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Vijay Goyal
Research Scholar,
J.J.T. University,
Jhunjhnu (Rajasthan),
India.

Dr. Pardeep Goel
Associate Professor,
M.M. (P.G.) College,
Fatehabad-125050,
(Haryana), India.

Correspondence
Vijay Goyal
Research Scholar,
J.J.T. University,
Jhunjhnu (Rajasthan),
India.

Behavior analysis of three unit system with preventive maintenance and degradation in one unit using RPGT

Vijay Goyal, Dr. Pardeep Goel

Abstract
In this paper Behavioral Analysis of three units system with preventive maintenance and degradation in one unit Post Failure and the other units with perfect repair using Regenerative Point Graphical Technique (RPGT) is discussed. Initially, the two units A,B & C 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 and C can fail directly. There is a single server (repairman) who inspects and repairs the units when need arise. On partial failure (before complete failure) server repairs the unit and on complete failure the unit A cannot be restored to its original capacity i.e. it is in degraded state. Fuzzy concept is used to determine failure/working state of a unit. If the server report, that unit A is not repairable, then it is replaced by a new one. Taking failure rates exponential, repair rates general and taking into consideration various probabilities, a transition diagram of the system is developed to determine Primary circuits, Secondary circuits & Tertiary circuits and Base state. Problem is formulated and solved using RPGT. Repair and Failure are statistically independent. Expressions for system parameters i.e. mean time to system failure, availability, number of server visits and busy period of the server are evaluated to study the behavior of the system for steady state. Profit optimization is also discussed. System Behavior is discussed with the help of graphs and tables.

Keywords: Availability, Circuits, Degraded & Base state, RPGT.

1. Introduction
Various industries and processing systems are assembly of a number of units. Here we have discussed the behavior of a three units system prevalent in various process industries. Considering the importance of individual units in system Kumar, J. & Malik, S. C. [1] have discussed the concept of preventive maintenance for a single unit system. Gupta,P., Sharma, S.K., Goel, A. & Modgal, V. [2], Malik, S. C. [3] have discussed reliability analysis of a one unit system with un-repairable spare units and its applications. Gupta, P., Lal, A. K., Sharma, R. K. and Singh, J. [4] Goel, P. & Singh J. [5], Gupta, P., Singh, J. & Singh, I.P. [6], Kumar, S. & Goel, P. [7] and Gupta, V. K. [8] have discussed behavior of systems with imperfect switch using RPGT. We have discussed the behavioral analysis of three unit system in which unit A have parallel sub units so it can work in reduced capacity as well as in full capacity. The system can fail from normal mode to complete failure directly or via partial failure. Most of the systems consist a number of units and one of these units may be important for working of system, hence need more care over other units. Since the capability of unit after repair depends on the repair mechanism adopted and unit may have increased failure rate on subsequent failures. The system may go under imperfect repair on complete failure and unit is degraded but operative state is obtained again and again. Server inspects and repairs the unit as and when need arise. After a limiting situation, when no further repair is possible, then system is replaced by new one

2. Assumptions and Notations
The following assumptions and notations are taken: -

1. Two Server Facility is available for repairing the Units. Repair of unit A is imperfect and repaired unit is not good as new one on complete failure. Whereas repair of unit B is perfect.
2. Unit B is Repaired in mean time when Standby Unit C is working.

3. The distributions of failure times and repair times are exponential and general respectively and also different. Failures and repairs are statistically independent.
4. Nothing can fail when the system is in failed state.
5. The system is discussed for steady-state conditions.

m-$\overline{cycle}$: A circuit (may be formed through un-failed regenerative or non-regenerative state) whose terminals are at the regenerative m state.

$\left(i \xrightarrow{s_r} j\right)$: *r*-th directed simple path from *i*-state to j-state; r takes positive integral values for different paths from *i*-state to j-state.

$\left(\xi \xrightarrow{sff} i\right)$: A directed simple failure free path from ξ -state to i-state.

$V_{m,m}$: Probability factor of the state m reachable from the terminal state m of the m-cycle.

$V_{\overline{m,m}}$: Probability factor of the state m reachable from the terminal state m of the m-$\overline{cycle}$.

R_i (t) : Reliability of the system at time t, given that the system entered the un-failed regenerative state 'i' at t = 0.

μ_i : Mean sojourn time spent in state i, before visiting any other states;

μ_i^1 : The total un-conditional time spent before transiting to any other regenerative states, given that the system entered regenerative state 'i' at t=0.

n_i : Expected waiting time spent while doing a given job, given that the system entered regenerative state 'i' at t=0; $\eta_i = W_i^*(0)$.

ξ : Base state of the system.

f_j : Fuzziness measure of the j-state.

Taking into consideration the above assumptions and notations the Transition Diagram of the system is given in Figure1.

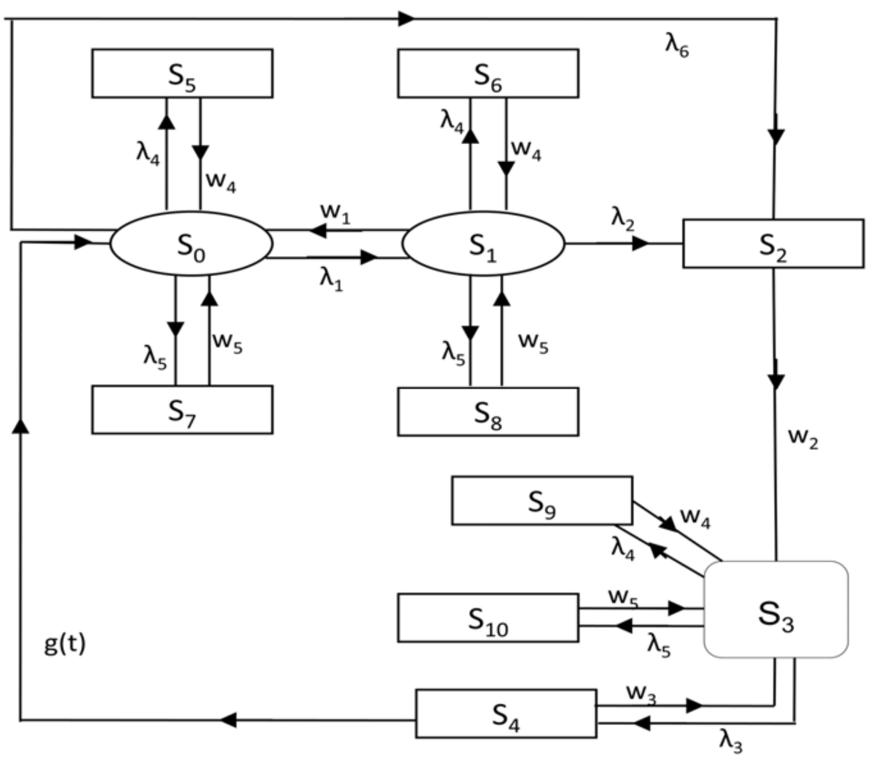

Figure-1

The system can be in any of the following states with respect to the above symbols.
S_0=ABCS_1=$\bar{A}$BC S_2=aBC S_3 =A_1BC S_4= a_1BC S_5=AbC S_6 = $\bar{A}$bC
S_7=ABc S_8 $\bar{A}$BcS_9 =A_1bC S_{10}=A_1Bc

Where

1. λ_1, $\lambda_2$and λ_3 are Failure Rates of Unit A from A to $\bar{A}$, $\bar{A}$ to a and A_1 to a_1 Respectively, λ_4 is Failure Rate B to b and λ_5 is Failure Rate C to c
2. w_1, w_2 and w_3 are Repair Rates of Unit A from $\bar{A}$ to A, a to A_1 and a_1 to A_1 Respectively, w_4 is Repair Rate from b to B and w_5 is Repair Rate c to C

3. Transition Probability and the Mean sojourn times.

$q_{i,j}(t)$**:** Probability density function (p.d.f.) of the first passage time from a regenerative state 'i' to a regenerative state 'j' or to a failed state 'j' without visiting any other regenerative state in (0,t].

$p_{i,j}$ **:** Steady state transition probability from a regenerative state 'i' to a regenerative state 'j' without visiting any other regenerative state. $p_{i,j} = q^*_{i,j}(0)$; where * denotes Laplace transformation.

Transition Probabilities

$q_{i,j}^{(t)}$	$P_{ij} = q^*_{i,j}{}^{(t)}$
$q_{0,1}= \lambda_1 e^{-(\lambda_1+\lambda_4+\lambda_5+\lambda_6)t}$ $q_{0,2}= \lambda_6 e^{-(\lambda_1+\lambda_4+\lambda_5+\lambda_6)t}$ $q_{0,5}= \lambda_4 e^{-(\lambda_1+\lambda_4+\lambda_5+\lambda_6)t}$ $q_{0,7}= \lambda_5 e^{-(\lambda_1+\lambda_4+\lambda_5+\lambda_6)t}$	$p_{0,1}= \lambda_1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$ $p_{0,2}= \lambda_6/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$ $p_{0,5}= \lambda_4/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$ $p_{0,7}= \lambda_5/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$q_{1,0}= w_1 e^{-(w_1+\lambda_2+\lambda_4+\lambda_5)t}$ $q_{1,2}= \lambda_2 e^{-(w_1+\lambda_2+\lambda_4+\lambda_5)t}$ $q_{1,6}= \lambda_4 e^{-(w_1+\lambda_2+\lambda_4+\lambda_5)t}$ $q_{1,8}= \lambda_5 e^{-(w_1+\lambda_2+\lambda_4+\lambda_5)t}$	$p_{1,0}= w_1/(w_1+\lambda_2+\lambda_4+\lambda_5)$ $p_{1,2}= \lambda_2/(w_1+\lambda_2+\lambda_4+\lambda_5)$ $p_{1,6}= \lambda_4/(w_1+\lambda_2+\lambda_4+\lambda_5)$ $p_{1,8}= \lambda_5/(w_1+\lambda_2+\lambda_4+\lambda_5)$
$q_{2,3}= w_2 e^{-w_2 t}$	$p_{2,3}= w_2/w_2 = 1$
$q_{3,4}= \lambda_3 e^{-(\lambda_3+\lambda_4+\lambda_5)t}$ $q_{3,9}= \lambda_4 e^{-(\lambda_3+\lambda_4+\lambda_5)t}$ $q_{3,10}= \lambda_5 e^{-(\lambda_3+\lambda_4+\lambda_5)t}$	$p_{3,4}= \lambda_3/(\lambda_3+\lambda_4+\lambda_5)$ $p_{3,9}= \lambda_4/(\lambda_3+\lambda_4+\lambda_5)$ $p_{3,10}= \lambda_5/(\lambda_3+\lambda_4+\lambda_5)$
$q_{4,3}= w_3 e^{-w_3 t}\overline{g(t)}$ $q_{4,0}= g(t)e^{-w_3 t}$	$p_{4,3}= 1-g^*w_3$ $p_{4,0}= g^*w_3$
$q_{5,0}= w_4 e^{-w_4 t}$	$p_{5,0}= w_4/w_4 = 1$
$q_{6,1}= w_4 e^{-w_4 t}$	$p_{5,0}= w_4/w_4 = 1$
$q_{7,0}= w_5 e^{-w_5 t}$	$p_{7,0}= w_5/w_5 = 1$
$q_{8,1}= w_5 e^{-w_5 t}$	$p_{8,1}= w_5/w_5 = 1$
$q_{9,3}= w_4 e^{-w_4 t}$	$p_{9,3}= w_4/w_4 = 1$
$q_{10,3}= w_5 e^{-w_5 t}$	$p_{10,3}= w_5/w_5 = 1$

Mean Sojourn Times

$R_i(t)$: Reliability of the system at time t, given that the system in regenerative state i.
μ_i : Mean sojourn time spent in state i, before visiting any other states;

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

Using Notations for Secondary Circuits as
$(0,5,0) = L_1$ $(0,7,0) = L_2$ $(1,6,1) = L_3$ $(1,8,1) = L_4$ $(3,4,3) = L_5$
$(3,93) = L_6$ $(3,10,3) = L_7$
$V_{0,0} = (0,5,0)+(0,7,0)+(0,1,0)/(1-L_3)(1-L_4)+(0,2,3,4,0)/(1-L_5)(1-L_6)(1-L_7)+(0,1,2,3,4,0)/(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_7)$

Now
$1-L_1 = 1 = 1-p_{0,5}p_{5,0} = 1-\lambda_4/(\lambda_1+\lambda_4+\lambda_5+\lambda_6) = (\lambda_1+\lambda_5+\lambda_6)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$1-L_2 = 1 = 1-p_{0,7}p_{7,0} = 1-\lambda_5/(\lambda_1+\lambda_4+\lambda_5+\lambda_6) = (\lambda_1+\lambda_4+\lambda_6)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$1-L_3 = 1 = 1-p_{1,6}p_{6,1} = 1-\lambda_4/(w_1+\lambda_2+\lambda_4+\lambda_5) = (w_1+\lambda_2+\lambda_5)/(w_1+\lambda_2+\lambda_4+\lambda_5)$
$1-L_4 = 1 = 1-p_{1,8}p_{8,1} = 1-\lambda_5/(w_1+\lambda_2+\lambda_4+\lambda_5) = (w_1+\lambda_2+\lambda_4)/(w_1+\lambda_2+\lambda_4+\lambda_5)$
$1-L_5 = 1 = 1-p_{3,4}p_{4,3} = 1-\lambda_4(1-g^*w_3)/(\lambda_3+\lambda_4+\lambda_5) = (\lambda_4+\lambda_5+\lambda_3 g^*w_3)/(\lambda_3+\lambda_4+\lambda_5)$
$1-L_6 = 1 = 1-p_{3,9}p_{9,3} = 1-\lambda_4/(\lambda_3+\lambda_4+\lambda_5) = (\lambda_3+\lambda_5)/(\lambda_3+\lambda_4+\lambda_5)$
$1-L_7 = 1 = 1-p_{3,10}p_{10,3} = 1-\lambda_5/(\lambda_3+\lambda_4+\lambda_5) = (\lambda_3+\lambda_5)/(\lambda_3+\lambda_4+\lambda_5)$

Using there values, we get
$V_{0,0} =1$, $V_{0,1} = p_{0,1} = \lambda_1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$V_{0,2} = (0,2)+(0,1,2)/(1-L_3)(1-L_4) = p_{0,2}+ p_{0,1}p_{1,2}/(1-p_{1,6}p_{6,1})(1-p_{1,8}p_{8,1}) = \lambda_1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$= \lambda_6/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)+\lambda_1\lambda_2(w_1+\lambda_2+\lambda_4+\lambda_5)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_5)(w_1+\lambda_2+\lambda_4)$
$V_{0,3} = (0,2,3)+(0,1,2,3)/(1-L_3)(1-L_4) = p_{0,2}p_{2,3}+p_{0,1}p_{1,2}p_{2,3}/(1-p_{1,6}p_{6,1})(1-p_{1,8}p_{8,1})$
$= \lambda_6/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)+\lambda_1\lambda_2(w_1+\lambda_2+\lambda_4+\lambda_5)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_5)(w_1+\lambda_2+\lambda_4)$
$V_{0,4} = (0,2,3,4)/(1-L_6)(1-L_7)+(0,1,2,3,4)/(1-L_3)(1-L_4)(1-L_6)(1-L_7) = p_{0,2}p_{2,3}p_{3,4}+p_{0,1}p_{1,2}p_{2,3}$
$/(1-p_{3,9}p_{9,3})(1-p_{3,10}p_{10,3})+p_{0,1}p_{1,2}p_{2,3}p_{3,4}/(1-p_{1,6}p_{6,1})(1-p_{1,8}p_{8,1})(1-p_{3,9}p_{9,3})(1-p_{3,10}p_{10,3})$
$V_{0,5} = p_{0,5} = \lambda_4/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$V_{0,6} = (0,1,6)/1-(1,8,1) = p_{0,1}p_{1,6}/(1-p_{1,8}p_{8,1}) = \lambda_1\lambda_4/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4)$
$V_{0,7} = p_{0,7} = \lambda_5/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)$
$V_{0,8} = (0,1,8)/(1-L_3) = p_{0,1}p_{1,8}/(1-p_{1,6}p_{6,1}) = \lambda_1\lambda_5/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(\lambda_2+\lambda_5+w_1)$
$V_{0,9} = (0,2,3,9)/(1-L_5)(1-L_7)+(0,1,2,3,9)/(1-L_3)(1-L_4)(1-L_5)(1-L_7)$
$=\lambda_4\lambda_6(\lambda_3+\lambda_4+\lambda_5)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(\lambda_3+\lambda_4)(\lambda_4+\lambda_5+\lambda_3 g^*w_3)+\lambda_1\lambda_2\lambda_4(\lambda_3+\lambda_4+\lambda_5)$
$(w_1+\lambda_2+\lambda_4+\lambda_5)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4)(w_1+\lambda_2+\lambda_5)(\lambda_3+\lambda_4)(\lambda_4+\lambda_5+\lambda_3 g^*w_3)$
$V_{0,10} = (0,2,3,10)/(1-L_5)(1-L_6)+(0,1,2,3,10)/(1-L_3)(1-L_4)(1-L_5)(1-L_6)$
$=\lambda_5\lambda_6(\lambda_3+\lambda_4+\lambda_5)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(\lambda_3+\lambda_5)(\lambda_4+\lambda_5+\lambda_3 g^*w_3)+\lambda_1\lambda_2\lambda_5(\lambda_3+\lambda_4+\lambda_5)$
$(w_1+\lambda_2+\lambda_4+\lambda_5)/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4)(w_1+\lambda_2+\lambda_5)(\lambda_3+\lambda_5)(\lambda_4+\lambda_5+\lambda_3 g^*w_3)$

4. **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 ‘ξ’ = ‘0’.

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

$T_0 = [(0,0)\mu_0+(0,1)\mu_1]\div[1-(0,1,0)/(1-L_3)(1-L_4)]$
$= [(1/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(1+\lambda_1)(w_1+\lambda_2+\lambda_4+\lambda_5)]\div[1-\lambda_1 w_1(w_1+\lambda_2+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_5)(w_1+\lambda_2+\lambda_4)]$
$= [w_1+\lambda_1+\lambda_2+\lambda_4+\lambda_5/(\lambda_1+\lambda_4+\lambda_5+\lambda_6)(w_1+\lambda_2+\lambda_4+\lambda_5)]\div[1-\lambda_1 w_1(w_1+\lambda_2+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_5)(w_1+\lambda_2+\lambda_4)]$

5. **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

$$A_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}fj,\mu j}{\Pi_{m_1\neq\xi}\left\{1\text{-}V_{\overline{m_1m_1}}\right\}}\right\}\right]\div\left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_2\neq\xi}\left\{1\text{-}V_{\overline{m_2m_2}}\right\}}\right\}\right]$$
$A_0 = \left[\sum_j V_{\xi,j}, f_j, \mu_j\right] \div \left[\sum_i V_{\xi,i}, f_j, \mu_i^1\right]$
$A_0 = (V_{0,0}f_0\mu_0+V_{0,1}f_1\mu_1+V_{0,3}f_3\mu_3)\div(V_{0,0}\mu_0^1+V_{0,1}\mu_1^1+V_{0,2}\mu_2^1+V_{0,3}\mu_3^1+V_{0,4}\mu_4^1+V_{0,5}\mu_5^1$
$+V_{0,6}\mu_6^1+V_{0,7}\mu_7^1+V_{0,8}\mu_8^1+V_{0,9}\mu_9^1+V_{0,10}\mu_{10}^1)$
Taking fuzzy values for working state $f_0 = f_1 = f_3 = 1$ and $\mu_i^1 = \mu_i$ we get
$= (V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,3}\mu_3)\div(V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,7}\mu_7$
$+V_{0,8}\mu_8+V_{0,9}\mu_9+V_{0,10}\mu_{10})$

6. **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

$$B_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\},nj}{\Pi_{m_1\neq\xi}\left\{1\text{-}V_{\overline{m_1m_1}}\right\}}\right\}\right]\div\left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{m_2\neq\xi}\left\{1\text{-}V_{\overline{m_2m_2}}\right\}}\right\}\right]$$
$B_0 = \left[\sum_j V_{\xi,j}, n_j\right] \div \left[\sum_i V_{\xi,i}, \mu_i^1\right]$
$B_0= V_{0,1}n_1+V_{0,2}n_2+V_{0,4}n_4+V_{0,5}n_5+V_{0,6}n_6+V_{0,7}n_7+V_{0,8}n_8+V_{0,9}n_9+V_{0,10}n_{10}/V_{0,0}\ \mu^1{}_0+V_{0,1}\mu^1{}_1 +V_{0,2}\mu^1{}_2+V_{0,3}\mu^1{}_3+V_{0,4}\ \mu^1{}_4+V_{0,5}\ \mu^1{}_5+V_{0,6}$
$\mu^1{}_6+V_{0,7}\mu^1{}_7+V_{0,8}\mu^1{}_8+V_{0,9}\mu^1{}_9+V_{0,10}\mu^1{}_{10}$
Taking $n_i = \mu_i = \mu_i^1$, we get

7. **Expected Number of Inspections by the repair man:** 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

$$V_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\to}j)\}}{\Pi_{k_1\neq\xi}\{1\text{-}V_{\overline{k_1k_1}}\}}\right\}\right]\div\left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\to}i)\}\mu_i^1}{\Pi_{k_2\neq\xi}\{1\text{-}V_{\overline{k_2k_2}}\}}\right\}\right]$$

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

$V_0= (V_{0,1}+V_{0,2}+V_{0,4}+V_{0,5}+V_{0,6}+V_{0,7}+V_{0,8}+V_{0,9}+V_{0,10})/(V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3$
$+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,7}\mu_7+V_{0,8}\mu_8+V_{0,9}\mu_9+V_{0,10}\mu_{10})$

8. **Particular Cases**

When all $\lambda_i = \lambda$ and $w_i = w$ (say), $g(t) = w_3e^{-w_3t}$
MTSF (T_0): - $[(4\lambda+w)/4\lambda(3\lambda+w)]\div[1-\lambda w(3\lambda+w)/(2\lambda+w)^2]$
$(4\lambda+w)(2\lambda+w)^2/4\lambda(3\lambda+w)\{(2\lambda+w)^2-\lambda w(3\lambda+w)\}$

T_0	W = 0.6	W = 0.7	W = 0.8
λ = 0.1	3.0337	3.4801	3.7152
λ = 0.2	1.7034	1.9121	2.0180
λ = 0.3	1.2307	1.4101	1.8306

Availability (A_0): - For this we get the following values
$V_{0,0} = 1, V_{0,1} = 1/4$ $V_{0,2} = 1/4\ (1+3\lambda+w)/(2\lambda+w)^2$ $V_{0,3} = 1/4\ (1+3\lambda+w)/(2\lambda+w)^2$
$V_{0,4} = 3/16\ (1+\lambda 3\lambda+w)/(2\lambda+w)^2 V_{0,5} = 1/4$ $V_{0,6} = \lambda/4(2\lambda+w) V_{0,7} = 1/4$
$V_{0,8} = \lambda^2/4\lambda(2\lambda+w) = \lambda/4\lambda(2\lambda+w)$ $V_{0,9} = 3/20\ (1+\lambda 3\lambda+w)/(2\lambda+w)^2$
$V_{0,9} = 3/20\ (3\lambda+w)/(2\lambda+w)^2$

Now putting these values, we get, $A_0 = N/D$

Where $N = 1/4\lambda+1/4(3\lambda+w)+1/2\lambda\{(1+3\lambda+w)/(2\lambda+w)^2\}$
$D = 1/4\lambda+1/4(3\lambda+w)+1/4\{(1+3\lambda+w)/(2\lambda+w)^2\}\{(1/w)+(1/3\lambda)\}+3/16$
$\{(1+3\lambda+w)/(2\lambda+w)^2\}1/2w+1/2w+\lambda/4(3\lambda+w)w+3/10w\{(1+3\lambda+w)/(2\lambda+w)^2\}$
The following table gives value of Availability of System for different values of repair and failure rate as

Availability Table

A_0	ω = 0.6	ω = 0.7	ω = 0.8
λ = 0.1	0.2156	0.3510	0.4274
λ = 0.2	0.1712	0.3116	0.3852
λ = 0.3	0.1154	0.2732	0.3214

Expected Number of Visits Table

V_0	ω = 0.6	ω = 0.7	ω = 0.8	ω = 0.9
λ = 0.1	0.1703	0.1621	0.1558	0.1452
λ = 0.2	0.2506	0.2431	0.2400	0.2377
λ = 0.3	0.3451	0.3299	0.3104	0.3042

9. **Conclusion**

From the tables and analytical discussions, we see that increase in the repair rate (w) increases the availability of the system and the mean time to system failure whereas increase in failure rate decrease the availability and mean time to system which should be so practically. The Regenerative Point Graphical Technique is useful to evaluate the key parameters of the system in a simple way, without writing any state equations and without doing any lengthy and cumbersome calculations. We also see from the busy period of server table that when we increase the repair rate busy period of server decrease and when we increase the failure rate then busy period of server also increase. Also from expected number of inspections by the repair man table we see that when we increase the repair rate the expected number of inspections by repairman increase and when we increase the failure rate then the expected number of inspections by repairman is also increase. In future, Researchers can evaluate the parameters, when repair rate sand failure rate are variable and also discuss the cost and profit benefit analysis. Further results can also be applied to find the waiting time of units and number of server visits, as if the states where the server is on prime visit or on a secondary visit are determined separately using the formula. Since the cost of secondary visit is usually less than primary visit of server, therefore the system can be run with low maintenance cost. Various system parameters can also be evaluated taking any state as base state. As failure rates are beyond control, so determine the repair rates and reduce the fixing the target of availability management can cost of maintenance.

10. References

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