



Cost Benefit Analysis of a Two Unit Standby Model with Repair, Inspection, Post-Repair and Random Appearance and Disappearance of Repairman in the System

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Abstract: The present paper deals with reliability analysis of a system composed of two non-identical units A and B in which unit A is operative and unit B is kept in standby mode. Upon failure of operative unit A, unit B becomes operative instantaneously. Each unit has two modes Normal and Failure. When unit A fails it is placed under repair if repair facility is available in the system else the unit will wait to get repaired as and when repair facility arrive. Further, after its repair it goes for inspection to decide whether the repair is perfect or not. If repair is found to be perfect, the repaired unit becomes operative, otherwise it is sent for post repair and if the unit B fails it gets priority over unit A and after repairing the unit B it becomes as good as new and its inspection or post repair is not required. Single repair facility is available to repair the failed units which appears and disappears from the system randomly. Once the repairman starts the repair of the failed unit, the repair facility remains with the system till the units are repaired, inspected and post repaired. The failure time distributions of unit A and B and inspection time of unit A are assumed to be exponential while the distribution of repair time of both the units is assumed to be general. The various important measures of system effectiveness have been obtained and studied.

Keywords: Mean time to system failure; Mean sojourn time; Availability; Busy period; number of visits; Profit analysis

I. INTRODUCTION

Reliable functioning of embedded systems is of paramount concern to the billions of users that depend on these systems every day. Unfortunately most embedded systems still fall short of user's expectation of reliability. The incorporation of redundancy is one of the important techniques to improve the reliability and hence the effectiveness of the system. The system models with standby redundancies have been frequently analysed by various authors with different assumptions due to their vital existence in modern industries and business. Gupta, Tyagi and Kishan [6] discussed the concept of a two unit system with correlated failures and repairs and random appearance and disappearance of repairman. Kishan and Jain [8] analysed a two non-identical unit standby system model with repair, inspection and post-repair under classical and Bayesian viewpoints. Agnihotri and Satsangi [1] considered two unit identical systems with priority based repair and inspection. While Tuteja and Malik [9] discussed about reliability and profit analysis of two single unit models with three modes and different repair policies of repairman who appears and disappears randomly. Goel, Sharma and Gupta [2] worked on cost analysis of a system with intermittent repair and inspection under abnormal weather. Further Joorel, Kumar and Lal [3] put forth the concept of Reliability analysis of a complex system composed of two parallel sub-systems without considering random appearance and disappearance of repairman in the system. Gupta, Goel and Tomer [7] provided the concept of analysis of a two unit standby system with correlated failure and repair and random appearance and disappearance of repairman. Nakagawa and Osaki [5] investigated stochastic behavior of two unit priority standby redundant system with repair. Recently Kakkar, Chitkara and Kumar [4] discussed reliability analysis of a cold standby system with repair equipment failure and appearance and disappearance of repairman with correlated lifetime.

The purpose of the present paper is to put forth the concept of random appearance and disappearance of repairman in the system. The system comprises of two non-identical units A and B, each unit having two modes Normal and Failure in which unit A is operative and unit B is kept in standby mode. Upon failure of operative unit, unit B

becomes operative instantaneously. When unit A fails it is placed under repair if repair facility is available in the system else the unit will wait to get repaired as and when repair facility arrive. Further, after its repair it goes for inspection to decide whether the repair is perfect or not. If repair is found to be perfect, the repaired unit becomes operative, otherwise it is sent for post repair and if the unit B fails it gets priority over unit A and after repairing it becomes operative and unit B is not inspected or post repaired by the repairman available in the system. Single repair facility is available to repair the failed units which appears and disappears from the system randomly. Once the repairman starts the repair of the failed unit, the repair facility remains with the system till the units are repaired, inspected and post repaired. The failure time distributions of unit A and B and inspection time of unit A are assumed to be exponential while the distribution of repair time of both the units is assumed to be general. Using regenerative point technique the following important reliability characteristics of interest are obtained:

- (i) Transition probabilities in transient and steady state
- (ii) Mean sojourn time
- (iii) Mean time to system failure (MTSF).
- (iv) Point wise and steady-state availabilities of the system.
- (v) Expected busy period of the repairman during $(0, t]$.
- (vi) Expected number of visits for the repair facility.
- (vii) Profit analysis of system.

II. NOTATION AND STATES OF THE SYSTEM

A) Notations :

- α_1 : Constant failure rate of unit-A.
 α_2 : Constant failure rate of unit-B.
 α_3 : Inspection rate of unit-A when unit is normal.
 α_4 : Inspection rate of unit-A when unit goes for post repair.
 a : Constant rate of appearance of repair man in the system.
 b : Constant rate of disappearance of repair man in the system.
 $\beta(x), f(x)$: Rate of repair and corresponding p.d.f. of repair time of unit-A by repairman s.t $f(x) = \beta(x) \exp \left[- \int_0^x \beta(u) du \right]$
 $\mu(x), g(x)$: Rate of repair and corresponding p.d.f. of repair time of unit-B by repairman s.t $g(x) = \mu(x) \exp \left[- \int_0^x \mu(u) du \right]$
 $P_j(t)$: Probability that the system is in state S_j at time t .
 $Q_k(x, t) dx$: Probability that the system is in state S_k at epoch t and has sojourned in this state for duration between x and $x + dx$

B) Symbols for the states of the system:

- A_0 : Unit-A is in normal (N) mode and operative.
 B_S : Unit-B is in standby mode.
 A_r/A_{wr} : Unit-A is in failure (F) mode and under repair / waits for repair.
 B_r/B_{wr} : Unit-B is in failure (F) mode and under repair / waits for repair.
 A_I/A_{wI} : Unit-A is under inspection / / waits for inspection
 A_{Pr}/A_{wPr} : Unit-A is in failure (F) mode and under post repair / waits for post repair.

C) States of the system

The possible states of the system are:

- | | |
|--------------------------|------------------------|
| $S_0 = [A_0, B_S]$ | $S_1 = [A_0, B_S]$ |
| $S_2 = [A_r, B_0]$ | $S_3 = [A_{wr}, B_0]$ |
| $S_4 = [A_{wr}, B_{wr}]$ | $S_5 = [A_{wr}, B_r]$ |
| $S_6 = [A_I, B_0]$ | $S_7 = [A_{wI}, B_r]$ |
| $S_8 = [A_{Pr}, B_0]$ | $S_9 = [A_{wPr}, B_r]$ |

The states S_0, S_1 and S_2, S_3, S_6, S_8 are up states while S_4, S_5, S_7 and S_9 are down states. Further, all the states are regenerative states.

With the help of above symbols and keeping in view the assumptions, the possible states S_0 to S_7 of the system along with the transitions between the states and transition rates are shown in Fig. 1

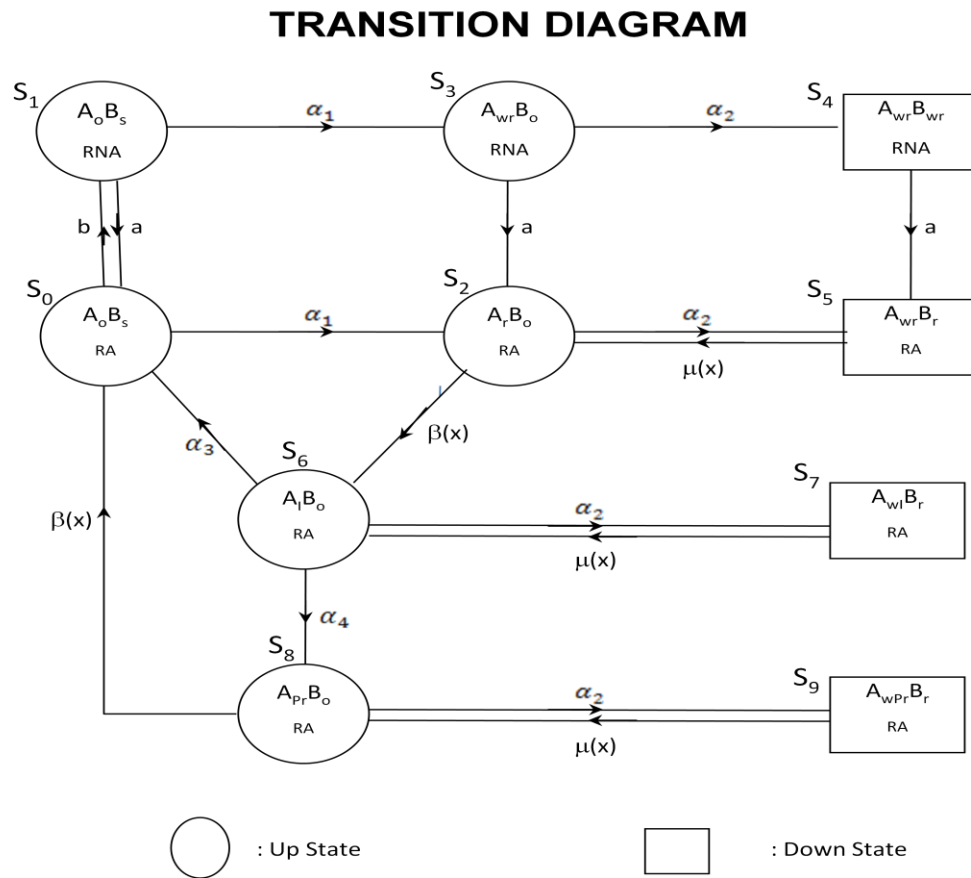


Fig. 1

III. TRANSITION PROBABILITIES

A) Steady state transition probabilities:

The steady state transition probabilities are defined as

$$P_{01} = Q_{ij}(\infty) \int_0^\infty Q_{ij}(t) dt$$

The following expressions for the non-zero elements are obtained

$$\begin{aligned}
 P_{01} &= \frac{\alpha_1}{\alpha_1 + b} & P_{02} &= \frac{b}{\alpha_1 + b} & P_{10} &= \frac{a}{\alpha_1 + a} \\
 P_{13} &= \frac{\alpha_1}{\alpha_1 + a} & P_{25} &= 1 - \tilde{\beta}(\alpha_2) & P_{26} &= \tilde{\beta}(\alpha_2) \\
 P_{32} &= \frac{a}{\alpha_2 + a} & P_{34} &= \frac{\alpha_2}{\alpha_2 + a} & P_{67} &= \frac{\alpha_2}{\alpha_2 + \alpha_3 + \alpha_4} \\
 P_{68} &= \frac{\alpha_4}{\alpha_2 + \alpha_3 + \alpha_4} & P_{80} &= \tilde{\beta}(\alpha_2) & P_{89} &= 1 - \tilde{\beta}(\alpha_2)
 \end{aligned}$$

$$P_{45} = P_{52} = P_{60} = P_{76} = P_{98} = 1$$

Here it can easily be verified that $\sum_j P_{ij} = 1$; for all possible values of i .

IV. MEAN SOJOURN TIME

The mean sojourn time in state S_i denoted by Ψ_i is defined as the expected time taken by the system in state S_i before transitioning to any other state. To obtain mean sojourn time Ψ_i in state S_i , we observe that as long as the system is in state S_i , there is no transition from S_i to any other state. If T_i denotes the sojourn time in state S_i then mean sojourn time Ψ_i in state S_i is:

$$\Psi_i = E[T_i] = \int_0^\infty P(T_i > t) dt, \text{ Thus}$$

$$\begin{aligned}\Psi_0 &= \frac{1}{(\alpha_1+b)} & \Psi_1 &= \frac{1}{(\alpha_1+a)} & \Psi_2 &= \frac{1}{\alpha_2} [1 - \tilde{\beta}(\alpha_2)] \\ \Psi_3 &= \frac{1}{(\alpha_2+a)} & \Psi_4 &= \frac{1}{a} & \Psi_6 &= \frac{1}{\alpha_2+\alpha_3+\alpha_4} \\ \Psi_8 &= \frac{1}{\alpha_2} [1 - \tilde{\beta}(\alpha_2)] & \Psi_5 &= \Psi_7 = \Psi_9 = \int_0^\infty \bar{\mu}(t) dt\end{aligned}$$

V. MEAN TIME TO SYSTEM FAILURE

Let the random variable T_i denotes the time to system failure when $E_0 = E_i \in E$ and $\pi_i(t)$ is the c.d.f. of the time to system failure for the first time when the system starts operation from state S_i . To obtain the expressions of $\pi_i(t)$ for different values of i , the arguments of regenerative point processes has been used. Taking the Laplace transform and solving the resultant set of equations for $A_0^*(s)$, we have

$$\tilde{\pi}_0(s) = \frac{N_1(s)}{D_1(s)}$$

where

$$\begin{aligned}N_1(s) &= \tilde{Q}_{01}(s)\tilde{Q}_{13}(s)\tilde{Q}_{34}(s) + [\tilde{Q}_{25}(s) + \tilde{Q}_{26}(s)\tilde{Q}_{67}(s) + \tilde{Q}_{26}(s)\tilde{Q}_{68}(s)\tilde{Q}_{89}(s)] \\ &\quad [\tilde{Q}_{01}(s)\tilde{Q}_{13}(s)\tilde{Q}_{32}(s) + \tilde{Q}_{02}(s)] \\ D_1(s) &= 1 - \tilde{Q}_{01}(s)\tilde{Q}_{10}(s) - [\tilde{Q}_{26}(s)\tilde{Q}_{67}(s) + \tilde{Q}_{26}(s)\tilde{Q}_{68}(s)\tilde{Q}_{80}(s)] \\ &\quad [\tilde{Q}_{01}(s)\tilde{Q}_{13}(s)\tilde{Q}_{32}(s) + \tilde{Q}_{02}(s)]\end{aligned}$$

On taking $s \rightarrow 0$ and using the relation $\tilde{Q}_{ij}(s) \rightarrow P_{ij}$, we have

$$\tilde{\pi}_0(0) = \frac{N_1(0)}{D_1(0)} = 1$$

Thus $N_1(0) = D_1(0)$ showing that $\tilde{\pi}_0(0) = 1$. Hence $\pi_0(t)$ is a proper cdf.

Therefore, mean time to system failure when the initial state is S_0 , is given by

$$E(T) = - \left. \frac{d\tilde{\pi}_0(s)}{ds} \right|_{s=0} = \frac{D_1'(0) - N_1'(0)}{D_1(0)}$$

where,

$$D_1'(0) - N_1'(0) = \Psi_0 + P_{01}\Psi_1 + (P_{01}P_{13}P_{32} + P_{02})\Psi_2 + P_{01}P_{13}\Psi_3 + (P_{01}P_{13}P_{32} + P_{02}) \\ P_{26}\Psi_6 + P_{26}P_{68}(P_{01}P_{13}P_{32} + P_{02})\Psi_8$$

$$D_1(0) = 1 - P_{01}P_{10} - [P_{01}P_{13}P_{32} + P_{02}][P_{26}P_{60} + P_{26}P_{68}P_{80}]$$

Now on putting the values of Ψ_i 's and P_{ij} 's in above equations, the required equation is given as:

$$\begin{aligned}D_1'(0) - N_1'(0) &= \alpha_2 [(\alpha_1 + a)\alpha_1] (\alpha_1 + a) (\alpha_2 + \alpha_3 + \alpha_4) + \alpha_1\alpha_2\alpha_1(\alpha_2 + \alpha_3 + \alpha_4) + [\alpha_1a\alpha_1 + \\ &\quad b(\alpha_1 + a)(\alpha_2 + a)]\{(\alpha_2 + \alpha_3 + \alpha_4)[1 - \tilde{\beta}(\alpha_2)] + (\alpha_2 + \alpha_4)[1 - \tilde{\beta}(\alpha_2)]\}\tilde{\beta}(\alpha_2) \\ D_1(0) &= [(\alpha_1 + a)(\alpha_1 + a) - a\alpha_1]\alpha_2(\alpha_2 + \alpha_3 + \alpha_4)(\alpha_2 + a) - [\alpha_3 + \alpha_4\tilde{\beta}(\alpha_2)]\alpha_2\tilde{\beta}(\alpha_2) \\ &\quad [\alpha_1a\alpha_1 + b(\alpha_1 + a)(\alpha_2 + a)]\end{aligned}$$

VI. AVAILABILITY ANALYSIS

We define $A_i(t)$ as the probability that the system is up at epoch 't' when it initially starts from regenerative state S_i . It is also called pointwise availability of the system. To obtain recurrence relations among different point wise availabilities $A_i(t)$, we use the simple probabilistic arguments. Taking the Laplace transform and solving the resultant set of equations for $A_0^*(s)$, we have:

$$A_0^*(s) = \frac{N_2(s)}{D_2(s)}$$

where

$$N_2(s) = (M_0^* + q_{01}^*M_1^* + q_{01}^*q_{13}^*M_3^*)(1 - q_{67}^*q_{76}^*)(1 - q_{89}^*q_{98}^*)(1 - q_{25}^*q_{52}^*) + (q_{01}^*q_{13}^*q_{32}^* + q_{01}^*q_{13}^*q_{34}^*q_{45}^*q_{52}^* + q_{02}^*)\{(1 - q_{67}^*q_{76}^*)(1 - q_{89}^*q_{98}^*)M_2^* + (1 - q_{89}^*q_{98}^*)q_{26}^*M_6^* + q_{26}^*q_{68}^*M_8^*\} \quad (1)$$

And

$$D_2(s) = (1 - q_{03}^*q_{30}^*)(1 - q_{67}^*q_{76}^*)(1 - q_{89}^*q_{98}^*)(1 - q_{25}^*q_{52}^*) - [q_{60}^*(1 - q_{89}^*q_{98}^*) + q_{68}^*q_{80}^*]q_{26}^*(q_{01}^*q_{13}^*q_{32}^* + q_{01}^*q_{13}^*q_{34}^*q_{45}^*q_{52}^* + q_{02}^*) \quad (2)$$

The steady state Availability will be given by

$$A_0 = \lim_{t \rightarrow \infty} A_0(t) = \lim_{s \rightarrow 0} s A_0^*(s) = N_2(0)/D_2'(0)$$

On substituting values of P_{ij} 's and Ψ_i 's, we get

$$N_2(0) = [(\alpha_1 + a)(\alpha_2 + a) + \alpha_1(\alpha_2 + a) + \alpha_1\alpha_1]\alpha_2\tilde{\beta}(\alpha_2)\tilde{\beta}(\alpha_2)(\alpha_3 + \alpha_4) + (\alpha_2 + a) \\ [(\alpha_1 + a)(\alpha_1 + b) - a\alpha_1]\{[1 - \tilde{\beta}(\alpha_2)]\tilde{\beta}(\alpha_2)(\alpha_3 + \alpha_4) + \alpha_2\tilde{\beta}(\alpha_2)\tilde{\beta}(\alpha_2) + \alpha_4 \\ [1 - \tilde{\beta}(\alpha_2)]\tilde{\beta}(\alpha_2)\} \quad (3)$$

and

$$D'_2(0) = \left[(\alpha_1 + a)(\alpha_2 + a) + \alpha_1(\alpha_2 + a) + \alpha_1\alpha_1 + \alpha_1\alpha_2\alpha_1 \left(\frac{1}{a} + \int_0^\infty \bar{\mu}(u) du \right) \right] \tilde{\beta}(\alpha_2)\tilde{\beta}(\alpha_2) \\ \alpha_2(\alpha_3 + \alpha_4) + [(\alpha_1 + a)(\alpha_1 + b) - a\alpha_1](\alpha_2 + a)\{(\alpha_3 + \alpha_4)\tilde{\beta}(\alpha_2)[1 - \tilde{\beta}(\alpha_2)] + \alpha_2 \\ \tilde{\beta}(\alpha_2)\tilde{\beta}(\alpha_2) (1 + \alpha_2 \int_0^\infty \bar{\mu}(u) du) + \alpha_4(1 + \alpha_2)[1 - \tilde{\beta}(\alpha_2)]\tilde{\beta}(\alpha_2) \int_0^\infty \bar{\mu}(u) du \quad (4)$$

VII. BUSY PERIOD ANALYSIS FOR REPAIRMAN

We define $B_i(t)$ as the probability that the repairman is busy in the repair of the failed unit when the system initially starts from state $S_i \in E$. Using probabilistic arguments, taking the Laplace transform and solving the resultant set of equations for $B_0^*(s)$, we have

$$B_0^*(s) = N_3(s)/D_2(s)$$

where

$$N_3(s) = q_{01}^*q_{13}^*q_{34}^*q_{45}^*(1 - q_{67}^*q_{76}^*)(1 - q_{89}^*q_{98}^*)(1 - q_{25}^*q_{52}^*)Z_5^* + \{(Z_2^* + q_{25}^*Z_5^*) \\ (1 - q_{67}^*q_{76}^*)(1 - q_{89}^*q_{98}^*) + (Z_6^* + q_{67}^*Z_7^*)q_{26}^*(1 - q_{89}^*q_{98}^*) + (Z_8^* + q_{89}^*Z_9^*) \\ q_{26}^*q_{68}^*\}(q_{01}^*q_{13}^*q_{34}^*q_{45}^*q_{52}^* + q_{01}^*q_{13}^*q_{32}^* + q_{02}^*) \\ D_3(s) = D_2(s) \text{ is same as in availability analysis which is given by (1)}$$

In the steady state, the probability that the regular repairman will be busy is given by

$$B_0 = \lim_{t \rightarrow \infty} B_0(t) = \lim_{s \rightarrow 0} s B_0^*(s) = N_3(0)/D'_2(0)$$

On substituting values of P'_{ij} s and Ψ'_i s, we get

$$N_3(0) = \{\alpha_1\alpha_2\alpha_1\tilde{\beta}(\alpha_2)(\alpha_3 + \alpha_4)\tilde{\beta}(\alpha_2) + [(\alpha_1 + a)(\alpha_1 + b) - a\alpha_1]\tilde{\beta}(\alpha_2)[1 - \tilde{\beta}(\alpha_2)] \\ (\alpha_3 + \alpha_4)(\alpha_2 + a)\}\alpha_2 \int_0^\infty \bar{\mu}(u) du + [(\alpha_1 + a)(\alpha_1 + b) - a\alpha_1](\alpha_2 + a)\{\tilde{\beta}(\alpha_2) \\ \alpha_2\tilde{\beta}(\alpha_2) (1 + \alpha_2 \int_0^\infty \bar{\mu}(u) du) + (\alpha_3 + \alpha_4)\tilde{\beta}(\alpha_2)[1 - \tilde{\beta}(\alpha_2)] + \alpha_4\tilde{\beta}(\alpha_2) \\ (1 + \alpha_2)[1 - \tilde{\beta}(\alpha_2)] \int_0^\infty \bar{\mu}(u) du \}$$

and $D'_3(0) = D'_2(0)$ is same as in the case of availability given by (4)

VIII. EXPECTED NUMBER OF VISITS BY REPAIRMAN

Let us define $V_i(t)$ as the expected number of visits by repairman during the time interval $(0, t]$ when the system initially starts from regenerative state S_i . Using probabilistic arguments, taking the Laplace transform and solving the resultant set of equations for $\tilde{V}_0(s)$, we get

$$\tilde{V}_0(s) = \frac{N_5(s)}{D_2(s)}$$

where

$$N_4(s) = (\tilde{q}_{02} + \tilde{q}_{01}\tilde{q}_{13}\tilde{q}_{32} + \tilde{q}_{01}\tilde{q}_{13}\tilde{q}_{34}\tilde{q}_{45})(1 - \tilde{q}_{25}\tilde{q}_{52})(1 - \tilde{q}_{67}\tilde{q}_{76})(1 - \tilde{q}_{89}\tilde{q}_{98}) \\ D_4(s) = D_2(s) \text{ is same as in availability analysis given by (1)}$$

In steady state, number of visits per unit time is given by

$$V_0(0) = \lim_{t \rightarrow \infty} \frac{V_0(t)}{t} = \frac{N_4(0)}{D'_2(0)}$$

Substituting values of P'_{ij} s and Ψ'_i s in $N_5(0)$ and $D'_2(0)$ we get,

$$N_4(0) = [(\alpha_1 + a)(\alpha_1 + b) - a\alpha_1]\alpha_2(\alpha_2 + a)(\alpha_3 + \alpha_4)\tilde{\beta}(\alpha_2)\tilde{\beta}(\alpha_2)$$

and $D'_5(0) = D'_2(0)$ is same as availability analysis which is given by (4)

IX. PROFIT ANALYSIS

The expected uptime, down time of the system and busy period of the repairman in $(0, t]$ is given as:

$$\mu_{up}(t) = \int_0^1 A_0(u) du$$

$$\mu_{dn}(t) = 1 - \mu_{up}(t)$$

$$\mu_b = \int_0^1 B_0(u) du$$

So that

$$\mu_{up}^*(s) = A_0^*(s)/s$$

$$\mu_{dn}^*(s) = 1/s^2 - \mu_{up}^*(s)$$

$$\mu_b^*(s) = B_0^*(s)/s$$

The expected profits incurred in $(0, t] =$ expected total revenue in $(0, t] -$ expected total repair in $(0, t] -$ expected cost of visits by repairman in $(0, t]$

Therefore, profit analysis of the system can be written as:

$$P_1 = K_0 A_0 - K_1 B_0 - K_2 V_0$$

K_0 = Revenue per unit up time of the system,

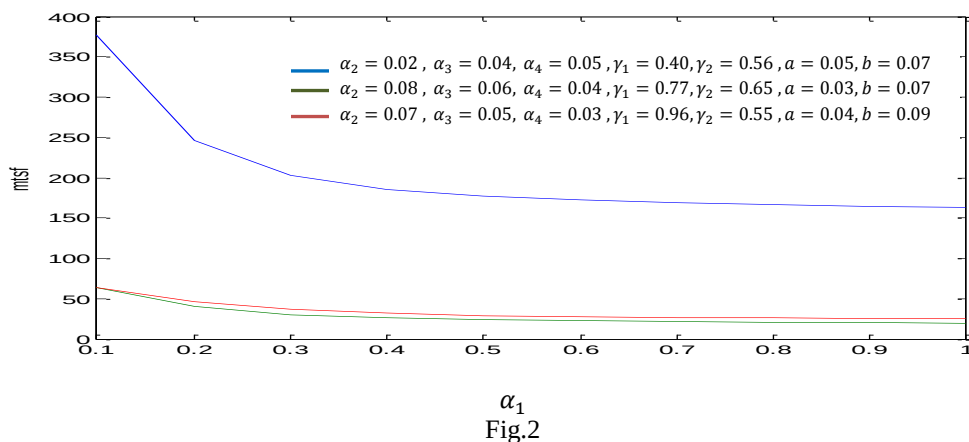
K_1 = Cost per unit time for which the repair is busy,

K_2 = Cost per unit visits by the repairman.

IX. GRAPHICAL STUDY OF THE SYSTEM MODEL

The behavior of MTSF, Availability and Profit analysis of the system is studied graphically in this section. To plot their graphs, the repair time distributions of units A and B are also assumed to be distributed exponentially with repair rate as γ_1 and γ_2 respectively. The graphs of MTSF, availability and that of profit are depicted with respect to the different parameters. It is observed that the MTSF, Availability and the profit analysis of the system decreases uniformly as the failure rates of the system increases irrespective of the other fixed parameters. However, we note that MTSF, Availability and the profit analysis increases with increasing repair rates. Hence, it can be concluded that the expected life of the system can be increased by decreasing failure rate and increasing repair rate of the unit which in turn will improve the reliability and hence the effectiveness of the system.

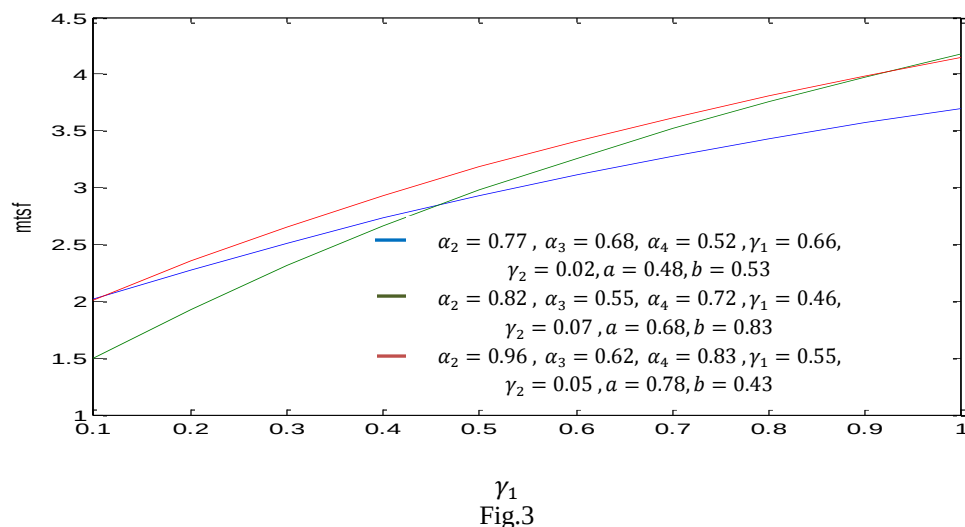
BEHAVIOUR OF MTSF W.R.T. α_1 FOR DIFFERENT VALUES OF $\alpha_2, \alpha_3, \alpha_4, \gamma_1, \gamma_2, a, b$



α_1
Fig.2

In fig 2, we plot MTSF w.r.t. α_1 and fixed values of parameter $\alpha_2, \alpha_3, \alpha_4, \gamma_1, \gamma_2, a, b$. It is observed that MTSF of the system decreases w.r.t. α_1 irrespective of the other parameters so that we conclude that expected life of the system increases with decreasing failure rate of unit in minor failure mode (α_1).

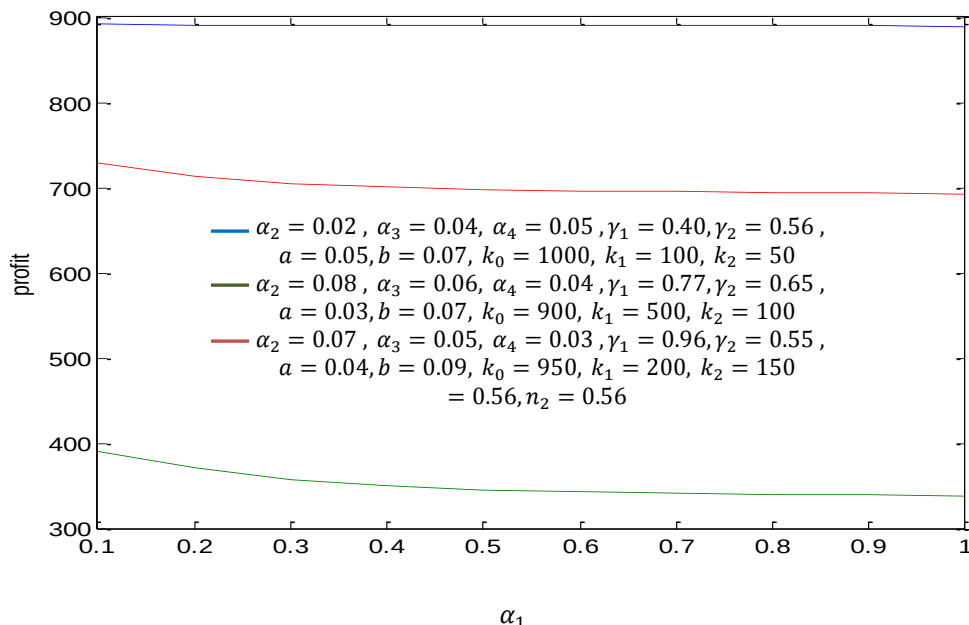
BEHAVIOUR OF MTSF W.R.T. γ_1 FOR DIFFERENT VALUES OF $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \gamma_2, a, b$



γ_1
Fig.3

In fig 3, we plot MTSF γ_1 w.r.t. and fixed values of parameter $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \gamma_2, n_1, n_2$. It is quiet clear that MTSF of the system increases w.r.t. γ_1 irrespective of the other parameters so that we conclude that expected life of the system increases with increasing repair rate of unit in repair mode (γ_1).

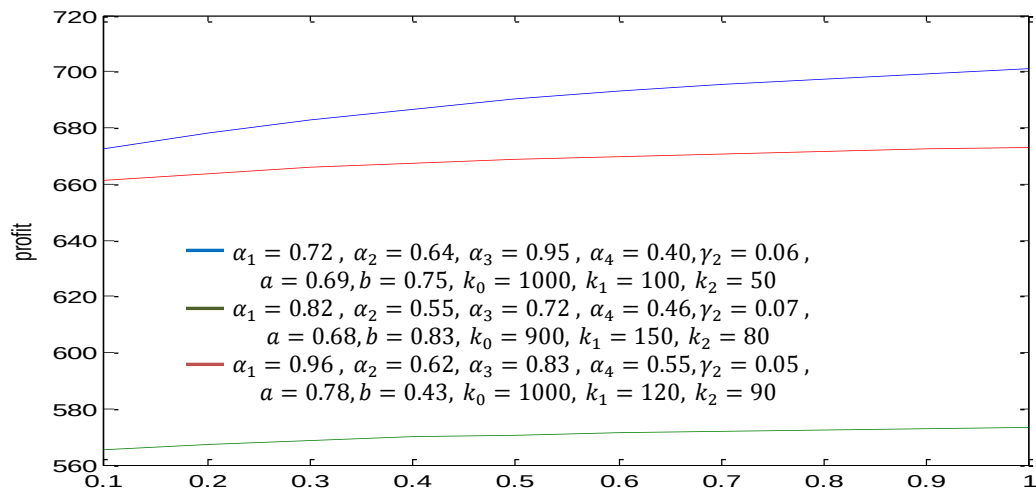
BEHAVIOUR OF PROFIT W.R.T. α_1 FOR DIFFERENT VALUES OF $\alpha_2, \alpha_3, \alpha_4, \gamma_1, \gamma_2, n_1, n_2$



α_1
Fig.4

In fig 4, we plot profit w.r.t. α_1 and fixed values of parameter $\alpha_2, \alpha_3, \alpha_4, \gamma_1, \gamma_2, n_1, n_2$. It is observed that profit of the system decreases w.r.t. α_1 irrespective of the other parameters so that we conclude that expected life of the system increases with decreasing failure rate of unit in minor failure mode (α_1).

BEHAVIOUR OF PROFIT W.R.T. γ_1 FOR DIFFERENT VALUES OF $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \gamma_2, n_1, n_2$



γ_1
Fig.5

In fig 5, we plot profit w.r.t. γ_1 and fixed values of parameter $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \gamma_2, n_1, n_2$. It is quiet clear that profit of the system increases w.r.t. γ_1 irrespective of the other parameters so that we conclude that expected life of the system increases with increasing repair rate of unit in repair mode (γ_1).

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