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Raj Kumar
Research Scholar, J.J.T. University, Jhunjhnu Rajasthan.

Mahender Poonia
Associate Professor of Maths, JJTU, Jhunjhnu.

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

Correspondence
Raj Kumar
Research Scholar, J.J.T. University, Jhunjhnu Rajasthan.

Availability analysis of two unit system with warm standby having imperfect switch-over device using RPGT

Raj Kumar, Mahender Poonia and Dr. Pardeep Goel

Abstract
In this paper Availability Modeling of Two Unit Warm Standby System Having Imperfect Switch-Over Device using RPGT is discussed. Initially the main unit is working at full capacity which may have two types of failures, one is direct and the second one is through partial failure mode. Second unit have warm standby unit switched in by a switch-over device which may not be perfect .There is a single server (repairman) who inspects and repairs the unit on each failure. Fuzzy concept is used to determine failure/working state of a unit. 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 to determine system parameters i.e. Mean Time to System Failure, Busy period of the Server, Expected No. of Server’s Visits. Particular cases are taken for warm, hot and cold standby cases. System parameters have been discussed with the help of graphs and tables.

Keywords: Availability, Reliability, Primary Circuits, Tertiary Circuits, Degraded state, Base-State, Regenerative Point Graphical Technique (RPGT), Mean Time to System Failure, Busy period of the Server, Expected No. of Server’s Visits, Fuzzy Logic, Steady State. Hot Standby, Cold Standby, Warm Stand-by imperfect switch.

Introduction
Various Mechanical systems are assembly of a number of units in which each unit is important for the system to work efficiently. If a single unit fails then the whole system fails. 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. Liu., R. [2], Malik, S. C. [3], Nakagawa, T. and Osaki, S. [4] have discussed reliability analysis of a one unit system with un-repairable spare units and its applications. Goel, P. & Singh J. [5], Gupta, P., Singh, J. & Singh, I.P. [6], Kumar, S. & Goel, P. [7], Gupta, V. K. [8], Chaudhary, Goel & Kumar [9] Sharma & Goel [10], Ritikesh & Goel [11] and Goyal & Goel [12] have discussed behavior with perfect and imperfect switch-over of systems using RPGT.
In this paper Availability Modeling of Two Unit Warm Standby System Having Imperfect Switch-Over Device using RPGT is discussed. Initially the main unit is working at full capacity which may have two types of failures, one is direct and the second one is through partial failure mode. Second unit have warm standby unit switched in by a switch-over device which may not be perfect .There is a single server (repairman) who inspects and repairs the unit on each failure. Fuzzy concept is used to determine failure/working state of a unit. 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 to determine system parameters i.e. Mean Time to System Failure, Busy period of the Server, Expected No. of Server’s Visits. Particular cases are taken for warm, hot and cold standby cases. System parameters have been discussed with the help of graphs and tables.

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

1. The System consists of these non-identical units initially, two units are operative and other unit is kept in warm standby.
2. Switching over is imperfect.
3. There is a single repairman for repair of failed units, and switch over device.
4. The failures rates are exponentially distributed and repair rate are general and are independent and are different for different operative units i.e. main unit, standby and switch over device.
5. Unit A and B are of different capacities.
6. Repairs are perfect. Repaired unit works as a new one.
7. The order of priority of repair is switch, unit A, unit D, standby unit B.
8. The system is down when both units 'A' and 'B' fail or D fails or switch over device fails to do its function while switching.
9. The system is discussed for steady state conditions.

$\overline{cycle}$: A circuit formed through un-failed states.

m-cycle: A circuit (may be formed through regenerative or non-regenerative / failed state) whose terminals are at the regenerative state m.

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.

A_i (t): Probability of the system in up time at time 't', given that the system entered regenerative state 'i' at t = 0.

B_i (t): Reliability that the server is busy for doing a particulars job at time 't'; given that the system entered regenerative state 'i' at t = 0.

V_i (t): The expected no. of server visits for doing a job in (o,t] given that the system entered regenerative state 'i' at t = 0.

',' denote derivative

W_i (t): Probability that the server is busy doing a particular job at time t without transiting to any other regenerative state 'i' through one or more non-regenerative states, given that the system entered the regenerative state 'i' at t = 0.

μ_i : Mean sojourn time spent in state i, before visiting any other states; $\mu_i = \int_0^\infty R_i(t)dt$

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.

λ_1 : Constant failure rate of unit A to reduced state.

λ_2 : Constant failure rate of unit A to from , λ_3 : Constant failure rate of unit B.

λ_4 : $(1+\delta_i)\lambda_{n-3}$ increased failure rate of unit A as complete failure.

A/$\bar{A}$/a: Unit in full capacity working / reduced state / failed state.

p: probability of switch working successfully.

Table 1

State	Symbol	Model
Regenerative State	◯ (circle)	0,9
Reduced State	⬭ (ellipse)	5,2
Failed State	▭ (rectangle)	1,3,4,6,7,8

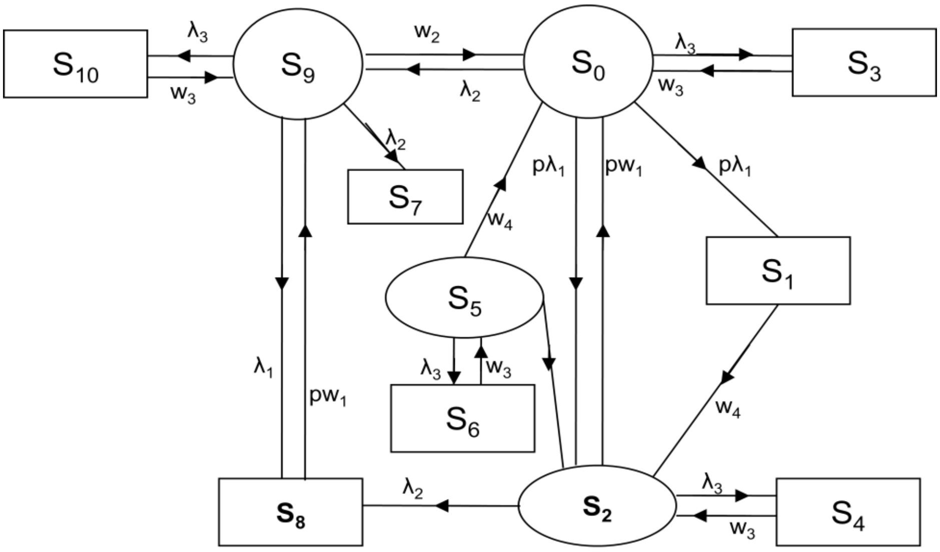


Fig 1: Taking into consideration the above assumptions and notations the Transition Diagram of the system is given in Figure 1.

Table 2: Primary, Secondary, Tertiary Circuits w.r.t. the Simple Paths (Base-State '0').

Vertex j	$\left(\mathbf{0} \overset{S_r}{\rightarrow} \boldsymbol{j}\right)$**: (P0)**	**(P1)**	**(P2)**
0	$\left(0 \overset{S_1}{\rightarrow} 0\right)$: (0,3,0) $\left(0 \overset{S_2}{\rightarrow} 0\right)$: (0,2,5,7,9,0) $\left(0 \overset{S_3}{\rightarrow} 0\right)$: (0,2,0) $\left(0 \overset{S_4}{\rightarrow} 0\right)$: (0,1,2,0) $\left(0 \overset{S_5}{\rightarrow} 0\right)$: (0,1,2,5,0) $\left(0 \overset{S_6}{\rightarrow} 0\right)$: (0,1,2,5,7,9,0) $\left(0 \overset{S_7}{\rightarrow} 0\right)$: (0,2,8,9,0) $\left(0 \overset{S_8}{\rightarrow} 0\right)$: (0,1,2,8,9,0) $\left(0 \overset{S_9}{\rightarrow} 0\right)$: (0,2,5,0) $\left(0 \overset{S_{10}}{\longrightarrow} 0\right)$: (0,9,0)	Nil (2,4,2) (5,6,5) (9,8,9) (9,10,9) (2,4,2) (2,4,2) (2,4,2) (5,6,5) (2,4,2) (5,6,5) (9,8,9) (9,10,9) (2,4,2) (8,9,8) (9,10,9) (2,4,2) (8,9,8) (9,10,9) (2,4,2) (5,6,5) (9,10,9) (9,8,9)	Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil (9,10,9) Nil Nil (9,10,9) Nil Nil Nil Nil Nil
1	$\left(0 \overset{S_1}{\rightarrow} 1\right)$: (0,1)	Nil	Nil
2	$\left(0 \overset{S_1}{\rightarrow} 2\right)$: (0,2) $\left(0 \overset{S_2}{\rightarrow} 2\right)$: (0,1,2)	(2,4,2) (2,4,2)	Nil Nil
3	$\left(0 \overset{S_1}{\rightarrow} 3\right)$: (0,3)	Nil	Nil
4	$\left(0 \overset{S_1}{\rightarrow} 4\right)$: (0,2,4) $\left(0 \overset{S_2}{\rightarrow} 4\right)$: (0,1,2,4)	(2,4,2) (2,4,2)	Nil Nil

5	$\left(0 \xrightarrow{S_1} 5\right)$: (0,2,5) $\left(0 \xrightarrow{S_2} 5\right)$: (0,1,2,5)	(2,4,2) (5,6,5) (2,4,2) (5,6,5)	Nil Nil Nil Nil
6	$\left(0 \xrightarrow{S_1} 6\right)$: (0,2,5,6) $\left(0 \xrightarrow{S_2} 6\right)$: (0,1,2,5,6)	(2,4,2) (5,6,5) (2,4,2) (5,6,5)	Nil Nil Nil Nil
7	$\left(0 \xrightarrow{S_1} 7\right)$: (0,2,5,7) $\left(0 \xrightarrow{S_2} 7\right)$: (0,1,2,5,7)	(2,4,2) (5,6,5) (2,4,2) (5,6,5)	Nil Nil Nil Nil
8	$\left(0 \xrightarrow{S_1} 8\right)$: (0,2,8) $\left(0 \xrightarrow{S_2} 8\right)$: (0,1,2,8) $\left(0 \xrightarrow{S_3} 8\right)$: (0,2,5,7,9,8) $\left(0 \xrightarrow{S_4} 8\right)$: (0,1,2,5,7,9,8)	(2,4,2) (8,9,8) (2,4,2) (8,9,8) (2,4,2) (5,6,5) (9,10,9) (2,4,2) (5,6,5) (9,10,9) (9,8,9)	Nil (9,10,9) Nil (9,10,9) Nil Nil Nil Nil Nil Nil Nil
9	$\left(0 \xrightarrow{S_1} 9\right)$: (0,2,8,9) $\left(0 \xrightarrow{S_2} 9\right)$: (0,1,2,8,9) $\left(0 \xrightarrow{S_3} 9\right)$: (0,2,5,7,9) $\left(0 \xrightarrow{S_4} 9\right)$: (0,1,2,5,7,9) $\left(0 \xrightarrow{S_5} 9\right)$: (0,9)	(2,4,2) (8,9,8) (9,10,9) (9,8,9) (2,4,2) (8,9,8) (9,10,9) (9,8,9) (2,4,2) (5,6,5) (9,10,9) (9,8,9) (2,4,2) (5,6,5) (9,10,9) (9,8,9) (9,10,9) (9,8,9)	Nil (9,10,9) Nil Nil Nil (9,10,9) Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil
10	$\left(0 \xrightarrow{S_1} 10\right)$: (0,2,8,9,10) $\left(0 \xrightarrow{S_2} 10\right)$: (0,1,2,8,9,10) $\left(0 \xrightarrow{S_3} 10\right)$: (0,2,5,7,9,10) $\left(0 \xrightarrow{S_4} 10\right)$: (0,1,2,5,7,9,10)	(2,4,2) (8,9,8) (9,10,9) (9,8,9) (2,4,2) (8,9,8) (9,10,9) (9,8,9) (2,4,2) (5,6,5) (9,10,9) (9,8,9) (2,4,2) (5,6,5) (9,10,9) (9,8,9)	Nil (9,10,9) Nil Nil Nil (9,10,9) Nil Nil Nil Nil Nil Nil Nil Nil Nil Nil

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.

Table 3

Transition Probabilities

$q_{i,j}^{(t)}$	$P_{ij} = q^*_{i,j}{}^{(t)}$
$q_{0,1} = \bar{p}\lambda_1 e^{-(\bar{p}\lambda_1+p\lambda_1+\lambda_2+\lambda_3)t}$ $= \bar{p}\lambda_1 e^{-(\lambda_1+\lambda_2+\lambda_3)t}$ $q_{0,2} = p\lambda_1 e^{-(\lambda_1+\lambda_2+\lambda_3)t}$ $q_{0,3} = \lambda_3 e^{-(\lambda_1+\lambda_2+\lambda_3)t}$ $q_{0,9} = \lambda_2 e^{-(\bar{p}\lambda_1+p\lambda_1+\lambda_2+\lambda_3)t}$	$p_{0,1} = \bar{p}\lambda_1/(\lambda_1+\lambda_2+\lambda_3)$ $p_{0,2} = p\lambda_1/(\lambda_1+\lambda_2+\lambda_3)$ $p_{0,3} = \lambda_3/(\lambda_1+\lambda_2+\lambda_3)$ $p_{0,9} = \lambda_2/(\lambda_1+\lambda_2+\lambda_3)$
$q_{1,2} = w_4 e^{-w_4 t}$	$p_{1,2} = 1$
$q_{2,0} = pw_1 e^{-(pw_1+\bar{p}w_1+\lambda_2+\lambda_3)t}$ $q_{2,4} = \lambda_3 e^{-(pw_1+\bar{p}w_1+\lambda_2+\lambda_3)t}$ $q_{2,5} = \bar{p}w_1 e^{-(pw_1+\bar{p}w_1+\lambda_2)t}$ $q_{2,8} = \lambda_2 e^{-(pw_1+\bar{p}w_1+\lambda_2)t}$	$p_{2,0} = pw_1/(w_1+\lambda_2+\lambda_3)$ $p_{2,4} = \lambda_3/(w_1+\lambda_2+\lambda_3)$ $p_{2,5} = \bar{p}w_1/(w_1+\lambda_2+\lambda_3)$ $p_{2,8} = \lambda_2/(w_1+\lambda_2+\lambda_3)$
$q_{3,0} = w_3 e^{-w_3 t}$	$p_{3,0} = 1$
$q_{4,2} = w_3 e^{-w_3 t}$	$p_{4,2} = 1$
$q_{5,0} = w_4 e^{-(w_4+\lambda_2+\lambda_3)t}$ $q_{5,6} = \lambda_3 e^{-(w_4+\lambda_2+\lambda_3)t}$ $q_{5,7} = \lambda_2 e^{-(w_4+\lambda_2+\lambda_3)t}$	$p_{5,0} = w_4/(w_4+\lambda_2+\lambda_3)$ $p_{5,6} = \lambda_3/(w_4+\lambda_2+\lambda_3)$ $p_{5,7} = \lambda_2/(w_4+\lambda_2+\lambda_3)$
$q_{6,5} = w_3 e^{-w_3 t}$	$p_{6,5} = 1$
$q_{7,9} = w_4 e^{-w_4 t}$	$p_{7,9} = 1$
$q_{8,9} = pw_1 e^{-pw_1 t}$	$p_{8,9} = 1$
$q_{9,0} = w_2 e^{-(w_2+\lambda_1+\lambda_3)t}$ $q_{9,8} = \lambda_1 e^{-(w_2+\lambda_1+\lambda_3)t}$ $q_{9,10} = \lambda_3 e^{-(w_2+\lambda_1+\lambda_3)t}$	$p_{9,0} = w_2/(w_2+\lambda_1+\lambda_3)$ $p_{9,8} = \lambda_1/(w_2+\lambda_1+\lambda_3)$ $p_{9,10} = \lambda_3/(w_2+\lambda_1+\lambda_3)$
$q_{10,9} = w_3 e^{-w_3 t}$	$p_{10,9} = 1$

Mean Sojourn Times

$R_i(t)$	$\mu_i = R_i^*(0)$
$R_0^{(t)} = e^{-(\bar{p}\lambda_1+p\lambda_1+\lambda_2+\lambda_3)t}$	$\mu_0 = 1/(\lambda_1+\lambda_2+\lambda_3)$
$R_1^{(t)} = e^{-w_4 t}$	$\mu_1 = 1/w_4$
$R_2^{(t)} = e^{-(\bar{p}w_1+pw_1+\lambda_2+\lambda_3)t}$	$\mu_2 = 1/(w_1+\lambda_2+\lambda_3)$
$R_3^{(t)} = e^{-w_3 t}$	$\mu_3 = 1/w_3$
$R_4^{(t)} = e^{-w_3 t}$	$\mu_4 = 1/w_3$
$R_5^{(t)} = e^{-(w_4+\lambda_2+\lambda_3)t}$	$\mu_5 = 1/(w_4+\lambda_2+\lambda_3)$
$R_6^{(t)} = e^{-w_3 f}$	$\mu_6 = 1/w_3$
$R_7^{(t)} = e^{-w_4 t}$	$\mu_7 = 1/w_4$
$R_8^{(t)} = e^{-pw_1 t}$	$\mu_8 = 1/pw_4$
$R_9^{(t)} = e^{-(w_2+\lambda_3+\lambda_1)t}$	$\mu_9 = 1/(w_2+\lambda_1+\lambda_3)$
$R_{10}^{(t)} = e^{-w_3 t}$	$\mu_{10} = 1/w_3$

Transition Probability

The mean time to system failure and al the key parameters of the system (under steady state conditions) are evaluated by using Regenerative Point Graphical Technique and using '0' as the base state of the system.

$V_{0,0}$ = (0,3,0)+(0,2,5,7,9,0)+(0,2,0)+(0,1,2,0) +(0,1,2,5,0) +(0,1,2,5,7,9,0) +(0,2,8,9,0)+(0,1,2,8,9,0)+(0,2,5,0)

$= p_{0,3}p_{3,0}+p_{0,2}p_{2,5}p_{5,7}p_{7,9}p_{9,0}+p_{0,2}p_{2,0}+p_{0,1}p_{1,2}p_{2,0}+p_{0,1}p_{1,2}p_{2,5}p_{5,0}+p_{0,1}p_{1,2}p_{2,5}p_{5,7}p_{7,9}p_{9,0}$ $+p_{0,2}p_{2,8}p_{8,9}p_{9,0}+p_{0,1}p_{1,2}p_{2,8}p_{8,9}p_{9,0}+p_{0,2}p_{2,5}p_{5,0}+p_{0,9}p_{9,0}$ = 1(Verified)

$V_{0,1}$ = (0,1) = $p_{0,1}$ = $\bar{p}\lambda_1/(\lambda_1+\lambda_2+\lambda_3)$

$V_{0,2}$ = (0,2)+(0,1,2) = $p_{0,2}+p_{0,1}\,p_{1,2}$ = $\lambda_1/(\lambda_1+\lambda_2+\lambda_3)$

$V_{0,3}$ = (0,3) = $p_{0,3}$ = $\lambda_3/(\lambda_1+\lambda_2+\lambda_3)$

$V_{0,4} = (0,2,4)+(0,1,2,4) = p_{0,2}p_{2,4}+p_{0,1}p_{1,2}p_{2,4} = \lambda_1\lambda_3/(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)$

$V_{0,5} = (0,2,5)+(0,1,2,5) = p_{0,2}p_{2,5}+p_{0,1}p_{1,2}p_{2,5} = \bar{p}\lambda_1 w_1/(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)$

$V_{0,6} = (0,2,5,6)+(0,1,2,5,6) = p_{0,2}p_{2,5}p_{5,6}+p_{0,1}p_{1,2}p_{2,5}p_{5,6}$

$= \bar{p}\lambda_1\lambda_3 w_1/(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)(w_4+\lambda_2+\lambda_3)$

$V_{0,7} = (0,2,5,7)+(0,1,2,5,7) = p_{0,2}p_{2,5}p_{5,7}+p_{0,1}p_{1,2}p_{2,5}p_{5,7} = \bar{p}\lambda_1\lambda_2 w_1/(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)(w_4+\lambda_2+\lambda_3)$

$V_{0,8} = (0,2,8)+(0,1,2,8)+(0,2,5,7,9,8)+(0,1,2,5,7,9,8)$

$= p_{0,2}p_{2,8}+p_{0,1}p_{1,2}p_{2,8}+p_{0,2}p_{2,5}p_{5,7}p_{7,9}p_{9,8}+p_{0,1}p_{1,2}p_{2,5}p_{5,7}p_{7,9}p_{9,8}$

$= \lambda_1\lambda_2[(w_4+\lambda_2+\lambda_3)(w_2+\lambda_1+\lambda_3)+\bar{p}\lambda_1 w_1]/[(w_4+\lambda_2+\lambda_3)(w_2+\lambda_1+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)]$

$V_{0,9} = (0,2,8,9)+(0,1,2,8,9)+(0,2,5,7,9)+(0,1,2,5,7,9)+(0,9)$

$= p_{0,2}p_{2,8}p_{8,9}+p_{0,1}p_{1,2}p_{2,8}p_{8,9}+p_{0,2}p_{2,5}p_{5,7}p_{7,9}+p_{0,1}p_{1,2}p_{2,5}p_{5,7}p_{7,9}+p_{0,9}$

$= \lambda_1\lambda_2(w_4+\bar{p}w_1+\lambda_2+\lambda_3)/(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)(w_4+\lambda_2+\lambda_3)+\lambda_2/(\lambda_1+\lambda_2+\lambda_3)$

$V_{0,10} = (0,2,8,9,10)+(0,1,2,8,9,10)+(0,2,5,7,9,10)+(0,1,2,5,7,9,10)$

$= p_{0,2}p_{2,8}p_{8,9}p_{9,10}+p_{0,1}p_{1,2}p_{2,8}p_{8,9}p_{9,10}+p_{0,2}p_{2,5}p_{5,7}p_{7,9}p_{9,10}+p_{0,1}p_{1,2}p_{2,5}p_{5,7}p_{7,9}\,p_{9,10}$

$= \lambda_1\lambda_2\lambda_3(w_4+\bar{p}w_1+\lambda_2+\lambda_3)/(\lambda_1+\lambda_2+\lambda_3)(w_1+\lambda_2+\lambda_3)(w_2+\lambda_1+\lambda_3)(w_4+\lambda_2+\lambda_3)$

Evaluation of Parameters

i.e. Mean Time to System Failure (T_0), Availability of the System (A_0), Busy Period of the Server (B_0) & Expected Number of Inspections by the Repairman (V_0)

The mean time to system failure and all the key parameters of the system (under steady state conditions) are evaluated by applying Regenerative Point Graphical Technique (RPGT) taking '0' as the base state.

(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' = 2,5,9 taking 'ξ' = '0'.

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

$T_0 = (0,0)\mu_0+(0,2)\mu_2+ (0,2,5)\mu_5+(0,9)\mu_9/[1-(0,2,0)-(0,9,0)-(0,2,5,0)$

$= (p_{0,0}\mu_0+p_{0,2}\mu_2+p_{0,2}p_{2,5}\mu_5+p_{0,9}\mu_9)/p_{0,1}p_{1,2}p_{2,5}\mu_5/1-(p_{0,2}p_{2,0}+p_{0,9}p_{9,0}$
$+p_{0,2}\,p_{2,5}\,p_{5,0})$

Availability of the System: The regenerative states at which the system is available are 'j' = 0,2,5,9 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

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

$A_0 = V_{0,0}f_0\mu_0+V_{0,2}f_2\mu_2+V_{0,5}f_5\mu_5+V_{0,9}f_9\mu_9 \div V_{0,0}\mu_0^1+V_{0,1}\mu_1^1+V_{0,2}\mu_2^1+V_{0,3}\mu_3^1+V_{0,4}\mu_4^1$
$+V_{0,5}\mu_5^1+V_{0,6}\mu_6^1+V_{0,7}\mu_7^1+V_{0,8}\mu_8^1+V_{0,9}\mu_9^1+V_{0,10}\mu_{10}^1$

$= (V_{0,0}\mu_0+V_{0,2}\mu_2+V_{0,5}\mu_5+V_{0,9}\mu_9)/K$

where $f_0 = f_2 = f_5 = f_9 = 1$, $\mu_i = \mu_i^1$

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

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

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

$B_0= V_{0,1}\eta_1+V_{0,2}\eta_2+V_{0,3}\eta_3+V_{0,4}\eta_4+V_{0,5}\eta_5+V_{0,6}\eta_6+V_{0,7}\eta_7+V_{0,8}\eta_8+V_{0,9}\eta_9+V_{0,10}\eta_{10}/$
$V_{0,0}\mu_0^1+V_{0,1}\mu_1^1+V_{0,2}\mu_2^1+V_{0,3}\mu_3^1+V_{0,4}\mu_4^1+V_{0,5}\mu_5^1+V_{0,6}\mu_6^1+V_{0,7}\mu_7^1+V_{0,8}\mu_8^1+V_{0,9}\mu_9^1$
$+V_{0,10}\mu_{10}^1$

where $\eta_i = \mu_i = \mu_i^1$

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

Expected Number of Inspections by the repair man: The regenerative states where the repair man do this job j = 1,2,3,9 the regenerative states are i = 0 to 10, Taking 'ξ' = '0', the number of visit by the repair man is given by

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

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

where $\eta_i = \mu_i = \mu_i^1$

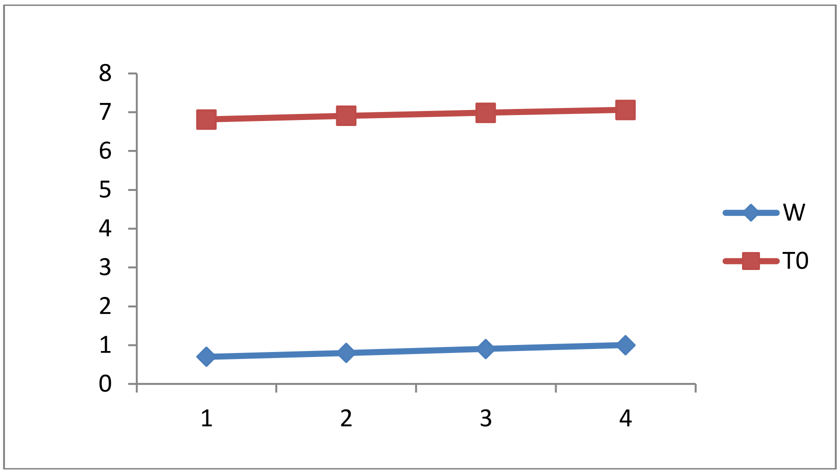
$= V_{0,1}+V_{0,2}+V_{0,3}+V_{0,9}/V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,7}\mu_7$
$+V_{0,8}\mu_8+V_{0,9}\mu_9+V_{0,10}\mu_{10}= (V_{0,1}+V_{0,2}+V_{0,3}+V_{0,9})/K$

Special Case
Warm Standby $\lambda_1 = 0.2$, $\lambda_2 = 0.1$, $\lambda_3 = 0.1$ $w_1 = w_2 = w_3 = w_4 = w$, $p = 0.9$
a. Mean Time to System Failure (T_0)

Table 5

W	0.7	0.8	0.9	1
T_0	6.81237	6.90446	6.98614	7.05900

Mean Time to System Failure Graph



b. Availability of the System (A_0)

Table 6

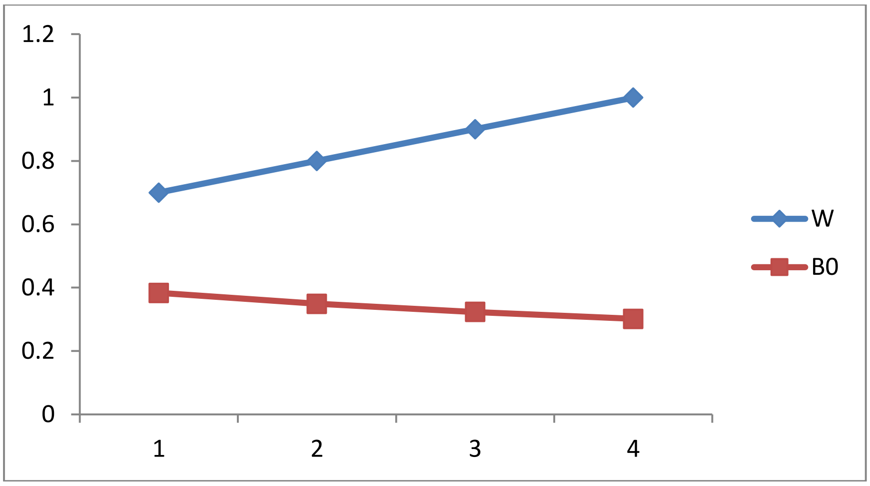
W	0.7	0.8	0.9	1
A_0	0.84110	0.86353	0.87724	0.88847

c. Busy Period of the Server (B_0)

Table 7

W	0.7	0.8	0.9	1
B_0	0.38310	0.34903	0.32332	0.30115

Busy Period of the Server Graph

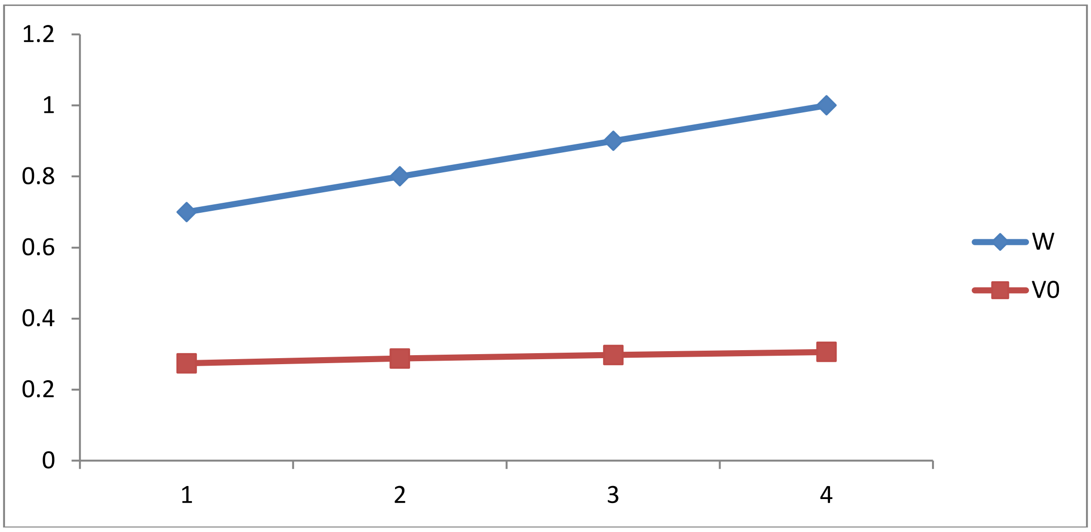


d. Expected Number of Server's Visits (V_0)

Table 8

W	0.7	0.8	0.9	1
V_0	0.27386	0.28746	0.29751	0.30612

Expected Number of Server's Visits Graph



Cold Standby

$\lambda_1 = \lambda$, $\lambda_2 = 0$, $\lambda_3 = 0.1$, $w_1 = w_2 = w_3 = w_4 = w$, $p = 0.9$

a. Availability of the System (A_0)

Table 9

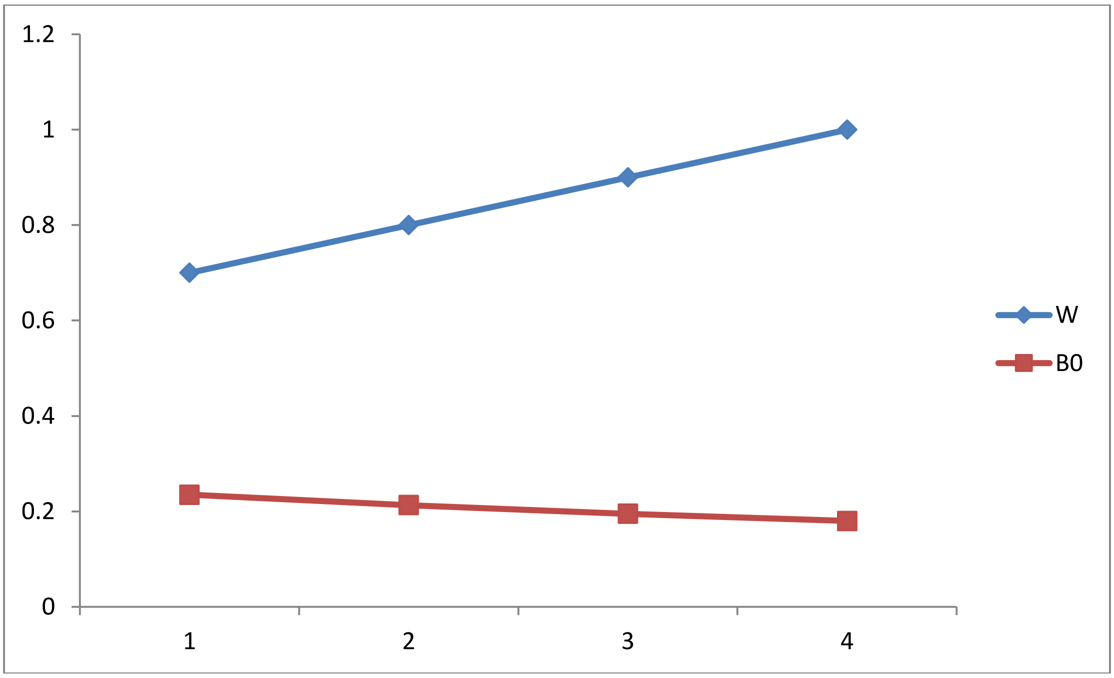
W	0.7	0.8	0.9	1
A_0	0.86933	0.88226	0.89282	0.90163

b. Busy Period of the Server (B_0)

Table 10

W	0.7	0.8	0.9	1
B_0	0.23469	0.21295	0.19492	0.17971

Busy Period of the Server Graph

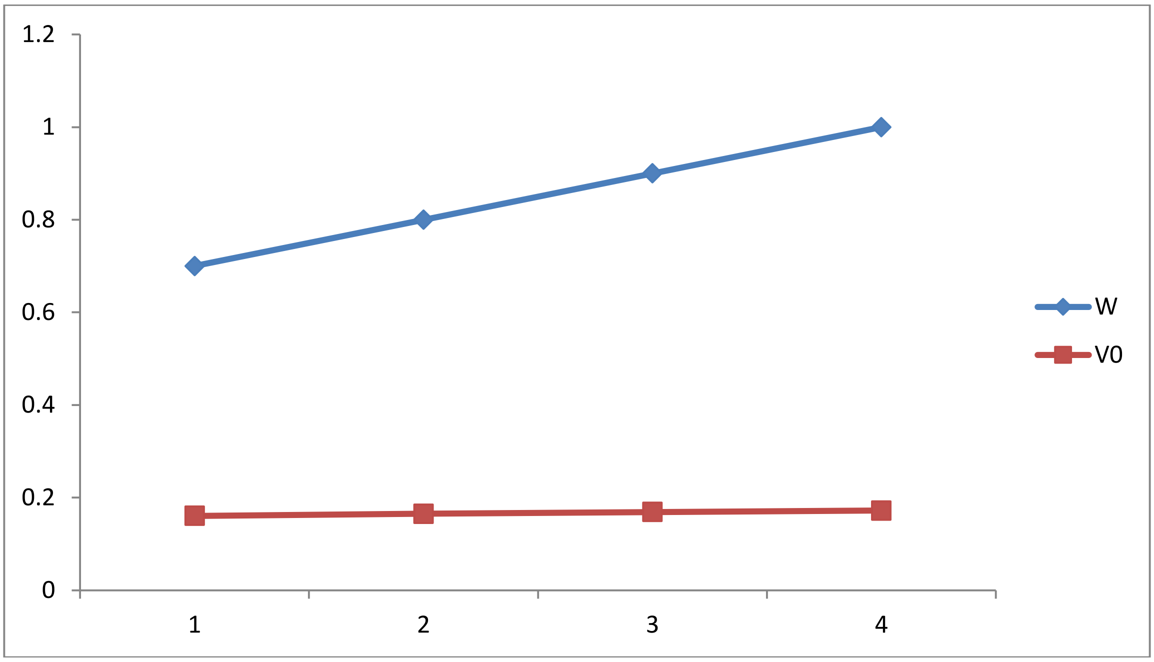


c. Expected Number of Server's Visits (V_0)

Table 11

W	0.7	0.8	0.9	1
V_0	0.16071	0.16527	0.16906	0.17225

Expected Number of Server's Visits Graph



Conclusion

From above tables and graph we see that the result obtained using Regenerative Point Graphical Technique is same as obtained by using Regenerative Point Technique and other techniques. But in Regenerative Point Graphical Technique, we obtained the results very easily and quickly without writing any state equations and without any cumbersome procedures, long calculations and simplifications. Regenerative Point Graphical Technique is applied to study the behavior and profit analysis of various process industries like soap, soft drink and dairy plant, paper industry, soap industry etc. It is hoped that the Regenerative Point Graphical Technique for the analysis of the system will be very helpful to the managements, manufactures and the personal engaged in reliability engineering and working for the behavior and profit analysis of stochastic systems.

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