kumar et al. [2019] used RPGT. Two halves make up the current paper, one of which is in use and the other of which is in cold standby mode. The good and fully failed modes are the only differences between online and cold standby equipment. A case study of an EAEP manufacturing facility was examined by Rajbala et al. [2019] in their work on system modeling and analysis in 2019. A study of the urea fertilizer industry's behavior was conducted by Kumar et al. [2017]. PSO was used by Kumari et al. [2021] to research limited situations. Using a heuristic approach, Rajbala et al. [2022] investigated the redundancy allocation problem in the cylinder manufacturing plant.The mathematical formulation and profit function of an edible oil refinery facility were investigated by Kumar et al. in 2017. In a paper mill washing unit, Kumar et al. [2019] investigated mathematical formulation and behavior study. In their study, Kumar et al. [2018] investigated a 3:4::G outstanding system plant's sensitivity analysis.

2. Assumptions and Notations

- A single repair facility is available 24*7.
- Repairs are perfect.
- Repaired unit works like a new one.

A,B,C,D/a,b,c,d: Working State/ failed state.

$w_i/\boldsymbol{\lambda}_i$ – respective mean constant repair/failure rates.; I = 0 to 6

3. Model Description

Considering the various possibilities and following the assumptions and notations the transition diagram of the system is drawn as under in Figure 1

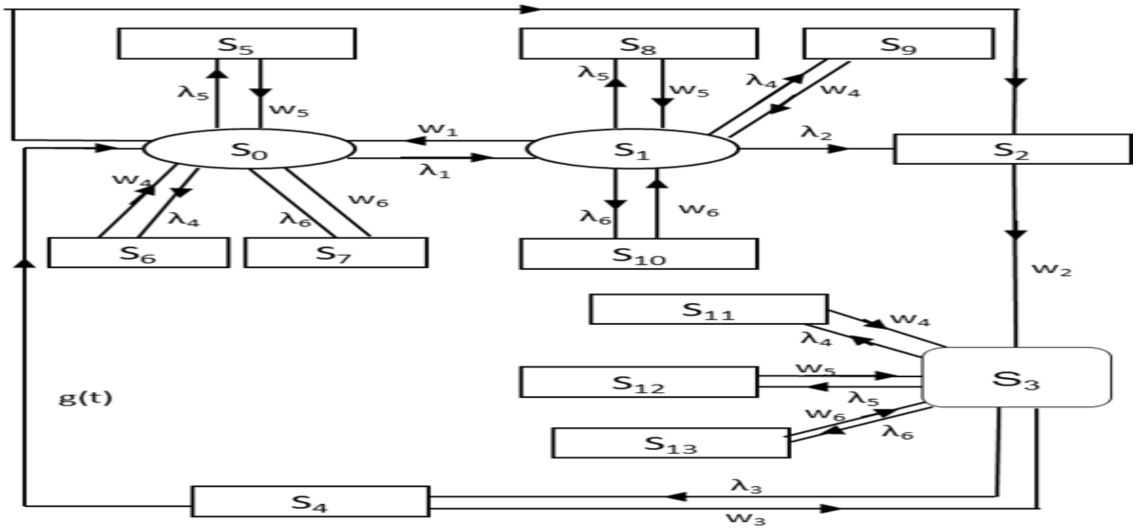

Figure 1: Transition Diagram

The system can be in any of the following states with respect to the above symbols.

S_0	=	ABcD	S_1	=	$\bar{A}$BCD	S_2	=	aBCD
S_3	=	$\bar{A}_1$BCD	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}	=	$\bar{A}_1$bCD
S_{12}	=	$\bar{A}_1$BcD	S_{13}	=	$\bar{A}_1$BCd			

4. Transition Probability and the Mean sojourn times.

Table 3: Transition Probabilities

$q_{i,j}^{(t)}$	$P_{ij} = q^*_{i,j}{}^{(t)}$
$q_{4,0} = g(t)e^{-w_3(t)}$ $q_{4,3} = w_3 e^{-w_3 t}\overline{g(t)}$	$p_{4,0} = g^*(w_3)$ $p_{4,3} = 1 - g^*(w_3)$
$q_{5,0} = w_5 e^{-w_3 t}$	$P_{5,0} = w_5/w_5 = 1$
$q_{6,0} = w_4 e^{-w_4 t}$	$P_{6,0} = w_4/w_4 = 1$
$q_{7,0} = w_6 e^{-w_6 t}$	$P_{7,0} = w_6/w_6 = 1$
$q_{8,1} = w_5 e^{-w_5 t}$	$P_{8,1} = w_5/w_5 = 1$
$q_{9,1} = w_4 e^{-w_4 t}$	$P_{9,1} = w_4/w_4 = 1$
$q_{10,1} = w_6 e^{-w_6 t}$	$P_{10,1} = w_6/w_6 = 1$
$q_{11,3} = w_4 e^{-w_4 t}$	$P_{11,3} = w_4/w_4 = 1$
$q_{12,3} = w_5 e^{-w_5 t}$	$P_{12,3} = w_5/w_5 = 1$
$q_{13,3} = w_6 e^{-w_6 t}$	$P_{13,3} = w_6/w_6 = 1$

Table 4: Mean Sojourn Times

$R_i(t)$	$\mu_i = R_i^*(0)$
$R_0^{(t)} = e^{-(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)t}$	$\mu_0 = 1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)$
$R_1^{(t)} = e^{-(w_1+\lambda_5+\lambda_4+\lambda_6+\lambda_2)t}$	$\mu_1 = 1/(w_1+\lambda_5+\lambda_4+\lambda_6+\lambda_2)$
$R_2^{(t)} = e^{-w_2 t}$	$\mu_2 = 1/w_2$
$R_3^{(t)} = e^{-(\lambda_3+\lambda_4+\lambda_5+\lambda_6)t}$	$\mu_3 = 1/(\lambda_3+\lambda_4+\lambda_5+\lambda_6)$
$R_4^{(t)} = e^{-w_3 t}\overline{g(t)}$	$\mu_4 = (1-g^* w_3)/w_3$
$R_5^{(t)} = e^{-w_5 t}$	$\mu_5 = 1/w_5$
$R_6^{(t)} = e^{-w_4 t}$	$\mu_6 = 1/w_4$
$R_7^{(t)} = e^{-w_6 t}$	$\mu_7 = 1/w_6$
$R_8^{(t)} = e^{-w_5 t}$	$\mu_8 = 1/w_5$
$R_9^{(t)} = e^{-w_4 t}$	$\mu_9 = 1/w_4$
$R_{10}^{(t)} = e^{-w_6 t}$	$\mu_{10} = 1/w_6$
$R_{11}^{(t)} = e^{-w_4 t}$	$\mu_{11} = 1/w_4$
$R_{12}^{(t)} = e^{-w_5 t}$	$\mu_{12} = 1/w_5$
$R_{13}^{(t)} = e^{-w_6 t}$	$\mu_{13} = 1/w_6$

5. Path Probability

path probability are given from state 'o' to different rates 'i' are given as

$V_{0,0} = 1$ (verified)

$V_{0,1} = p_{0,1} = \lambda_1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda)$

$V_{0,2} = \lambda_1\lambda_2/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6) \div (w_1+\lambda_2+\lambda_4+\lambda_6)(w_1+\lambda_2+\lambda_5+\lambda_6)$
$(w_1+\lambda_2+\lambda_4+\lambda_5)/(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)^3+\lambda/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)$

$V_{0,3} =$ …….continuous

Path Probabilities from state '3' to different vertices are given as

$V_{3,0} = \lambda_3 g^*(w_3)/(\lambda_3+\lambda_4+\lambda_5+\lambda_6) \div 1- \lambda_1 w_1/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_6)$
$(\lambda+\lambda_1+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_5)/(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)^3$

$V_{3,1} = \lambda_3\lambda_1 g^*(w_3)/(\lambda_3+\lambda_4+\lambda_5+\lambda_6)(\lambda_1+\lambda_4+\lambda_5+\lambda_6+\lambda) \div (\lambda+\lambda_1+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_6)$
$(\lambda+\lambda_1+\lambda_4+\lambda_5)(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)^3(w_1+\lambda_2+\lambda_4+\lambda_6)(w_1+\lambda_2+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5)$
$/(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)^3$

$V_{3,2} =$ …….continued

6. EVALUATION OF PARAMETERS OF THE SYSTEM:

(i). MTSF(T_0): The regenerative un-failed states to which the system can transit(initial state '0'), before entering any failed state are: 'i' = 0,1,2,3,4 taking 'ζ' = '0'.

$$\text{MTSF } (T_0) = \left[\sum_{i,sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr\,(sff)}i\right)\right\}\mu i}{\Pi_{m_{1\neq\xi}}\{1-V_{\overline{m1m_1}}\}}\right\}\right] \div \left[1-\sum_{sr}\left\{\frac{\left\{pr\left(\xi\xrightarrow{sr\,(sff)}\xi\right)\right\}}{\Pi_{m_{2\neq\xi}}\{1-V_{\overline{m2m_2}}\}}\right\}\right]$$

$$T_0 = (w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)+\lambda_1\div(w_1+\lambda_2+\lambda_4+\lambda_5+\lambda_6)(\lambda+\lambda_1+\lambda_4+\lambda_5+\lambda_6)-\lambda_1 w_1$$

Availability of the System: The regenerative states at which the system is available are 'j' = 0,1,2,3,4 and the regenerative states are 'i' = 0 to 10 taking 'ξ' = '0' the total fraction of time for which the system is available is given by

$$A_0 = \left[\sum_{j,sr}\left\{\frac{\{pr\,(\xi^{sr}\rightarrow j)\}fj,\mu j}{\Pi_{m_{1\neq\xi}}\{1-V_{\overline{m1m_1}}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr\,(\xi^{sr}\rightarrow i)\}\mu_i^1}{\Pi_{m_{2\neq\xi}}\{1-V_{\overline{m2m_2}}\}}\right\}\right]$$

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

Proportional Busy Period of the Server: The regenerative states where server 'j' = 1,2,3,4,5,6, 7,8,9,10 and regenerative states are 'i' = 0 to 10, taking ξ = '0', the total fraction of time for which the server remains busy is

$$B_0 = \left[\sum_{j,sr}\left\{\frac{\{pr\,(\xi^{sr}\rightarrow j)\},nj}{\Pi_{m_{1\neq\xi}}\{1-V_{\overline{m1m_1}}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr\,(\xi^{sr}\rightarrow i)\}\mu_i^1}{\Pi_{m_{2\neq\xi}}\{1-V_{\overline{m2m_2}}\}}\right\}\right]$$

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

Expected Fractional Number of repairman's visits: The regenerative states where the repair man do this job j = 1 the regenerative states are i = 0 to 10, Taking 'ξ' = '0', the number of visit by the repair man is given by

$$V_0 = \left[\sum_{j,sr}\left\{\frac{\{pr\,(\xi^{sr}\rightarrow j)\}}{\Pi_{k_{1\neq\xi}}\{1-V_{\overline{k1k_1}}\}}\right\}\right] \div \left[\sum_{i,s_r}\left\{\frac{\{pr\,(\xi^{sr}\rightarrow i)\}\mu_i^1}{\Pi_{k_{2\neq\xi}}\{1-V_{\overline{k2k_2}}\}}\right\}\right]$$

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

7. Particular Cases

Sensitivity Analysis

Besides, the above after sections portray two sensitivity analysis scenarios and relating brings about plain and graphical structures broke down.

Scenario1: Sensitivity analysis regarding change in repair rates. Taking, $\lambda_i = 0.10$ ($1 \leq i \leq 6$) and fluctuating w_i individually separately at 0.60, 0.65, 0.70, 0.75, 0.80 and 0.85.

Availability of System (A_0)

Table 1: Availability of System (A_0)

w_i	w_1	w_2	w_3	w_4	w_5	w_6
0.60	0.915	0.892	0.878	0.865	0.851	0.834
0.65	0.937	0.915	0.896	0.879	0.865	0.849
0.70	0.948	0.923	0.915	0.894	0.879	0.862
0.75	0.963	0.941	0.923	0.915	0.894	0.875
0.80	0.978	0.958	0.941	0.923	0.915	0.892
0.85	0.992	0.972	0.958	0.941	0.923	0.915

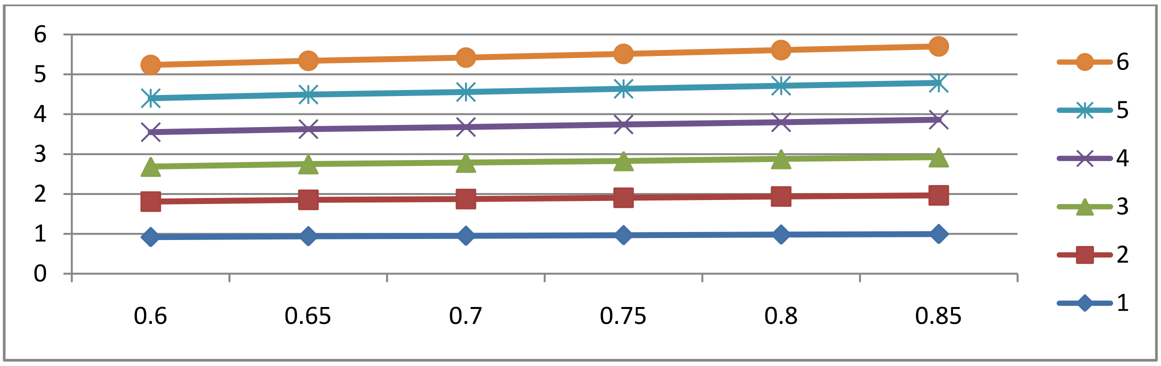

Figure 2: Availability of System

Table 1 and figure 2 it inferred that accessibility is greatest when the maintenance rate of unit first is most extreme in contrast to the repair rates of different units.

Scenario2: Now study the sensitivity analysis scenario 2 with respect to variation in FR: captivating, $w_i = 0.70$ $(1 \leq i \leq 6)$ and changing λ_i one by one individually at 0.10, 0.15, 0.20, 0.25, 0.30, 0.35.

Availability of System (A_0)

Table 2: Availability of System (A_0)

λ_i	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
0.10	0.689	0.702	0.723	0.735	0.748	0.761
0.15	0.667	0.689	0.702	0.723	0.735	0.748
0.20	0.653	0.667	0.689	0.702	0.723	0.735
0.25	0.637	0.653	0.667	0.689	0.702	0.723
0.30	0.628	0.637	0.653	0.667	0.689	0.702
0.35	0.616	0.628	0.637	0.653	0.667	0.689

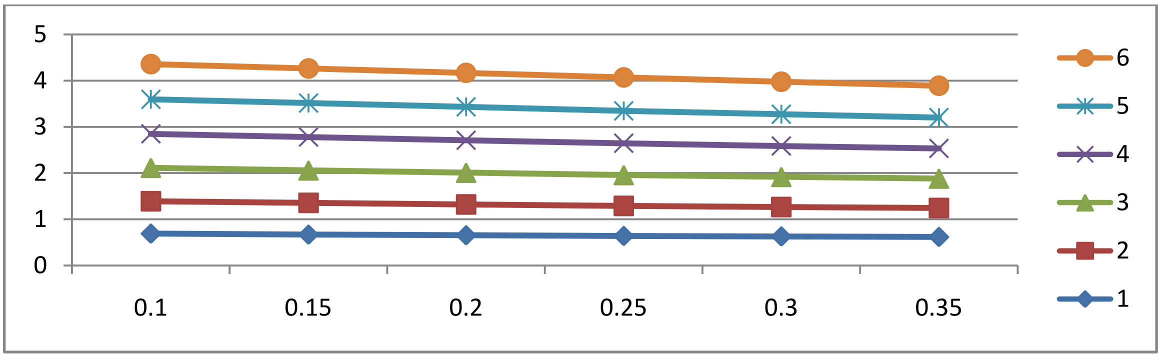

Figure 3: Availability of System

The above table 2 and figure 3, it is established that availability is Minimum when the disappointment rate of unit is maximum, and its value is 0.616.

8. Conclusion

Methods of controlling unit failure along with repair rates relating to financial resources but instead market conditions to obtain optimum values for system parameters.Now, main purpose of our study the system is to optimize the availability of system. The height of system has three parameters as availability of working states of system primary period of server and visits made by the servers. Since the industries have to made a fix investment to set up the system of any type of industry.The system's availability are all observed to decrease with an increase in failure rate and to increase with the repair rate, based on the analytical and figure discussions. By raising the repair rate and lowering the failure rate, the plant's effectiveness and dependability can be enhanced. 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.

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