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Sensitivity analysis of fertilizer plant

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Abstract
This paper is concerned with modeling and sensitivity analysis of a urea fertilizer making system consisting of a number of subsystems of varying nature. Taking constant failure and general repair rates for each subsystem, the system is analyzed by using Regenerative Point Graphical Technique (RPGT). A common cause failure is also considered in modeling. A state diagram of the system depicting the transition rates is drawn expression for path probabilities mean sojourn times, mean time to system failure, availability of the system, busy period of the server, expected number of server's visits are derived using RPGT, which are useful to system managers, engineers, training supervisors and reliability analysts are obtained. Particular cases and sensitivity analysis w. r. t. various rates are also carried out follow by graphs and conclusion.

Keywords: Reliability, Availability, MTSF, Busy Period of Repairman, Regenerative Point Graphical Technique (RPGT), Profit Function etc

Introduction

- A number of researchers have analyzed availability parameters of various industrial system using different methods. In this research paper Behavioral Analysis of Urea Fertilizer Industry has been discussed using regenerative point graphical technique.

Kumar, J. & Malik, S. C. [1] have discussed the concept of preventive maintenance for a single unit system. Others like, Nakagawa, T. and Osaki, S. [2] have discussed reliability analysis of a one unit system with un-repairable spare units and its applications. Some interconnected studies were also found such as Goel, P. & Singh J. [3], Gupta, P., Singh, J. & Singh, I.P. [4], Gupta, V. K. [5], Chaudhary, Goel& Kumar [6] Sharma &Goel [7], Gupta, R., Sharma, S. & Bhardwaj, P. [8], Ms. Rachita and Garg, D. [9] and Garg, D. and Yadav, R. [10] have discussed behavior with perfect and imperfect switch-over of systems using various techniques.

A urea fertilizer industry consists of six sub-units Ammonia Making Section (A), Medium Pressure Section (B), Low Pressure Section (C), Pre-vacuum Section (D), Vacuum Section (E) & Periling Section (F) and three pressure units low pressure, medium pressure and high pressure units (P_1, P_2& P_3), whenever low or high pressure units fail, then low and medium pressure steams can be obtained from high pressure unit and whenever high pressure unit fail then high pressure steam cannot be obtained, thus the whole system is failed. The failed pressure units are repaired only when the whole system is in failed state. System works in full capacity when all units are good and fails when any one of the six sub-systems fails. Common cause failures may also lead the system to complete failure. All the units have sub units in series, so any one of the sub unit fails then the unit fails and the system fails when the number of failed units is more than two. Fuzzy concept is used to determine failure/working state of a unit. For failure / repair rates constant, independent and considering transition probability, a transition diagram of the system is drawn in Figure 1 to find Primary circuits, Secondary circuits & Tertiary circuits and Base state. Problem is solved using RPGT to determine system parameters. System behavior is discussed with the help of graphs and tables. Particular cases are also taken for different repair and failure rates of the system.

Assumptions, Notations & Model Description: - The following assumptions and notations are taken: -

1. There is single repair facility which is always available.

2. The distributions of failure and repair times of units 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. Failure of any of the subsystems leads to failure of the system.
7. Low pressure and medium pressure can be obtained from high pressure unit by scientific logic.
8. The failed pressure units will be repaired only when the system is failed.

$\left(i \overset{s_r}{\rightarrow} j\right)$: *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.

$\left(\xi \overset{sff}{\longrightarrow} i\right)$: 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 industry at general time t

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) : The server is busy in repair at time‘t’

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

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

μ_i : = $\int_0^\infty R_i(t)dt$

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

ξ : Base state of the system.

f_j : Fuzziness measure of the j-state.

○ : Full Capacity Working State

□ : Failed State

$P_n(t)$: Probability that the system is in state $S_n$at time t.(n = 0,1,2,...,29)

α_i: Constant failure rates of subsystem A,B,C,D,E and F respectively for i = 1,2,..,6.

α_7, α_8, α_9 : Constant failure rate of pressure unit P_1,P_2 and P_3 respectively.

α_0: Constant failure rate of entire system from any of its operative state.

β_i, $g_i(t)$: Constant repair rate of subsystem A,B,C,D,E and F respectively for i = 1,2,..,6 and corresponding p. d. f., such that) =β_i (t) exp [-$\int_0^t \beta_i(u)du$]

h, $g_h(t)$: Constant repair rate of system failed due to pressure unit P3 and corresponding p.d.f.

$g_h(t)$ = h(t)exp[-$\int_0^t h_i(u)du$]

c, $g_c(t)$: Constant repair rate of system failed due to common cause failure and corresponding p. d. f.

$g_c(t)$ = c(t)exp [-$\int_0^t c_i(u)du$]

a: Indicates that subsystem A is failed, similarly for other units.

S_0 : Initial operative state of the system where all the subsystems and units are in good condition.

S_{21} : Failed state of the system due to the failure of pressure unit P3.

S_{22} : Failed state of the system due to the common cause failure.

S_i, S_{7+i}, S_{14+i}, S_{23+i}: Failed states of the system due to the failure of any of the subsystem A,B,C,D,E and F respectively for i = 1,2,3,4,5 and 6 when all the three pressure units are good.

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

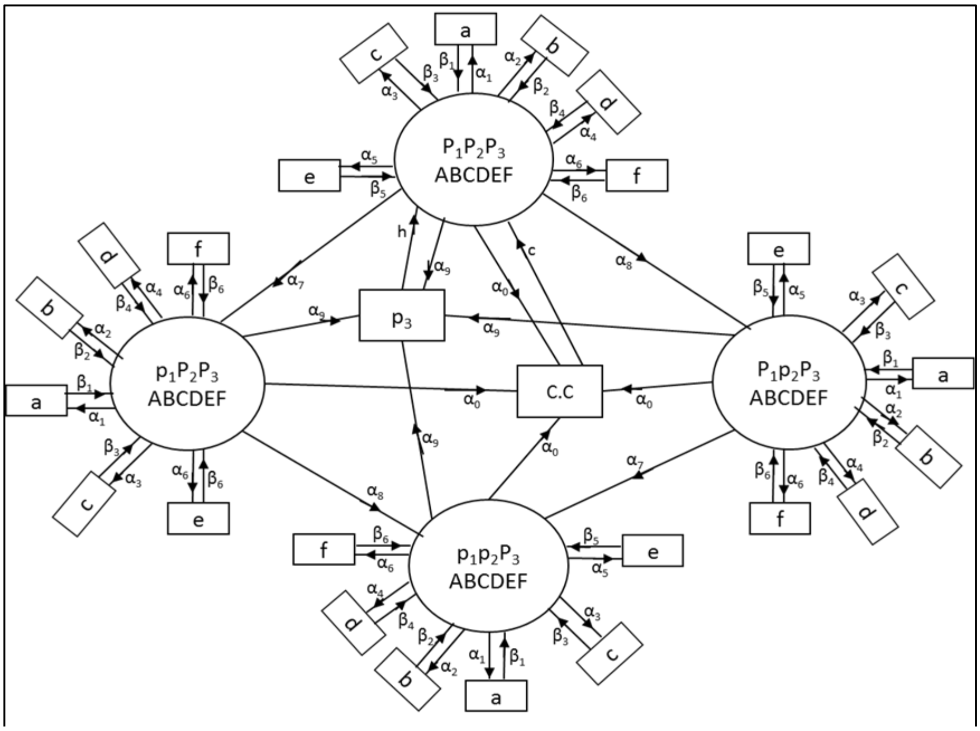

Fig 1

From the state transition Figure 1, we see that there are maximum number of primary circuits and minimum number of secondary circuits; hence vertex ‘0’ is the base state.

Primary, Secondary, Tertiary Circuits w. r. t. the Simple Paths (Base-State ‘0’)

Table 1

Vertex j	$\left(\mathbf{0} \xrightarrow{S_r} \boldsymbol{j}\right)$: ($P_0$)	(P_1)
0	$\left(0 \xrightarrow{S_0} 0\right)$: (0,1,0) $\left(0 \xrightarrow{S_1} 0\right)$: (0,2,0) $\left(0 \xrightarrow{S_2} 0\right)$: (0,3,0) $\left(0 \xrightarrow{S_3} 0\right)$: (0,4,0) $\left(0 \xrightarrow{S_4} 0\right)$: (0,5,0) $\left(0 \xrightarrow{S_5} 0\right)$: (0,6,0) $\left(0 \xrightarrow{S_6} 0\right)$: (0,22,0) $\left(0 \xrightarrow{S_7} 0\right)$: (0,21,0) $\left(0 \xrightarrow{S_8} 0\right)$: (0,14,22,0) $\left(0 \xrightarrow{S_9} 0\right)$: (0,23,22,0) $\left(0 \xrightarrow{S_{10}} 0\right)$: (0,7,21,0) $\left(0 \xrightarrow{S_{11}} 0\right)$: (0,7,22,21,0) $\left(0 \xrightarrow{S_{12}} 0\right)$: (0,7,23,22,0) $\left(0 \xrightarrow{S_{13}} 0\right)$: (0,7,22,0) $\left(0 \xrightarrow{S_{14}} 0\right)$: (0,14,21,0)	Nil Nil Nil Nil Nil Nil Nil Nil (14,19,14), (14,16,14), (14,17,14), (14,20,14) (14,15,14), (14,18,14) (14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14)
1	$\left(0 \xrightarrow{S_1} 1\right)$: (0,1)	Nil
2	$\left(0 \xrightarrow{S_1} 2\right)$: (0,2)	Nil
3	$\left(0 \xrightarrow{S_1} 3\right)$: (0,3)	Nil
4	$\left(0 \xrightarrow{S_1} 4\right)$: (0,4)	Nil
5	$\left(0 \xrightarrow{S_1} 5\right)$: (0,5)	Nil
6	$\left(0 \xrightarrow{S_1} 6\right)$: (0,6)	Nil

7	$\left(0 \xrightarrow{S_1} 7\right)$: (0,7)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7)
8	$\left(0 \xrightarrow{S_1} 8\right)$: (0,7,8)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (8,7,8)
9	$\left(0 \xrightarrow{S_1} 9\right)$: (0,7,9)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (9,7,9)
10	$\left(0 \xrightarrow{S_1} 10\right)$: (0,7,10)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (10,7,10)
11	$\left(0 \xrightarrow{S_1} 11\right)$: (0,7,11)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (11,7,11)
12	$\left(0 \xrightarrow{S_1} 12\right)$: (0,7,12)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (12,7,12)
13	$\left(0 \xrightarrow{S_1} 13\right)$: (0,7,13)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (13,7,13)
14	$\left(0 \xrightarrow{S_1} 14\right)$: (0,14)	(14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14)
15	$\left(0 \xrightarrow{S_1} 15\right)$: (0,14,15)	(14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (15,14,15)
16	$\left(0 \xrightarrow{S_1} 16\right)$: (0,14,16)	(14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (16,14,16)
17	$\left(0 \xrightarrow{S_1} 17\right)$: (0,14,17)	(14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (17,14,17)
18	$\left(0 \xrightarrow{S_1} 18\right)$: (0,14,18)	(14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (18,14,18)
19	$\left(0 \xrightarrow{S_1} 19\right)$: (0,14,19)	(19,14,19), (14,19,14), (14,17,14), (14,15,14) (14,16,14), (14,18,14), (14,20,14)
20	$\left(0 \xrightarrow{S_1} 20\right)$: (0,14,20)	(14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (20,14,20)
21	$\left(0 \xrightarrow{S_1} 21\right)$: (0,21) $\left(0 \xrightarrow{S_2} 21\right)$: (0,14,21) $\left(0 \xrightarrow{S_3} 21\right)$: (0,7,21) $\left(0 \xrightarrow{S_4} 21\right)$: (0,7,23,21) $\left(0 \xrightarrow{S_5} 21\right)$: (0,14,23,21)	Nil (14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23) (14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23)
22	$\left(0 \xrightarrow{S_1} 22\right)$: (0,22) $\left(0 \xrightarrow{S_2} 22\right)$: (0,14,22) $\left(0 \xrightarrow{S_3} 22\right)$: (0,7,22) $\left(0 \xrightarrow{S_4} 22\right)$: (0,7,23,22)	Nil (14,19,14), (14,17,14), (14,15,14), (14,16,14) (14,20,14), (14,18,14) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23)
23	$\left(0 \xrightarrow{S_1} 23\right)$: (0,7,23) $\left(0 \xrightarrow{S_2} 23\right)$: (0,14,23)	(7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23) (14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23)
24	$\left(0 \xrightarrow{S_1} 24\right)$: (0,14,23,24) $\left(0 \xrightarrow{S_2} 24\right)$: (0,7,23,24)	(14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23) (24,23,24) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23), (24,23,24)
25	$\left(0 \xrightarrow{S_1} 25\right)$: (0,14,23,25) $\left(0 \xrightarrow{S_2} 25\right)$: (0,7,23,25)	(14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23) (25,23,25) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23), (25,23,25)
26	$\left(0 \xrightarrow{S_1} 26\right)$: (0,14,23,26) $\left(0 \xrightarrow{S_2} 26\right)$: (0,7,23,26)	(14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23) (26,23,26) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23), (26,23,26)

27	$\left(0 \overset{S_1}{\rightarrow} 27\right)$: (0,14,23,27) $\left(0 \overset{S_2}{\rightarrow} 27\right)$: (0,7,23,27)	(14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23) (27,23,27) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23), (27,23,27)
28	$\left(0 \overset{S_1}{\rightarrow} 28\right)$: (0,14,23,28) $\left(0 \overset{S_2}{\rightarrow} 28\right)$: (0,7,23,28)	(14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23), (23,28,23), (23,29,23) (28,23,28) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23), (28,23,28)
29	$\left(0 \overset{S_1}{\rightarrow} 29\right)$: (0,14,23,29) $\left(0 \overset{S_2}{\rightarrow} 29\right)$: (0,7,23,29)	(14,15,14), (14,16,14), (14,17,14), (14,18,14) (14,19,14), (14,20,14), (23,24,23), (23,25,23) (23,26,23), (23,27,23),(23,28,23), (23,29,23) (29,23,29) (7,8,7), (7,9,7), (7,10,7), (7,11,7), (7,12,7), (7,13,7) (23,24,23), (23,25,23), (23,26,23), (23,27,23) (23,28,23), (23,29,23), (29,23,29)

There are no tertiary circuits for all simple paths

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 in transiting from state i → j $p_{i,j} = q^*_{i,j}(0)$;

Transition Probabilities

Table 2.

$q_{i,j}(t)$	$P_{ij} = q^*_{i,j}(0)$
$q_{0,i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_8+\alpha_0)t}$ $q_{0,14}(t) = \alpha_8 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$ $q_{0,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$ $q_{0,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$ Where i = 1 to 7	$p_{0,i} = \alpha_i/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_8+\alpha_0)$ $p_{0,14} = \alpha_8/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)$ $p_{0,21} = \alpha_9/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)$ $p_{0,22} = \alpha_0/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)$
$q_{i,0}(t) = \beta_i e^{-\beta_i t}$, $q_{7+i}(t) = \beta_{7+i} e^{-\beta_i t}$ $q_{14+i}(t) = \beta_{14+i} e^{-\beta_i t}$, $q_{21+i}(t) = \beta_{21+i} e^{-\beta_i t}$	$p_{7+i} = 1$, $p_{14+i} = 1$, $p_{21+i} = 1$ $p_{i,0} = 1$, where $1 \le i \le 6$
$q_{7,7+i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$ $q_{7,23}(t) = \alpha_8 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$ $q_{7,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$ $q_{7,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$	$p_{7,7+i} = \alpha_i/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)$ $p_{7,23} = \alpha_8/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)$ $p_{7,21} = \alpha_9/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)$ $p_{7,22} = \alpha_0/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)$
$q_{7+i,7}(t) = \beta_1 e^{-\beta_1 t}$	$p_{7+i,7} = 1$, where $1 \le i \le 6$
$q_{14,14+i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$ $q_{14,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$ $q_{14,23}(t) = \alpha_7 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$ $q_{14,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)t}$	$p_{14,14+i} = \alpha_i/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)$ $p_{14,22} = \alpha_0/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)$ $p_{14,23} = \alpha_7/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)$ $p_{14,21} = \alpha_9/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_9+\alpha_0)$
$q_{14+i,14}(t) = \beta_1 e^{-\beta_1 t}$, $q_{23+i,23}(t) = \beta_i e^{-\beta_i t}$	$p_{14+i,14} = 1$, $p_{23+i,23} = 1$, where $1 \le i \le 6$
$q_{21,0}(t) = he^{-ht}$, $q_{22,0}(t) = ce^{-ct}$	$p_{21,0} = 1$, $p_{22,0} = 1$
$q_{23,22}(t) = \alpha_0 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)t}$ $q_{23,23+i}(t) = \alpha_i e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)t}$ $q_{23,21}(t) = \alpha_9 e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)t}$	$p_{23,22} = \alpha_0/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)$ $p_{23,23+i} = \alpha_i/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)$ $p_{23,21} = \alpha_9/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_9)$

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;

Mean Sojourn Times

Table 3

$R_i(t)$	$\mu_i=R_i^*(0)$
$R_0(t)= e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)t}$	$\mu_0 = 1/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_7+\alpha_8+\alpha_9+\alpha_0)$
$R_{k+i}(t)= e^{-\beta_i t}$	$\mu_i = 1/\beta_i$, where $1 \leq i \leq 6$, k = 0, 7, 14, 23
$R_j(t)= e^{-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)t}$ where j = 7, 14, 23	$\mu_j = 1/(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5+\alpha_6+\alpha_0+\alpha_8+\alpha_9)$
$R_{21}(t)= e^{-ht}$, $R_{22}(t)= e^{-ct}$	$\mu_{21} = 1/h$, $\mu_{22} = 1/c$

Parameters Evaluation

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

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

$V_{0,0} = 1, V_{0,1} = (0,1) = p_{0,1}, V_{0,2} = (0,2) = p_{0,2}, V_{0,3} = (0,3) = p_{0,3}, V_{0,4} = (0,4) = p_{0,4}$

$V_{0,5} = (0,5) = p_{0,5}, V_{0,6} = (0,6) = p_{0,6}, V_{0,7} = (0,7)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)\}$

$V_{0,8} = (0,7,8)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_7)\}, V_{0,9} = (0,7,9)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_8)\}$

$V_{0,10} = (0,7,10)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_9)\}$

$V_{0,11} = (0,7,11)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{10})\}$

$V_{0,12} = (0,7,12)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{11})\}$

$V_{0,13} = (0,7,13)/\{(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{12})\}$

$V_{0,14} = (0,14)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})\}$

$V_{0,15} = (0,14,15)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{19})\}$

$V_{0,16} = (0,14,16)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{20})\}$

$V_{0,17} = (0,14,17)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{21})\}$

$V_{0,18} = (0,14,18)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{22})\}$

$V_{0,19} = (0,14,19)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{23})\}$

$V_{0,20} = (0,14,20)/\{(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{24})\}$

$V_{0,21} = (0,21)+\{(0,14,21)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})\}+\{(0,7,21)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)\}\ )\}+\{(0,7,23,21)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}+\{(0,14,23,21)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}$

$V_{0,22} = (0,22)+\{(0,14,22)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})\}+\{(0,7,22)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)\}+\{(0,7,23,22)/(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}$

$V_{0,23} = \{(0,7,23)/\ (1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}+\{(0,14,23)/(1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})\}$

$V_{0,24} = \{(0,14,23,24)/\ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{31})\}+\{(0,7,23,24)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{31})\}$

$V_{0,25} = \{(0,14,23,25)/\ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{32})\}+\{(0,7,23,25)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{32})\}$

$V_{0,26} = \{(0,14,23,26)/\ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{33})\}+\{(0,7,23,26)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{33})\}$

$V_{0,27} = \{(0,14,23,27)/\ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{34})\}+\{(0,7,23,27)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{34})\}$

$V_{0,28} = \{(0,14,23,28)/\ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{35})\}+\{(0,7,23,28)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{35})\}$

$V_{0,29} = \{(0,14,23,29)/\ (1-L_{13})(1-L_{14})(1-L_{15})(1-L_{16})(1-L_{17})(1-L_{18})(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{36})\}+\{(0,7,23,29)//(1-L_1)(1-L_2)(1-L_3)(1-L_4)(1-L_5)(1-L_6)(1-L_{25})(1-L_{26})(1-L_{27})(1-L_{28})(1-L_{29})(1-L_{30})(1-L_{36})\}$

MTSF (T_0): The system is in working states (from initial state) before failure states are 0, 7, 14, 23, hence MTSF is given by

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

$T_0 = (V_{0,0}\mu_0+V_{0,7}\mu_7+V_{0,14}\mu_{14}+V_{0,23}\mu_{23})/(1-p_{0,7}p_{7,21}p_{21,0}-p_{0,7}p_{7,23}p_{23,21}p_{21,0}-p_{0,7}p_{7,23}p_{23,22}p_{22,0}-p_{0,14}p_{14,21}p_{21,0}-p_{0,14}p_{14,22}p_{22,0}-p_{0,14}p_{14,23}p_{23,21}p_{21,0}-p_{0,14}p_{14,23}p_{23,22}p_{22,0})$

Availability of the System(A_0): The states at which the system is available are 'j' = 0, 7, 14, 23 taking 'ξ' = '0' the total fraction of time for which the system is available is given by

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

$= (V_{0,0}\mu_0+V_{0,7}\mu_7+V_{0,14}\mu_{14}+V_{0,23}\mu_{23})/D$

Where $D = (V_{0,0}\mu_0+V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,7}\mu_7+V_{0,8}\mu_8$
$+V_{0,9}\mu_9+V_{0,10}\mu_{10}+V_{0,11}\mu_{11}+V_{0,12}\mu_{12}+V_{0,13}\mu_{13}+V_{0,14}\mu_{14}+V_{0,15}\mu_{15}+V_{0,16}\mu_{16}$
$+V_{0,17}\mu_{17}+V_{0,18}\mu_{18}+V_{0,19}\mu_{19}+V_{0,20}\mu_{20}+V_{0,21}\mu_{21}+V_{0,22}\mu_{22}+V_{0,23}\mu_{23}+V_{0,24}\mu_{24}$
$+V_{0,25}\mu_{25}+V_{0,26}\mu_{26}+V_{0,27}\mu_{27}+V_{0,28}\mu_{28}+V_{0,29}\mu_{29})$

Busy Period of the Server: The states where the server is busy are S_i, S_{7+i}, S_{14+i}, S_{23+i}, where $1 \leq i \leq 6$, S_{21}, S_{22} taking ξ = '0', the time server remains busy is

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

$B_0 = (V_{0,1}\mu_1+V_{0,2}\mu_2+V_{0,3}\mu_3+V_{0,4}\mu_4+V_{0,5}\mu_5+V_{0,6}\mu_6+V_{0,8}\mu_8+V_{0,9}\mu_9+V_{0,10}\mu_{10}+V_{0,11}\mu_{11}+V_{0,12}\mu_{12}$
$+V_{0,13}\mu_{13}+ V_{0,15}\mu_{15}+V_{0,16}\mu_{16}+V_{0,17}\mu_{17}+V_{0,18}\mu_{18}+V_{0,19}\mu_{19}+V_{0,20}\mu_{20}+V_{0,21}\mu_{21}+V_{0,22}\mu_{22}+V_{0,24}\mu_{24}$
$+V_{0,25}\mu_{25}+V_{0,26}\mu_{26}+V_{0,27}\mu_{27}+V_{0,28}\mu_{28}+V_{0,29}\mu_{29})/D$

Expected Fractional Number of Inspections by the repair man: The states where the repairman do visit's a fresh are S_i, S_{7+i}, S_{14+i}, S_{23+i}, where $1 \leq i \leq 6$, S_{21}, S_{23} taking 'ξ' = '0', the number of visit by the repair man is given by

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

Sensitivity Analysis w. r. t. change in repair rates:
Taking $\alpha_i = 0.1$ $(0 \leq i \leq \alpha)$ and varying β_1, β_2, β_3, β_4, β_5, β_6 one by one respectively at 0.75, 0.80, 0.85, 0.90, 0.95, 1

Mean Time to System Failure (T_0)
Mean Time to System Failure (T_0) Table

Table 4

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	c
0.75	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965
0.80	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965
0.85	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965
0.90	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965
0.95	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965
1	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965	1.63965

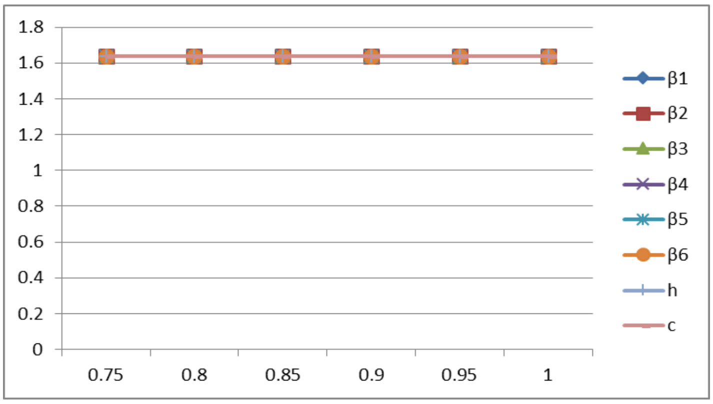

Fig 2: Mean Time to System Failure Graph

From the above table and graph we conclude that MTSF is independent of repair rates of various units.
Availability of the System (A_0)
Availability of the System (A_0) Table

Table 5

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	c
0.75	0.52072	0.51837	0.51631	0.51449	0.51288	0.51143	0.50065	0.50099
0.80	0.52309	0.52072	0.51865	0.51681	0.51516	0.51372	0.50284	0.50310
0.85	0.52521	0.52282	0.52072	0.51887	0.51723	0.51576	0.50479	0.50497
0.90	0.52710	0.52469	0.52258	0.52072	0.51907	0.51759	0.50654	0.50665
0.95	0.52881	0.52638	0.52426	0.52239	0.52072	0.51923	0.50811	0.50816
1	0.53035	0.52791	0.52578	0.52389	0.52222	0.52072	0.50953	0.50953

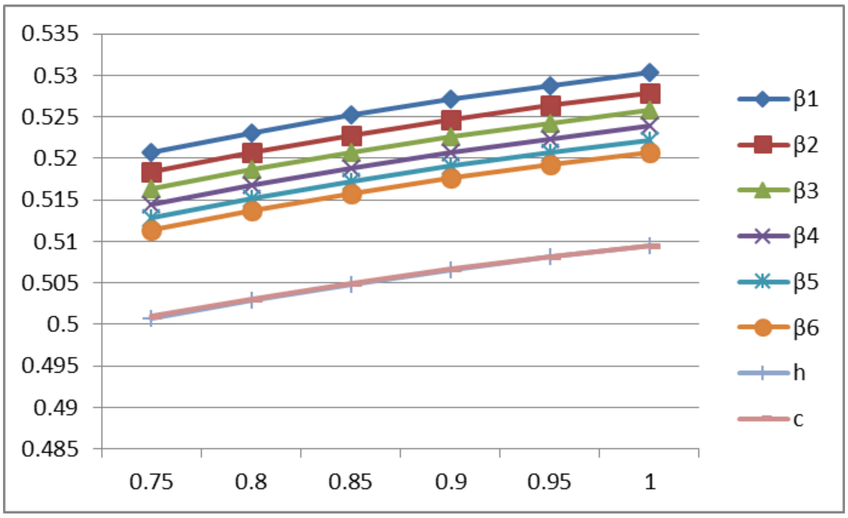

Fig 3: Availability of the System Graph

From the above table and graph we conclude that increase in repair rates do not have significant increase in the value of availability of the system. However, for maximum of availability repair rate of unit 'A' kept maximum.

Busy Period of the Server's Visits (B_0)
Busy Period of the Server's Visits(B_0) Table

Table 6

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	c
0.75	0.66957	0.67107	0.67237	0.67353	0.67455	**0.67547**	0.66773	0.66750
0.80	0.66807	0.66957	0.67089	0.67206	0.67310	0.67402	0.66628	0.66610
0.85	0.66673	0.66825	0.66957	0.67075	0.67179	0.67272	0.66498	0.66486
0.90	0.66553	0.66705	0.66839	0.66957	0.67063	0.67156	0.66382	0.66374
0.95	0.66444	0.66598	0.66733	0.66852	0.66957	0.67052	0.66278	0.66274
1	0.66346	0.66501	0.66637	0.66756	0.66862	0.66957	**0.66183**	**0.66183**

From the table 6 we see that busy period of the server maximum when repair rate of unit 'F' minimum in comparison to other units, hence repairman should be efficient in repairing the unit 'F' to have lower value of busy period of the server. Busy period is minimum when repair rate of pressure unit P_3 and that from common cause failure is maximum.

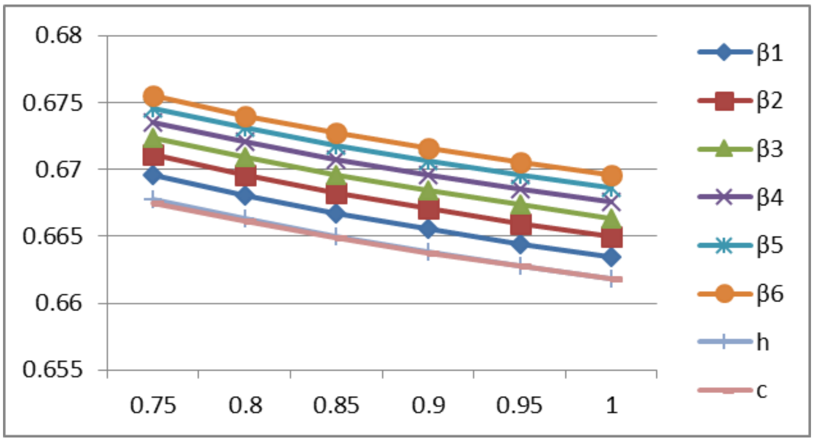

Fig 4: Busy Period of the Server's VisitsGraph

Expected Fractional Number of Inspection by the Repairman (V_0)
Expected Fractional Number of Inspection by the Repairman (V_0) Table

Table 7

β_i	β_1	β_2	β_3	β_4	β_5	β_6	H	c
0.75	0.49049	0.48823	0.48624	0.48449	0.48293	**0.48154**	0.48194	0.48327
0.80	0.49278	0.49049	0.48849	0.48672	0.48515	0.48375	0.48405	0.48531
0.85	0.49482	0.49252	0.49049	0.48719	0.48713	0.49572	0.48593	0.48712
0.90	0.49665	0.49432	0.49228	0.49049	0.48890	0.48747	0.48761	0.48875
0.95	0.49829	0.49595	0.49390	0.49210	0.49049	0.48906	0.48912	0.49021
1	0.49978	0.49743	0.49536	0.49355	0.49193	0.49040	0.49049	0.49153

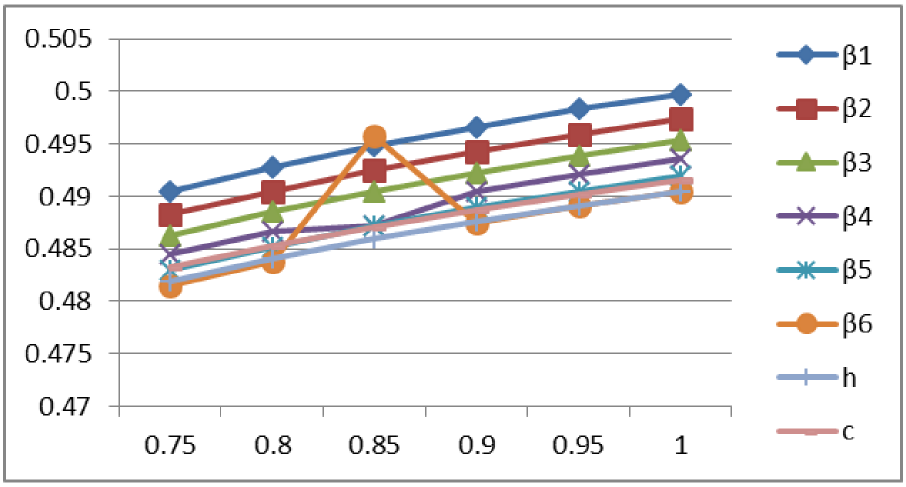

Fig 5: Expected Fractional Number of Inspection by the Repairman Graph

There is no significant change in the value of expected fraction of the number of visits by the repairman with the increase in repair rates of unit.

Sensitivity Analysis w. r. t. change in failure rates:
Fixing $\beta_i = 0.80$ $(0 \le i \le 6)$ h = 1, c = 1, $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0.01$
Taking α_i = 0.1, 0.2, 0.3, 0.4 for i = 0, 7, 8, 9, we have

Mean Time to System Failure (T_0)
Mean Time to System Failure (T_0) Table

Table 8.

α_i	α_0	α_6	α_7	α_8	α_9
0.1	2.88127	1.90761	3.26806	3.15184	17.21485
0.2	1.39829	1.35175	2.88127	3.02860	8.28176
0.3	1.32028	1.00665	2.59215	2.88127	4.64494
0.4	0.86355	0.74855	2.36740	2.62535	2.61925

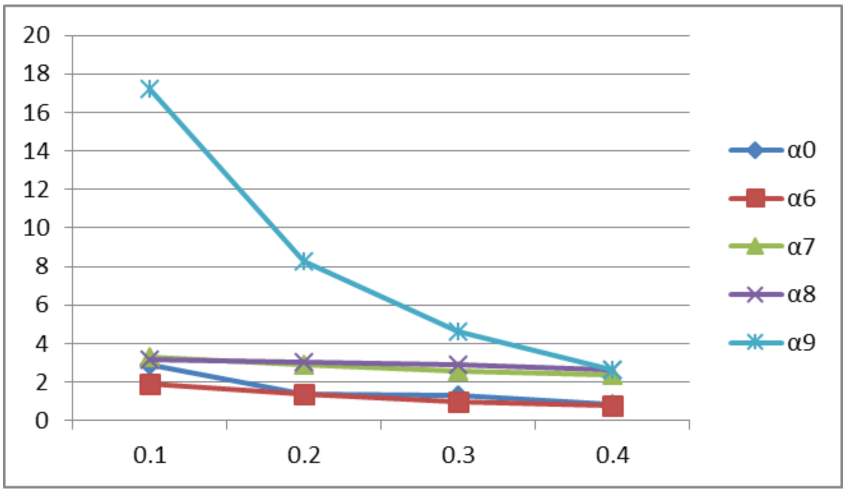

Fig 6: Mean Time to System Failure Graph

From the table and graph we see that MTSF is maximum when failure rate of higher pressure unit P_3 is minimum and MTSF is minimum when common cause failure rate is maximum. Hence, to have optimum value of MTSF failure rate of high pressure unit and common cause should be minimum.

Availability of the System (A_0)
Availability of the System (A_0) Table

Table 9.

α_i	α_0	α_6	α_7	α_8	α_9
0.1	0.63513	0.54051	0.77387	0.63730	0.80021
0.2	0.59134	0.47740	0.63513	0.63650	0.73625
0.3	0.56749	0.43190	0.62720	0.63513	0.64462
0.4	0.53866	0.40780	0.61278	0.63408	0.63513

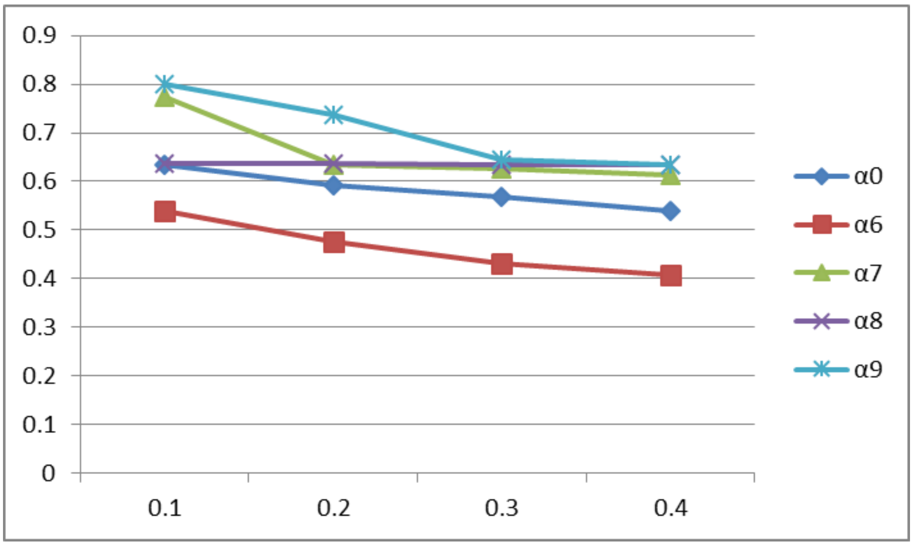

Fig 7: Availability of the System Graph

From the table and graph we see that availability is maximum when failure rate of high pressures unit P_3 and common cause failure rate are minimum and availability is minimum when failure rate of sub-units are maximum.

Busy Period of the Server's Visits (B_0)
Busy Period of the Server's Visits (B_0) Table

Table 10

α_i	α_0	α_6	α_7	α_8	α_9
0.1	0.67607	0.63074	0.57091	0.60098	0.52002
0.2	0.67782	0.67748	0.67607	0.65413	0.53951
0.3	0.67862	0.77832	0.71482	0.67607	0.61785
0.4	0.67980	0.89412	0.73151	0.70882	0.67607

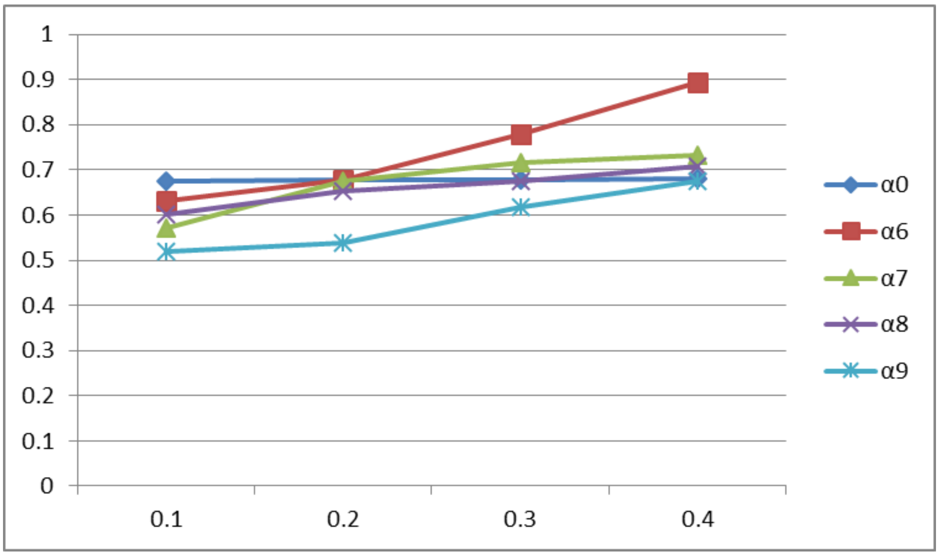

Fig 8: Busy Period of the Server's Visits Graph

From the above table and graph we see that optimum value of busy period is 0.52002 which suggests that failure rate of high pressure unit P_3 should be minimum. To avoid lower value of B_0 failure rate should be kept lowest.

Expected Fractional Number of Inspection by the Repairman (V_0)
Expected Fractional Number of Inspection by the Repairman (V_0) Table

Table 11

α_i	α_0	α_6	α_7	α_8	α_9
0.1	0.25385	0.13536	0.23051	0.15806	0.20995
0.2	0.25412	0.21479	0.25385	0.17688	0.22616
0.3	0.26083	0.21648	0.25593	0.25385	0.22749
0.4	0.26222	0.21902	0.28552	0.25786	0.25385

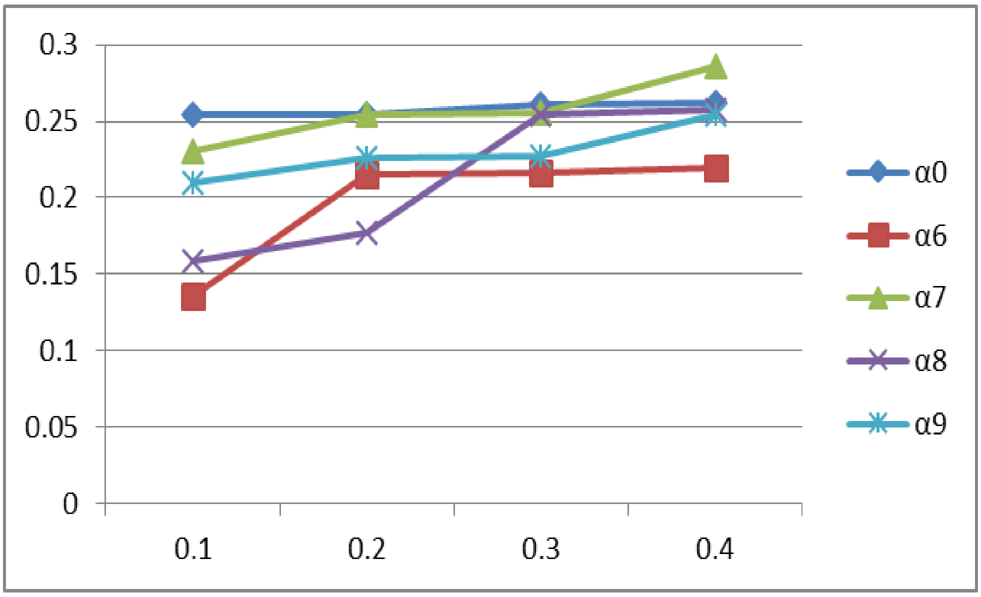

Fig 9: Expected Fractional Number of Inspection by the Repairman Graph

From the above table and graph for optimum value of V_0 failure rate of sub-unit should be minimum in comparison to the failure rate of pressure units and common cause failure rate.

Conclusion

To have optimum value of system parameters management may control the failure and repair rates of units depending upon the availability of finances and market circumstances.

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