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Sunita Thori
Research Scholar,
J.J.T. University,
Jhunjhnu, Rajasthan, India

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

Correspondence
Sunita Thori
Research Scholar,
J.J.T. University, Jhunjhnu,
Rajasthan, India

Stochastic analysis of edible oil refinery industry

Sunita Thori and Dr. Pardeep Goel

Abstract
This paper is concerned with the sensitivity analysis in terms of failure/repair rates of subunits of an edible oil refinery system consisting of a number of subunits of varying nature. The system consists of four different subsystems namely Crusher unit (A), Filter and refining unit (B), Boiler and kettle unit (D), Neutralizer unit (E). Sub unit 'A' have components in parallel and other units have components in series, so if one or more components fail in unit 'A' than the system works in reduced capacity and other subunits fail when one or more components fail then that unit fails causing the whole system to a failed state. Fuzzy logic is used to declare the failure of a unit. Four processing units are working in series in order A, B, D, E, so if any of the units fail, the system fails. Taking constant failure and general repair rates for each subunit several measures of system effectiveness such as reliability, MTSF, busy period of the server, availability of the system and expected number of server's visits etc. useful to industrial managers are obtained by using regenerative point technique followed by sensitivity analysis tables and graphs.

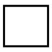
Keywords: Reliability, availability, MTSF, busy- period of repairman, RPGT etc

Introduction
A number of researchers have analyzed availability parameters of various industrial systems using different methods. In this research paper sensitivity analysis of Edible Oil Refinery Industry has been discussed using regenerative point graphical technique. Edible oil refinery have four units, subsystem 'A' have sub components in parallel, hence when some of its components fail, the unit 'A' can work in reduced capacity, hence the whole system works in reduced state which fails completely on the failure of unit A. Subunits B, D & E have a component in series so if any of the unit fails than the system is down i.e. failed. Fuzzy logic is used to declare the failure of a unit. All units have distinct failure/repair rates in all states. All the four units have different failure distributions; hence on failure of any unit leads system to failed state. Following the notations, abbreviations & assumptions system elements and process parameters are modeled using RPGT and is given in figure 1. Behavior shown by system parameters is discussed for different repair and failure rates by drawing tables and graphs. Repairs are perfect. Failure and repairs are independent. Four processing units are working in series in order A, B, D, E.

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], Goyal & Goel [12], Yusuf, I. [13], Gupta, R., Sharma, S. & Bhardwaj, P. [14] & Ms. Rachita and Garg, D. [15] have discussed behavior with perfect and imperfect switch-over of systems using various techniques.

Assumptions and Notations: - The following assumptions and notations are taken: -
1. There is single repairman who is always available.
2. The distributions of failure and repair times are constant and also different.
3. Failures and repairs are statistically independent.
4. Repair is perfect and repaired system is as good as new one.
5. Nothing can fail when the system is in failed state.

6. The system is discussed for steady-state conditions.
7. Assuming that DRR are never failed.

$\left(i \xrightarrow{s_r} j\right)$: *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.
',' : Dash denotes derivative
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.
 Full Capacity Working State
 Failed State
A/a : Unit in full capacity working state / failed state, similarly for other units.
w_i/ λ_i: Denote repair failure rates of units
Taking into consideration the above assumptions and notations the Transition Diagram of the system is given in Figure 1.

S_0 = ABDE,
S_1 = $\bar{A}$BDE,
S_2 = $\bar{A}$BDe,
S_3 = ABDe,
S_4 = AbDE,
S_5 = aBDE,
S_6 = $\bar{A}$bDE,
S_7 = ABdE,
S_8 = $\bar{A}$BdE

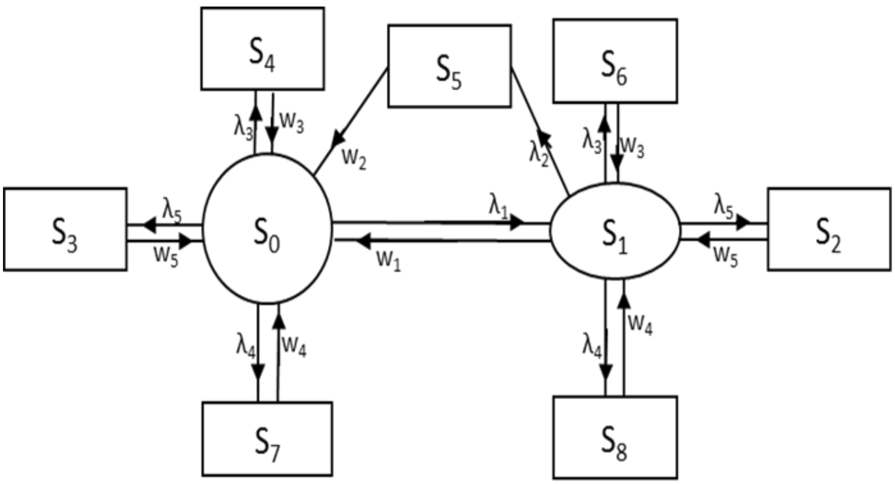


Fig 1.

The four units are symbolized as

Crusher unit	=	A,	Filter and refining unit	=	B
Boiler and kettle unit	=	D,	Neutralizer unit	=	E

Table 1: Primary, Secondary and Tertiary Circuits associated with the system are given in

Vertex i	CL1	CL2
0	(0,1,0) (0,3,0),(0,4,0),(0,7,0) (0,1,5,0)	(1,8,1),(1,2,1),(1,6,1) - (1,6,1),(1,2,1),(1,8,1)
1	(1,0,1) (1,8,1),(1,2,1),(1,6,1) (1,5,0,1)	(0,4,0),(0,3,0),(0,7,0) - (0,3,0),(0,4,0),(0,7,0)
2	(2,1,2)	(1,8,1),(1,6,1),(1,0,1),(1,5,0,1)
3	(3,1,3)	(1,8,1),(1,6,1),(1,5,0,1),(1,2,1) (1,0,1)
4	(4,0,4)	(0,1,0),(0,3,0),(0,7,0),(0,1,5,0)
5	(5,0,1,5)	(0,1,0),(0,3,0),(0,4,0),(0,7,0) (1,0,1),(1,8,1),(1,2,1),(1,6,1)
6	(6,1,6)	(1,0,1),(1,8,1),(1,2,1),(1,5,0,1)
7	(7,0,7)	(0,1,0),(0,30,),(0,4,0),(1,5,0,1)
8	(8,1,8)	(1,0,1),(1,2,1),(1,6,1),(1,5,0,1)

Table 1

As there are five primary cycles and six secondary cycles at vertices ‘0’ and ‘i’ so there is a tie between vertices ‘0’ and ‘i’ to change base state in such situation we have the discretion and we chase ‘0’ as the base state. Simple paths from the base state are given below

Table 2: Simple Paths (C_0)

Vertex j	$\left(\mathbf{0} \overset{S_r}{\rightarrow} \boldsymbol{j}\right)$**: (P0)**	**(P1)**
0	$\left(0 \overset{S_0}{\rightarrow} 0\right)$: (0,1,0) $\left(0 \overset{S_1}{\rightarrow} 0\right)$: (0,3,0) $\left(0 \overset{S_3}{\rightarrow} 0\right)$: (0,4,0) $\left(0 \overset{S_5}{\rightarrow} 0\right)$: (0,1,5,0) $\left(0 \overset{S_4}{\rightarrow} 0\right)$: (0,7,0)	(1,8,1),(1,2,1),(1,6,1) - - (1,8,1),(1,6,1),(1,2,1) -
1	$\left(0 \overset{S_1}{\rightarrow} 1\right)$: (0,1)	(1,8,1),(1,2,1),(1,6,1)
2	$\left(0 \overset{S_1}{\rightarrow} 2\right)$: (0,1,2)	(1,2,1),(1,8,1),(1,6,1)
3	$\left(0 \overset{S_1}{\rightarrow} 3\right)$: (0,3)	-
4	$\left(0 \overset{S_1}{\rightarrow} 4\right)$: (0,4)	-
5	$\left(0 \overset{S_1}{\rightarrow} 5\right)$: (0,1,5)	(1,2,1),(1,8,1),(1,6,1)
6	$\left(0 \overset{S_1}{\rightarrow} 6\right)$: (0,1,6)	(1,6,1),(1,2,1),(1,8,1)
7	$\left(0 \overset{S_1}{\rightarrow} 7\right)$: (0,7)	Nil
8	$\left(0 \overset{S_1}{\rightarrow} 8\right)$: (0,1,8)	(1,2,1),(1,8,1),(1,6,1)

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

$\mathbf{q_{i,j}(t)}$	$\mathbf{P_{ij} = q^*_{i,j}(t)}$
$q_{0,1} = \lambda_1 e^{-(\lambda_1+\lambda_3+\lambda_5+\lambda_4)t}$ $q_{0,3} = \lambda_5 e^{-(\lambda_1+\lambda_3+\lambda_5+\lambda_4)t}$ $q_{0,4} = \lambda_3 e^{-(\lambda_1+\lambda_3+\lambda_5+\lambda_4)t}$ $q_{0,7} = \lambda_4 e^{-(\lambda_1+\lambda_3+\lambda_5+\lambda_4)t}$	$p_{0,1} = \lambda_1/\{\lambda_1+\lambda_3+\lambda_5+\lambda_4\}$ $p_{0,3} = \lambda_5/\{\lambda_1+\lambda_3+\lambda_5+\lambda_4\}$ $p_{0,4} = \lambda_3/(\lambda_1+\lambda_3+\lambda_5+\lambda_4)$ $p_{0,7} = \lambda_4/(\lambda_1+\lambda_3+\lambda_5+\lambda_4)$
$q_{1,0} = w_1 e^{-(w_1+\lambda_2+\lambda_3+\lambda_5+\lambda_4)t}$	$p_{1,0} = w_1/\{w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5\}$

$q_{1,5}= \lambda_2 e^{-(w_1+\lambda_2+\lambda_3+\lambda_5+\lambda_4)t}$ $q_{1,6}= \lambda_3 e^{-(w_1+\lambda_2+\lambda_3+\lambda_5+\lambda_4)t}$ $q_{1,2}= \lambda_5 e^{-(w_1+\lambda_2+\lambda_3+\lambda_5+\lambda_4)t}$ $q_{1,8}= \lambda_4 e^{-(w_1+\lambda_2+\lambda_3+\lambda_5+\lambda_4)t}$	$p_{1,5}= \lambda_2/\{w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5\}$ $p_{1,6}= \lambda_3/\{w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5\}$ $p_{1,2}= \lambda_5/\{w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5\}$ $p_{1,8}= \lambda_4/\{w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5\}$
$q_{2,1}= w_5 e^{-w_5 t}$	$p_{2,1}= w_5/w_5 = 1$
$q_{3+i,0}= w_5 e^{-w_5 t}$	$p_{3+i,0}= 1,\ 0 \le i \le 5$

Table 4: Mean Sojourn Times

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

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;

Evaluation of Parameters: - The Mean time to system failure and all the key parameters of the system under steady state conditions are evaluated, applying Regenerative Point Graphical Technique (RPGT) and using '0' as the base-state of the system as under:

The transition probability factors of all the reachable states from the base state 'ξ' = '0' are:

Probabilities from state '0' to different vertices are given as

$V_{0,0} = 1$

$V_{0,1} = (0,1)/[1-(1,8,1)][1-(1,2,1)][1-(1,6,1)] \quad = p_{0,1}/(1-p_{1,8}p_{8,1})(1-p_{1,2}p_{2,1})(1-p_{1,6}p_{6,1})$

$= \{(\lambda_1/\lambda_1+\lambda_3+\lambda_5+\lambda_4)\}/\{[1-(\lambda_4/w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)][1-(\lambda_5/w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)]$

$[1-(\lambda_3/w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)\}]$

$=\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_2+\lambda_4+\lambda_5)/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)^3$

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

$=\lambda_1\lambda_5(w_1+\lambda_2+\lambda_3+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_2+\lambda_4+\lambda_5)/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)^4$

$V_{0,3} = (0,3), = p_{0,3}, \qquad = (\lambda_5/\lambda_1+\lambda_3+\lambda_4+\lambda_5)$

$V_{0,4} = (0,4), = p_{0,4}, \qquad = (\lambda_3/\lambda_1+\lambda_3+\lambda_4+\lambda_5)$

$V_{0,5} = (0,5), = p_{0,5}, \qquad = (0,1,5), \quad = p_{0,1}p_{1,5},$

$= \lambda_1\lambda_2/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)$

$V_{0,6} = (0,1,6), \quad = p_{0,1}p_{1,6}, \quad = \lambda_1\lambda_3/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)$

$V_{0,7} = (0,7), = p_{0,7}, \qquad = (\lambda_4/\lambda_1+\lambda_3+\lambda_4+\lambda_5)$

$V_{0,8} = (0,1,8), \quad = p_{0,1}p_{1,8}, \quad = \lambda_1\lambda_4/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)$

MTSF (T_0): The un-failed regenerative states to which the process can move taking (initial state '0'), before going to any down state are: 'i' = 5,6,7,8,2,3,4 taking 'ξ' = '0'.

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

$T_0 = (V_{0,0}\mu_0+V_{0,1}\mu_1)/1-(1,0,1)$

Availability of the System: The states where the system is working in reduced or full capacity are 'j' = 0,1 and the regenerative states are 'i' = 0 to 8 taking 'ξ' = '0' the availability as per RPGT is

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

$A_0 = [1/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)+ \lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4)$

$(w_1+\lambda_2+\lambda_4+\lambda_5)]/1/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)+\{1+(\lambda_5/w_5)+(\lambda_3/w_3)+(\lambda_4/w_4)\}+\{k+(\lambda_4/w_4)+(\lambda_5/w_5)$

$+(\lambda_2/w_2)+(\lambda_3/w_3)$

Server's Busy Period (B_0): The states where the server is busy are 'j' = 1,2,3,4,5,6,7,8 and regenerative states are 'i' = 0 to 8, taking ξ = '0', using RPGT is given as

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

$B_0=1-V_{0,0}\mu_0/1/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)+\{1+(\lambda_5/w_5)+(\lambda_3/w_3)+(\lambda_4/w_4)\}+\{\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)$
$/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_2+\lambda_4+\lambda_5)+(\lambda_4/w_4)+(\lambda_5/w_5)+(\lambda_2/w_2)$
$+(\lambda_3/w_3)$

Expected Number of Inspections by the repair man: The regenerative states where the repair man does this job are j = 2,3,4,5,6,7,8, Taking 'ξ' = '0', the number of visit by the repair man is given by

$$V_0=\left[\sum_{j,sr}\left\{\frac{\{pr(\xi^{sr\rightarrow}j)\}}{\Pi_{k_{1\neq\xi}}\left\{1-V_{\overline{k_1 k_1}}\right\}}\right\}\right]\div\left[\sum_{i,s_r}\left\{\frac{\{pr(\xi^{sr\rightarrow}i)\}\mu_i^1}{\Pi_{k_{2\neq\xi}}\left\{1-V_{\overline{k_2 k_2}}\right\}}\right\}\right]=\left[\sum_j V_{\xi,j}\right]\div\left[\sum_i V_{\xi,i}\,,\mu_i^1\right]$$

$V_0=\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_5)(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_2+\lambda_4+\lambda_5)$
$(w_1+2\lambda_2+2\lambda_3+2\lambda_4+\lambda_5)+[(\lambda_5+\lambda_3+\lambda_4)/(\lambda_1+\lambda_3+\lambda_4+\lambda_5)]$

Sensitivity Analysis w.r.t. change in repair rates

Fixing $\lambda_i=0.10$ ($1\leq i \leq 5$) and varying w_1, w_2, w_3, w_4, w_5 one by one respectively at 0.80, 085, 0.90, 0.95, 1

Table 5: Mean o System Failure (T_0)

w_i	w_1	w_2	w_3	w_4	w_5
0.80	3.2	3.2	3.2	3.2	3.2
0.85	3.2	3.2	3.2	3.2	3.2
0.90	3.2	3.2	3.2	3.2	3.2
0.95	3.2	3.2	3.2	3.2	3.2
1	3.2	3.2	3.2	3.2	3.2

The Mean time of system failure is fairly very large i.e. 3.2 and is independent of repair rates of units.

Availability of the Systems (A_0): - For various repair rates availability table is

Table 6.

w_i	w_1	w_2	w_3	w_4	w_5
0.80	0.75737	0.75705	0.74966	0.74729	0.74821
0.85	0.75739	0.75737	0.75372	0.75101	0.74938
0.90	0.75741	0.75765	0.75737	0.75435	0.75106
0.95	0.75746	0.75790	0.76066	0.75737	0.75437
1	0.75749	0.75813	0.76365	0.76010	0.75737

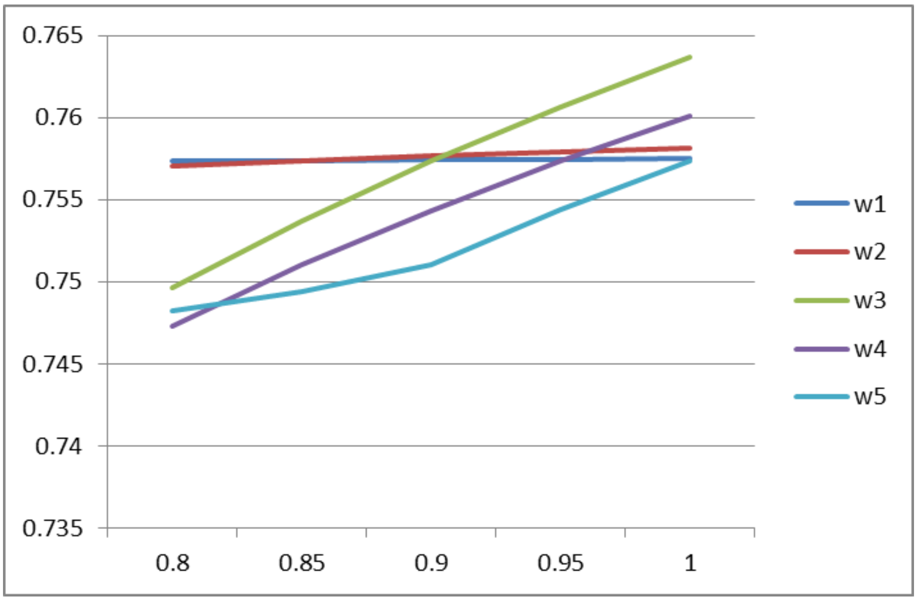


Fig 2: Availability of the System Graph

From the table and graph we see that availability is maximum when repair rate of unit 'C' is maximum in comparison to repair rate of other unit.

Busy Period of the Server's Visits (B_0): - For different repair rates of units busy period table is

Table 7

w_i	w_1	w_2	w_3	w_4	w_5
0.80	0.31656	0.31684	0.32351	0.32566	0.32268
0.85	0.31322	0.31656	0.31985	0.32229	0.32257
0.90	0.31016	0.31630	0.31656	0.31928	0.32225
0.95	0.30734	0.31608	0.31359	0.31656	0.31926
1	0.30597	0.31587	0.31089	0.31409	0.31656

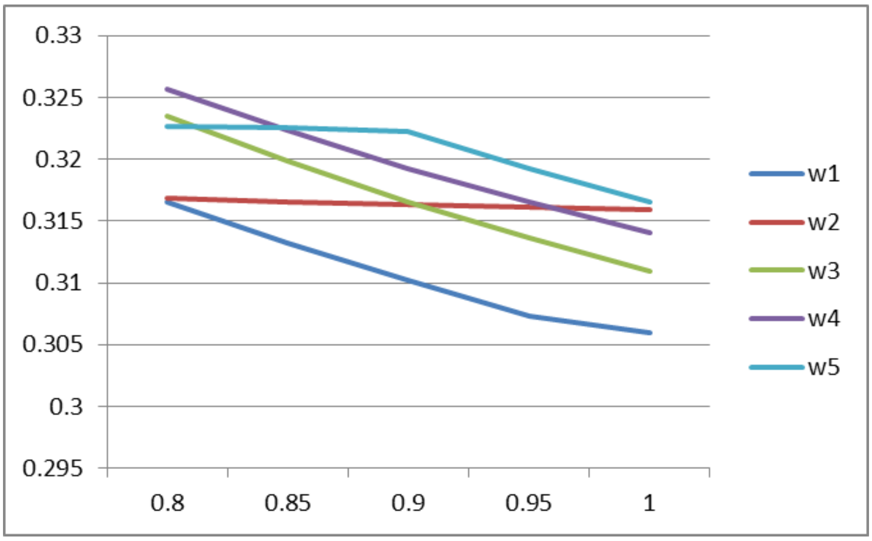


Fig 3: Busy Period of the Server's Visits Graph

Practically busy period of the system should decrease with increase in repair rates of units which is shown by the table and graph. The busy period is minimum when repair rate of system 'A' is 1 and minimum value is 0.30597 busy period of the server is maximum when Boiler and kettle unit repair rate in comparison to other units hence repairman should be efficient in repairing the Boiler and kettle unit. If the repair rates are lowest than the server will have to be more busy for fixing the problem, hence server will take more time to repair the units from the above table and graph while observing from top to bottom in columns we see that busy period of server decreases which is the practical trend in almost in all simulation above graph also verify for the similar results.

Expected Fractional Number of Inspection by the Repairman (V_0): - For Different repair rate of unit, the tabular values are given in table 8

Table 8.

w_i	w_1	w_2	w_3	w_4	w_5
0.80	0.22950	0.22941	0.22717	0.22645	**0.22524**
0.85	0.22956	0.22950	0.22840	0.22758	0.22648
0.90	0.22961	0.22959	0.22950	0.22859	0.22759
0.95	0.22964	0.22966	0.23050	0.22950	0.22859
1	0.22967	0.22973	0.23140	0.23033	0.22950

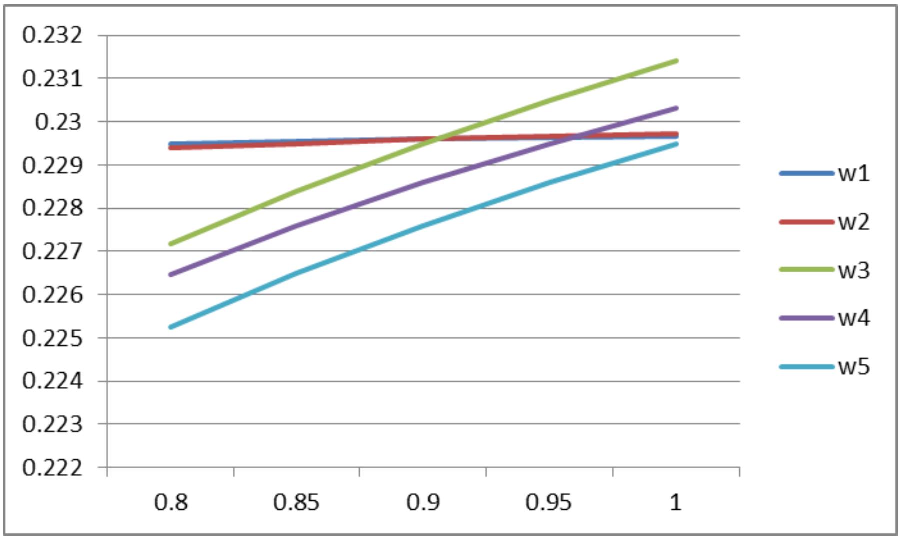


Fig 4: Expected Fractional Number of Inspection by the Repairman Graph

From the above table and graph we observe that the values in columns, while going from top to bottom it is concluded that proportional expected fractional number of inspection by the repairman is minimum when repair rate of unit 'E'is minimum in comparison to repair rates of other units, hence more care should be taken for repairing unit E over the other units.,.

Sensitivity Analysis w.r.t. change in failure rates
Fixing w_i =0.80 ($1 \le i \le 5$) and varying λ_1, λ_2, λ_3, λ_4, λ_5 one by one respectively at 0.10, 015, 0.20, 0.25, 0.30

Mean Time to System Failure (T_0): – for different failure rates of unit, the MTSF table is

Table 9

λ_i	λ_1	λ_2	λ_3	λ_4	λ_5
0.10	1.36360	1.37157	1.56747	1.72609	1.84172
0.15	1.35731	1.36360	1.45840	1.56713	1.69308
0.20	1.35015	1.35629	1.36360	1.45826	1.56676
0.25	1.34840	1.27660	1.28043	1.36360	1.45810
0.30	1.34747	**1.20590**	1.20687	1.28055	1.36360

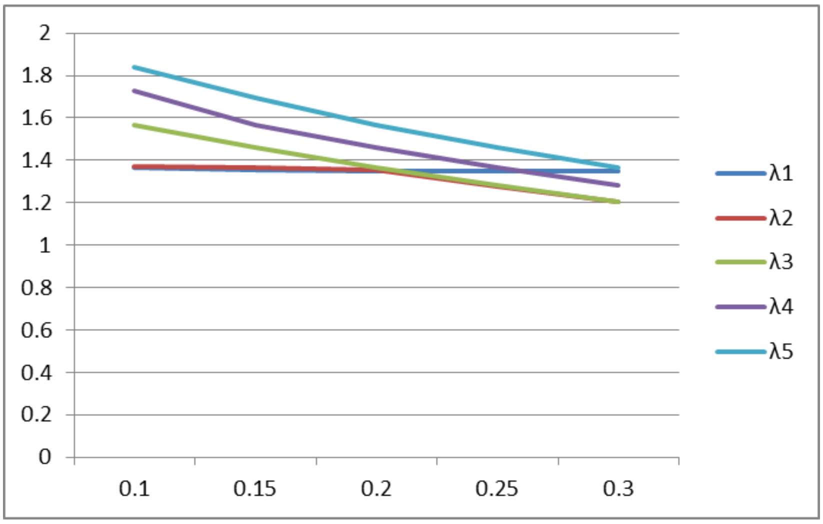


Fig 5: Mean Time to System Failure Graph

We see that MTSF is maximum when failure rate unit 'E' is minimum and MTSF is minimum when failure rate of filter unit 'B' is maximum. Hence to have optimum value of MTSF failure rate of 'E' should be kept minimum in comparison to the failure rates of other units.

Availability of the System (A0): - For different values of failure rates of units availability table is

Table 10.

λ_i	λ_1	λ_2	λ_3	λ_4	λ_5
0.10	0.52041	0.52173	0.55955	0.57527	0.59045
0.15	0.51172	0.52041	0.53648	0.55606	0.57347
0.20	0.51101	0.51919	0.52041	0.53831	0.55384
0.25	0.51046	0.51806	0.50418	0.52041	0.53711
0.30	0.50999	0.51754	0.48816	0.50556	0.52041

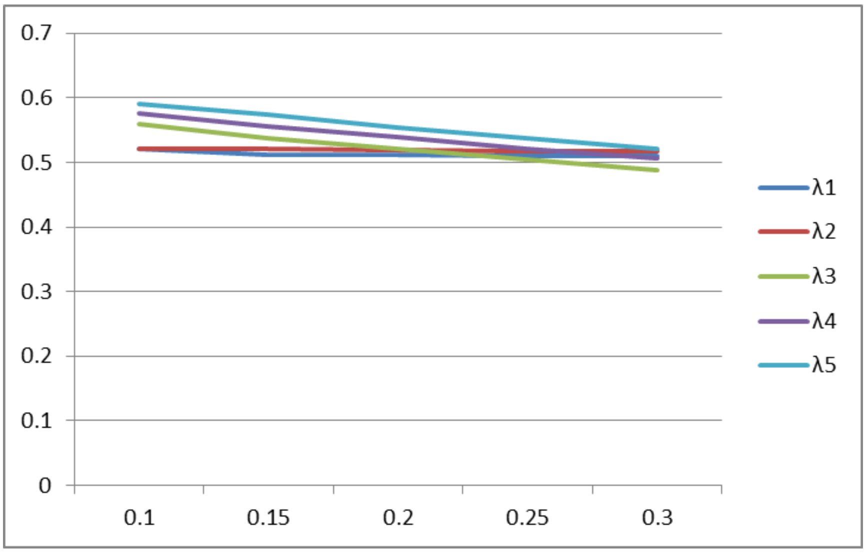


Fig 6: Availability of the System Graph

From above table and graph we see that availability is maximum when failure rate of unit E is minimum and its value is 0.59045 its minimum vale is 0.48816 corresponding to highest value of the failure rate of unit C.

Busy Period of the Server's Visits (B0)

Table 11

λ_i	λ_1	λ_2	λ_3	λ_4	λ_5
0.10	0.52468	0.51155	0.49003	0.47615	0.46267
0.15	0.54277	0.52468	0.51051	0.49309	0.47760
0.20	0.55809	0.53489	0.52468	0.50879	0.49501
0.25	0.57344	0.54472	0.53907	0.52468	0.50983
0.30	0.58774	0.55216	0.55332	0.53785	0.52468

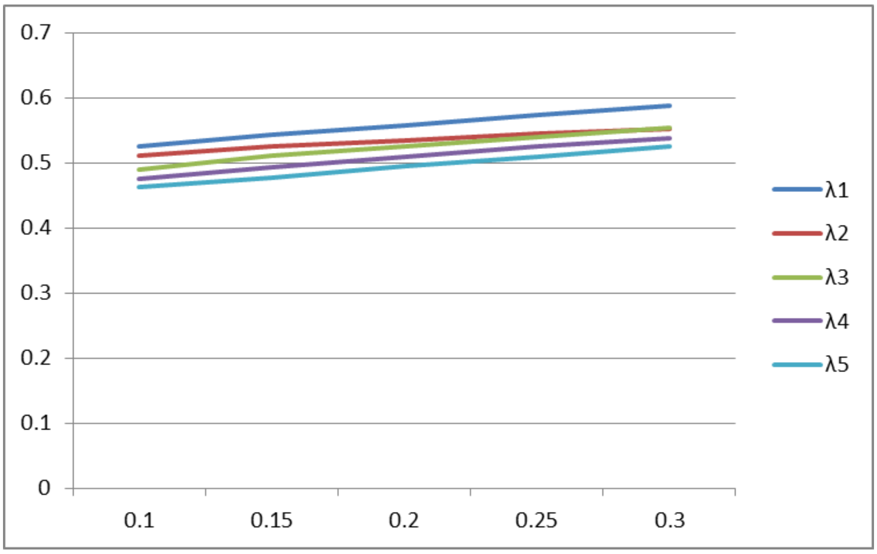


Fig 7: Busy Period of the Server's Visits Graph

The above table shows that the busy period of the server decreases with the increase in failure rates of units and is minimum hen the failure rate of unit E is minimum in comparison to the failure rates of other units.

Expected Fractional Number of Inspection by the Repairman (V0) – For different values of failure rate, the corresponding table is given below

Table 12

λ_i	λ_1	λ_2	λ_3	λ_4	λ_5
0.10	0.38367	0.38262	0.35236	0.33979	0.32763
0.15	0.38471	0.38367	0.37081	0.35515	0.34386
0.20	0.38560	0.38464	0.38367	0.36963	0.35693
0.25	0.38664	0.38556	0.39666	0.38367	0.37031
0.30	0.38702	0.38646	0.40947	0.39555	0.38367

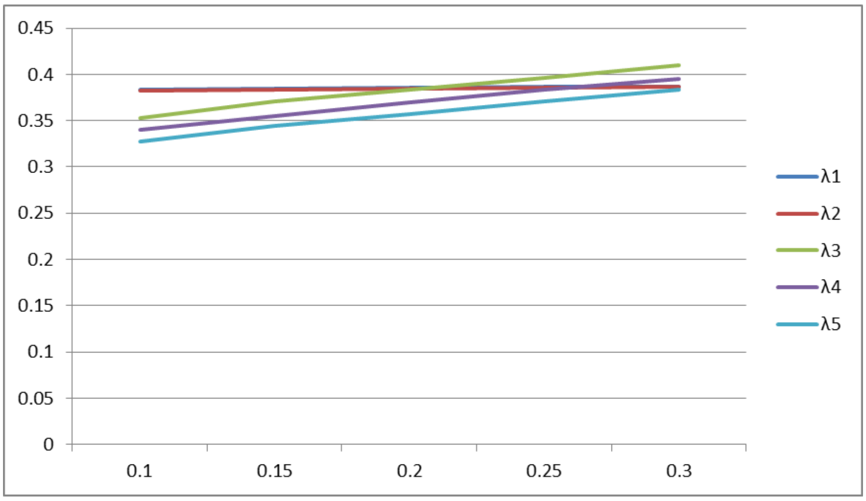


Fig 8: Expected Fractional Number of Inspection by the Repairman Graph

There is no significant change in the value of the expected fractional number of inspection due to increase in the values of the failure rates of the units but is minimum when the failure rate or unit E is minimum in comparison to the failure rates of other units.

Conclusion

To have optimum vale of system parameters management may control the failure and repair rates of units depending upon the availability of finances and market circumstances. Any state can be taken as the Base-state to evaluate the various parameters. Study can also be extended for time dependent cases also.

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