Profit Analysis of a System of Non-identical Units with Degradation and Replacement

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ABSTRACT

This paper presents the profit analysis of a system of two non-identical units in which one unit is original which is initially operative and the other is duplicate kept in cold standby. The units may fail completely directly from normal mode. There is a single server who visits the system immediately when required. The original unit undergoes for repair upon failure while only replacement of the duplicate unit is made by similar new one. The original unit does not work as new after repair and so called degraded unit. The system is considered in up-state if any one of new/duplicate/degraded unit is operative. The server inspects the degraded unit at its failure to see the feasibility of repair. The failure time of the units are exponentially distributed whereas the distributions of inspection time, replacement time of the duplicate unit and repair time of the original/duplicate/degraded unit are taken as arbitrary with different probability density functions. Some reliability characteristics of the system model are evaluated using semi-Markov process and regenerative point technique. The numerical results for a particular case are also obtained to depict the behavior of Mean Time to System Failure (MTSF), availability and profit function graphically.

Key Words: System of Non-Identical Units, Inspection, Degradation, Replacement and Profit Analysis.

2000 Mathematics Subject Classification: Primary 90 B25 and Secondary 60K10.

1. INTRODUCTION

In many industrial processes the provision of a standby unit is necessary for very high reliability. But it is not always possible to keep a high cost unit on standby. Therefore, to improve the reliability of a system, an ordinary unit (called duplicate) unit may be kept as spare which is capable of performing the same nominal system function but with different degree of reliability and desirability. An example, of this situation is a system comprised of an electrical device and a battery operated device. The battery device is switched on as and when the electrical device is failed.

The reliability models of standby systems have widely been studied by the engineers and scholars including Gopalan and Naidu (1984), Chung (1987) and Singh and Mishra (1994) under the assumptions that

i) The unit works as new after repair.
ii) Repair of the unit is always feasible.

Infect, these assumptions cannot be imposed always on every system. Because the working capacity and efficiency of a repaired unit depends on the skilled knowledge of the repair facility used. In case of being repaired by an ordinary server, the chances of its failure may be high and thus such a unit may be considered as degraded. Malik et al. (2008) analyzed a system with inspection considering the concept of degradation of the unit after repair.

In view of the above facts and observations, we in this paper analyzed a system of non-identical units- one unit is original which is initially operative and other is its duplicate kept in cold standby. There is a single server who visits the server immediately when required. The original unit undergoes for repair upon failure while the duplicate unit is replaced by similar new one. The original unit does not work as new after repair and so called degraded unit. The system is considered in up-state if any one of new/duplicate/degraded unit is operative. The server inspects the degraded unit at its failure to see the feasibility of repair. If repair of the degraded unit is not feasible, it is replaced by new one similar to the original unit in negligible time. The failure time of the units are exponentially distributed whereas the distributions of inspection time, replacement time of the duplicate unit and repair time of the original/duplicate/degraded unit are taken as arbitrary with different probability density functions. The random variables are mutually independent and uncorrelated. The expressions for some reliability characteristics such as mean sojourn times, Mean Time to System Failure, availability, busy period of the server, expected number of visits by the server and profit function are derived using semi-Markov process and regenerative point technique. The numerical results considering a particular case are also obtained to depict the graphically behavior of Mean Time to System Failure (MTSF), availability and profit of the system model.

2. NOTATIONS

E	:Set of regenerative states
No	:The unit is new and operative
DUo	:The unit is duplicate and operative
Do	:The unit is degraded and operative
Ncs /DUcs/Dcs	:The new/duplicate/degraded unit in cold standby
p/q	:Probability that repair of degraded unit is feasible/not feasible
$\lambda/\lambda_1/\lambda_2$	:Constant failure rate of new/duplicate /degraded unit
$g(t)/G(t)$, $g_1(t)/G_1(t)$	:pdf/cdf of repair time for new/degraded unit

$w(t)/W(t)$	:pdf/cdf of replacement time of the duplicate unit
$h(t)/H(t)$	:pdf/cdf of inspection time of the degraded unit
$N_{fur}/N_{FUR}/N_{fwr}$	:New unit is failed and under repair/under continuous repair from previous state/waiting for repair.
DU_{fure}/DU_{FURe} DU_{fwre}/DU_{FWRe}	:Duplicate unit is failed and under/ replacement/under continuous replacement from previous state/ waiting for replacement/continuously waiting for replacement from previous state.
D_{fur}/D_{FUR}	:Degraded unit is failed and under repair/under repair continuously from previous state.
$D_{fui}/D_{fwi}/D_{FUI}$	:Degraded unit is failed and under inspection/waiting for inspection/under inspection continuously from the previous state.
$q_{ij}(t), Q_{ij}(t)$	:pdf and cdf of first passage time from regenerative state *i* to a regenerative state *j* or to a failed state *j* without visiting any other regenerative state in (0,t].
$q_{ij.kr}(t), Q_{ij.kr}(t)$	:pdf and cdf of first passage time from regenerative state *i* to a regenerative state *j* or to a failed state *j* visiting state k,r once in (0,t].
$M_i(t)$	:Probability of system up initially in state $S_i \in E$ is up at time *t* without visiting to any other regenerative sate
$W_i(t)$	:Probability of server is busy in the state S_i up to time *t* without making any transition to any other regenerative state or returning to the same via one or more non-regenerative states.
m_{ij}	:Contribution to mean sojourn time in state $S_i \in E$ and non regenerative state if occurs before transition to $S_j \in E$.
®/©	:Symbols for Stieltjes convolution/ Laplace convolution
~|*	:Symbols for Laplace Stieltjes Transform (LST)/Laplace Transform (LT)
'(dash)	:Symbol for derivative of the function

The following are the possible transition states of the system model

$S_0 = (No, DUcs)$ $S_1 = (DUo, N_{fur})$

$S_2 = (DU_{fwre}, N_{FUR})$ $S_3 = (DUo, Dcs)$

$S_4 = (Do, DU_{fure})$ $S_5 = (D_{fwi}, DU_{FURe})$

$S_6 = (Do, DUcs)$ $S_7 = (DUo, D_{fui})$

$S_8 = (DUo, D_{fur})$ $S_9 = (DU_{fwre}, D_{FUI})$

$S_{10} = (DU_o, Ncs)$ $S_{11} = (No, DU_{fure})$

$S_{12} = (DU_{fwre}, D_{FUR})$ $S_{13} = (DU_{FWRe}, D_{fur})$

$S_{14} = (N_{fwr}, DU_{FURe})$

The states S_0, S_1, S_3, S_4, S_6 S_7, S_8, S_{10} and S_{11} are regenerative states while S_2, S_5, S_9, S_{12}, S_{13} and S_{14}, are non-regenerative states. Thus $E = \{S_0, S_1, S_3, S_4, S_6, S_7, S_8, S_{10}, S_{11}\}$.The possible transition between states along with transition rates for the model is shown in fig.1.

3. TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

Simple probabilistic considerations yield the following expressions for the non-zero elements

$p_{ij} = Q_{ij}(\infty) = \int q_{ij}(t)dt$ as

$$p_{01} = Q_{34} = p_{67} = p_{10,11} \qquad p_{12} = 1 - g^*(\lambda_1) = p_{1,4.2}$$

$$p_{13} = g^*(\lambda_1) \qquad p_{46} = w^*(\lambda_2)$$

$$p_{4,7.5} = 1 - w^*(\lambda_2) = p_{45} \qquad p_{7,10} = qh^*(\lambda_1)$$

$$p_{78} = ph^*(\lambda_1) \qquad p_{79} = 1 - h^*(\lambda_1)$$

$$p_{7,11.9} = \left[1 - h^*(\lambda_1)\right] q \qquad p_{7,4.9,13} = p\left[1 - h^*(\lambda_1)\right]$$

$$p_{83} = g_1^*(\lambda_1) \qquad p_{8,12} = 1 - g_1^*(\lambda_1) = p_{8,4.12}$$

$$p_{11,0} = w^*(\lambda) \qquad p_{11,1.14} = 1 - w^*(\lambda) = p_{11,14} \tag{1}$$

For these transition probabilities, it can be verified that

$$\begin{aligned} p_{01} &= p_{34} = p_{67} = p_{10,11} = p_{12} + p_{13} = p_{1,4.2} + p_{13} = p_{45} + p_{46} \\ &= p_{46} + p_{4,7.5} = p_{7,10} + p_{78} + p_{79} = p_{7,10} + p_{7,8} + p_{7,11.9} + p_{7,4.9,13} \\ &= p_{83} + p_{8,12} = p_{83} + p_{8,4.12} = p_{11,0} + p_{11,14} = p_{11,0} + p_{11,1.14} = 1 \end{aligned} \tag{2}$$

The mean sojourn times μ_i in state S_i are given by

$$\mu_0 = \frac{1}{\lambda} \qquad \mu_1 = \frac{1}{\lambda_1}\left[1 - g^*(\lambda_1)\right]$$

$$\mu_3 = \frac{1}{\lambda_1} = \mu_{10} \qquad \mu_4 = \frac{1}{\lambda_2}\left[1 - w^*(\lambda_2)\right]$$

$$\mu_6 = \frac{1}{\lambda_2} \qquad \mu_7 = \frac{1}{\lambda_1}\left[1 - h^*(\lambda_1)\right]$$

$$\mu_8 = \frac{1}{\lambda_1}\left[1 - g_1^*(\lambda_1)\right] \qquad \mu_{11} = \frac{1}{\lambda}\left[1 - w^*(\lambda)\right] \tag{3}$$

The unconditional mean time taken by the system to transit from any state S_i when time is counted from epoch at entrance into state S_j is stated as:

$$m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*\prime}(0) \text{ and}$$

$$\mu_i = E(T) = \int_0^\infty P(T > t)dt = \sum_j m_{ij} \tag{4}$$

where T denotes the time to system failure.
Thus

$m_{01} = \mu_0 \qquad m_{12} + m_{13} = \mu_1$

$m_{13} + m_{14.2} = \mu_1^1 (\text{say}) \qquad m_{34} = \mu_3$

$m_{45} + m_{46} = \mu_4 \qquad m_{46} + m_{4,7.5} = \mu_4^1 (\text{say})$

$m_{67} = \mu_6 \qquad m_{7,8} + m_{7,10} + m_{7,9} = \mu_7$

$m_{7,8} + m_{7,10} + m_{7,11.9} + m_{7,4.9,13} = \mu_7^1 (\text{say})$

$m_{83} + m_{8,12} = \mu_8 \qquad m_{83} + m_{8,4.12} = \mu_8^1 (\text{say})$

$m_{10,11} = \mu_{11} \qquad m_{11,14} + m_{11,0} = \mu_{11}$

$$m_{11,0} + m_{11,1.14} = \mu_{11}^1 (\text{say}) \tag{5}$$

4. MEAN TIME TO SYSTEM FAILURE

Let $\phi_i(t)$ be the cdf of the first passage time from regenerative state *i* to a failed state. Regarding the failed state as absorbing state, we have the following recursive relations for $\phi_i(t)$:

$$\phi_i(t) = \sum_j Q_{i,j}(t) \circledR \phi_j(t) + \sum_k Q_{i,k}(t) \tag{6}$$

where *j* is an operative regenerative state to which the given regenerative state *i* can transit and *k* is a failed state to which the state *i* can transit directly.

Taking L.S.T. of relations (6) and solving for $\tilde{\phi}_0(s)$.

Using this, we have

$$R^*(s) = (1 - \tilde{\phi}_0(s))/s \tag{7}$$

The reliability R(t) can be obtained by taking Laplace inverse transform of (7).

The mean time to system failure can be given by

$$\text{MTSF}(T_1) = \lim_{s \to 0} R^*(s) = \frac{N_{11}}{D_{11}} \tag{8}$$

where

$$N_{11} = p_{13}[\mu_0 + \mu_3 + \mu_4 + p_{46}\{(\mu_6 + \mu_7) + p_{78}\mu_8 + p_{7,10}(\mu_{10} + \mu_{11})\}] - p_{78}p_{83}p_{46}(\mu_0 + \mu_1)$$

and

$$D_{11} = 1 - p_{7,10}p_{46}p_{13}p_{11,0} - p_{78}p_{46}p_{83}$$

5. AVAILABILITY ANALYSIS

Let $A_i(t)$ be the probability that the system is in up state at instant *t* given that the system entered regenerative state *i* at *t=0*. The recursive relations for $A_i(t)$ are given by :

$$A_i(t) = M_i(t) + \sum_j q_{i,j}^{(n)}(t) \copyright A_j(t) \tag{9}$$

where *j* is any successive regenerative state to which the regenerative state *i* can transit through $n \geq 1$ (natural number) transitions.

We have,

$M_0(t) = e^{-\lambda t} \qquad M_1(t) = e^{-\lambda_1 t}\overline{G}(t)$

$M_3(t) = e^{-\lambda_1 t} = M_{10}(t) \qquad M_4(t) = e^{-\lambda_2 t}\overline{W}(t)$

$M_6(t) = e^{-\lambda_2 t} \qquad M_7(t) = e^{-\lambda_1 t}\overline{H}(t)$

$$M_8(t) = e^{-\lambda_1 t}\overline{G}_1(t) \qquad M_{11}(t) = e^{-\lambda t}\overline{W}(t), \tag{10}$$

Taking LT of relations (9) and solving for $A_0^*(s)$.

The steady-state availability of the system can be given by

$$A_0(\infty) = \lim_{s \to 0} s A_0^*(s) = \frac{N_{12}}{D_{12}} \tag{11}$$

where

$$N_{12} = (p_{7,10} + p_{7,11.9})(\mu_0 p_{11,0} + \mu_1 + \mu_{11}) + [\mu_4 + p_{46}\mu_6 + \mu_7 + p_{7,8}\mu_8 + p_{7,10}\mu_{10}] + \mu_3[p_{13}(p_{7,10} + p_{7,11.9} + p_{78}p_{83}]$$

$$D_{12} = (p_{7,10} + p_{7,11.9})[\mu_0 p_{11,0} + \mu_3 p_{13} + \mu_1^1 + \mu_{11}^1] + p_{78}(\mu_8^1 + p_{83}\mu_3) + \mu_4^1 + p_{46}\mu_6 + \mu_7^1 + p_{7,10}\mu_{10}$$

6. BUSY PERIOD ANALYSIS FOR SERVER

Let $B_i(t)$ be the probability that the server is busy at an instant *t* given that the system entered regenerative state *i* at *t*= 0. The following are the recursive relations for $B_i(t)$

$$B_i(t) = W_i(t) + \sum_j q_{i,j}^{(n)}(t) \copyright B_j(t) \tag{12}$$

where *j* is a subsequent regenerative state to which state *i* transits through $n \geq 1$ (natural number) transitions.

We have,

$W_1(t) = [e^{-\lambda_1 t} + (\lambda_1 e^{-\lambda_1 t} \copyright 1)]\overline{G}(t)$

$W_4(t) = [e^{-\lambda_2 t} + (\lambda_2 e^{-\lambda_2 t} \copyright 1)]\overline{W}(t)$

$W_7(t) = e^{-\lambda_1 t}\overline{H}(t) + [(\lambda_1 e^{-\lambda_1 t} \copyright 1)]\overline{H}(t) + (\lambda_1 e^{-\lambda_1 t} \copyright ph(t) \copyright 1)\overline{G}_1(t)$

$W_8(t) = e^{-\lambda_1 t}\overline{G}_1(t) + [(\lambda_1 e^{-\lambda_1 t} \copyright 1)]\overline{G}_1(t)$

$$W_{11}(t) = [e^{-\lambda t} + (\lambda_1 e^{-\lambda t} \copyright 1)]\overline{W}(t) \,. \tag{13}$$

Taking LT of relations (12) and solving for $B_0^*(s)$ and using this, we can obtain the fraction of time for which the repairman is busy in steady state

$$B_0 = \lim_{s \to 0} s B_0^*(s) = \frac{N_{13}}{D_{12}} \tag{14}$$

$$N_{13} = (p_{7,10} + p_{7,11.9})(W_1^*(0) + W_{11}^*(0)) + W_4^*(0) + W_7^*(0) + p_{78}W_8^*(0)$$

and D_{12} is already mentioned**.**

7. EXPECTED NUMBER OF VISITS BY SERVER

Let $N_i(t)$ be the expected number of visits by the server in (0,t] given that the system entered the regenerative state *i* at *t=0*. We have the following recursive relations for $N_i(t)$:

$$N_i(t) = \sum_j Q_{i,j}(t) \circledR [\delta_j + N_j(t)] \tag{15}$$

where j is any regenerative state to which the given regenerative state *i* transits and δ_i =1, if *j* is the regenerative state where the server does job afresh otherwise $\delta_i = 0$.

Taking LST of relations (15) and solving for $\tilde{N}_0(s)$.

The expected number of visits per unit time are given by

$$N_0 = \lim_{s \to 0} s\tilde{N}_0(s) = \frac{N_{14}}{D_{12}}, \tag{16}$$

where $N_{14} = (p_{7,10} + p_{7,11,9})(p_{11,0} + p_{13}) + p_{46} + p_{83}p_{7,8} + p_{7,10}$

and D_{12} is already specified.

8. PROFIT ANALYSIS

Profit incurred to the system model in steady state is given by

$P_1 = K_1A_0 - K_2B_0 - K_3 N_0$

Where K_1 = Revenue per unit up time of the system

K_2 = Cost per unit time for which server is busy

K_3 = Cost per visit by the server

9. PARTICULAR CASE

Let us take $g(t) = \theta e^{-\theta t}$, $g_1(t) = \theta_1 e^{-\theta_1 t}$, $h(t) = \alpha e^{-\alpha t}$ and $w(t) = \beta e^{-\beta t}$.

By using the non-zero elements p_{ij}, we get the following results:

MTSF(T_1)=N_{11}/D_{11} , Availability(A_0)=N_{12}/D_{12}

Busy Period(B_0)=N_{13}/D_{12},Expected no. of visits(N_0)=N_{14}/D_{12}

where

$$D_{11} = \lambda\lambda_1\lambda_2[(\theta+\lambda_1)(\alpha+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda_2)(\beta+\lambda) \\ -q\theta\alpha\beta^2(\lambda_1+\theta_1) - p\theta_1\alpha\beta(\lambda_1+\theta)(\beta+\lambda)]$$

$$N_{11} = \theta[\{(\lambda_1+\lambda)(\beta+\lambda_2)+\lambda\lambda_1\}\lambda_2(\alpha+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda) \\ +(\theta+\lambda_1)\lambda\beta\{\lambda_1(\beta+\lambda)\{(\lambda_1+\alpha+\lambda_2)(\lambda_1+\theta_1)+p\alpha\lambda_2\} \\ +\lambda_2\alpha q(\lambda_1+\theta_1)(\beta+\lambda+\lambda_1)\}] \\ -\lambda_1\theta_1\lambda_2\alpha p\beta(\theta+\lambda_1+\lambda)(\beta+\lambda)$$

$$D_{12} = q\lambda_2\theta_1(\alpha+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda_2)[\lambda_1(\theta+\lambda_1)\{\beta^2\theta \\ +(\beta+\theta)(\beta+\lambda)\lambda\}+\lambda\beta\theta^2(\beta+\lambda)]+p\alpha\lambda\theta\lambda_2\beta[\lambda_1(\lambda_1+\theta_1) \\ +\theta_1^2](\theta+\lambda_1)(\beta+\lambda_2)(\beta+\lambda)+\lambda\theta_1\theta(\theta+\lambda_1)(\lambda_1+\theta_1) \\ (\beta+\lambda)[\lambda_2(\beta+\lambda_2)\{\lambda_1(1+A\beta)(\alpha+\lambda_1)+q\beta\alpha\} \\ +\beta^2\lambda_1(\alpha+\lambda_1)]$$

$$N_{12} = \beta\theta\theta_1[q\lambda_1\lambda(\alpha+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda_2)(\beta+\lambda)(\lambda_1+\theta+\lambda) \\ +\lambda(\theta+\lambda_1)(\beta+\lambda)[\lambda_1(\alpha+\lambda_1)(\lambda_1+\theta_1)+\{\lambda_1(p\alpha+\lambda_1+\theta_1) \\ +q\alpha(\theta_1+\lambda_1)\}\lambda_2]+\lambda\lambda_2(\beta+\lambda_2)(\beta+\lambda)[q\theta(\alpha+\lambda_1)(\lambda_1+\theta_1) \\ +p\alpha\theta_1(\theta+\lambda_1)]]$$

$$N_{13} = \lambda\lambda_1\lambda_2(\theta+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda_2)(\beta+\lambda)[\theta_1(\alpha+\lambda_1) \\ [q(\theta+\beta)+\theta(1+\beta B)]+p\theta\alpha\beta]$$

$$N_{14} = \lambda\lambda_1\lambda_2\theta\theta_1\beta(\alpha+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda_2)+[\beta(\theta+\lambda_1) \\ +\theta(\beta+\lambda)]+p\alpha\theta_1(\theta+\lambda_1)(\beta+\lambda_2)(\beta+\lambda)+((\alpha+\lambda_1)\beta \\ +q\alpha(\lambda_2+\beta))(\theta+\lambda_1)(\lambda_1+\theta_1)(\beta+\lambda)$$

$$A = [[q(\alpha+\lambda_1)^2+\alpha^2 p]\alpha\theta_1+q\alpha[(\theta_1+\alpha)(\alpha+\lambda_1)^2 \\ -\alpha^2(\alpha+\theta_1+\lambda_1)]]/[(\theta_1\alpha^2(\alpha+\lambda_1)^2]$$

$$B = [\theta_1(\alpha+\theta_1)(\theta_1+\lambda_1)+\alpha^2 p\lambda_1]/[\theta_1\alpha(\alpha+\theta_1)(\theta_1+\lambda_1)].$$

10. CONCLUSION

From fig.2, fig.3 and fig.4, it is concluded that mean time to system failure (MTSF), availability and profit function decrease with the increase of failure rates λ and λ_2 for fixed values of other parameters including p=.7 and q=.3. However, their values increase if repair rate (θ) and replacement rate (β) of duplicate unit increase. It is interesting to note that the system becomes more profitable by interchanging the values of p and q.

Hence, on the basis of the results obtained for a particular case, it is suggested that replacement of the failed degraded unit by original unit should be preferred over the repair to increase of a system of non-identical units.

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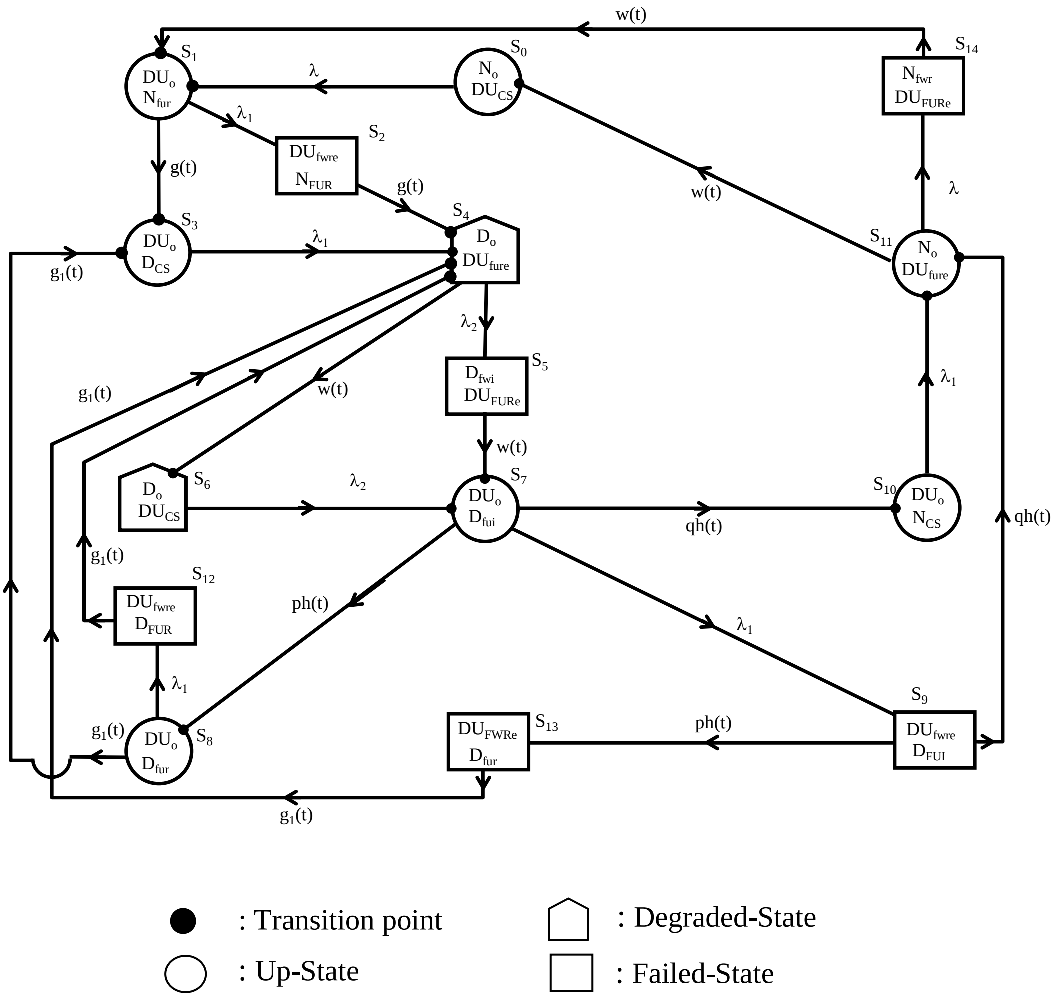
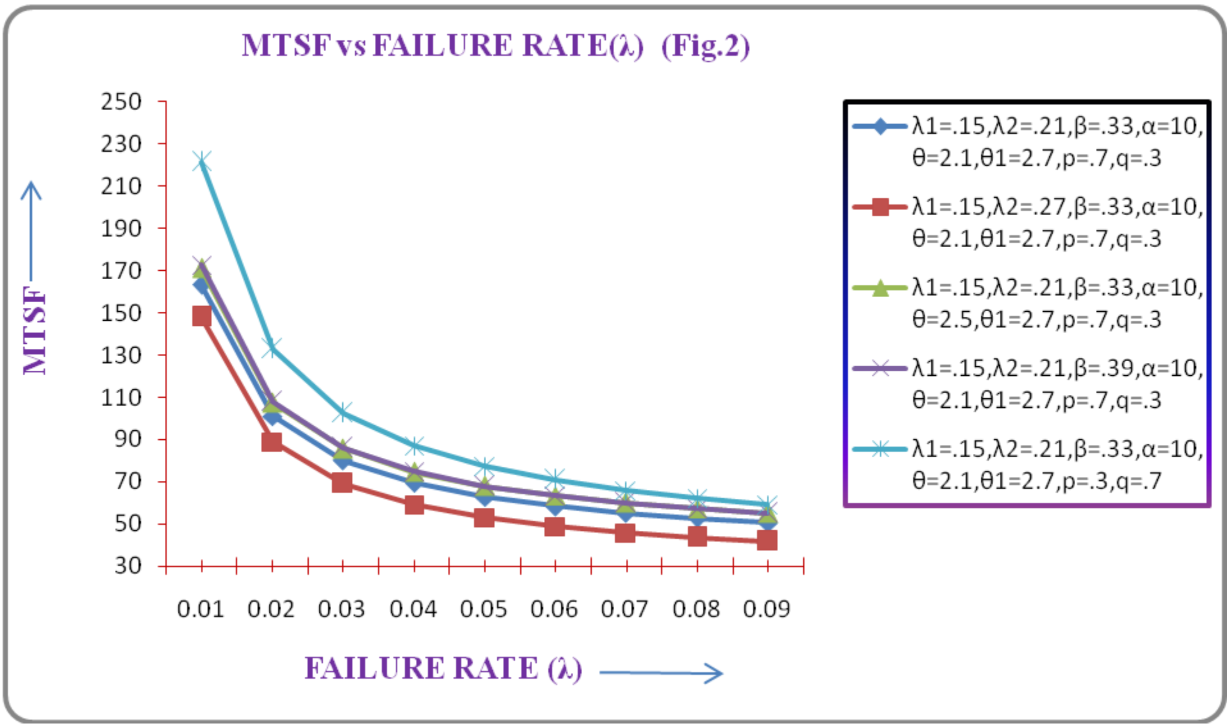
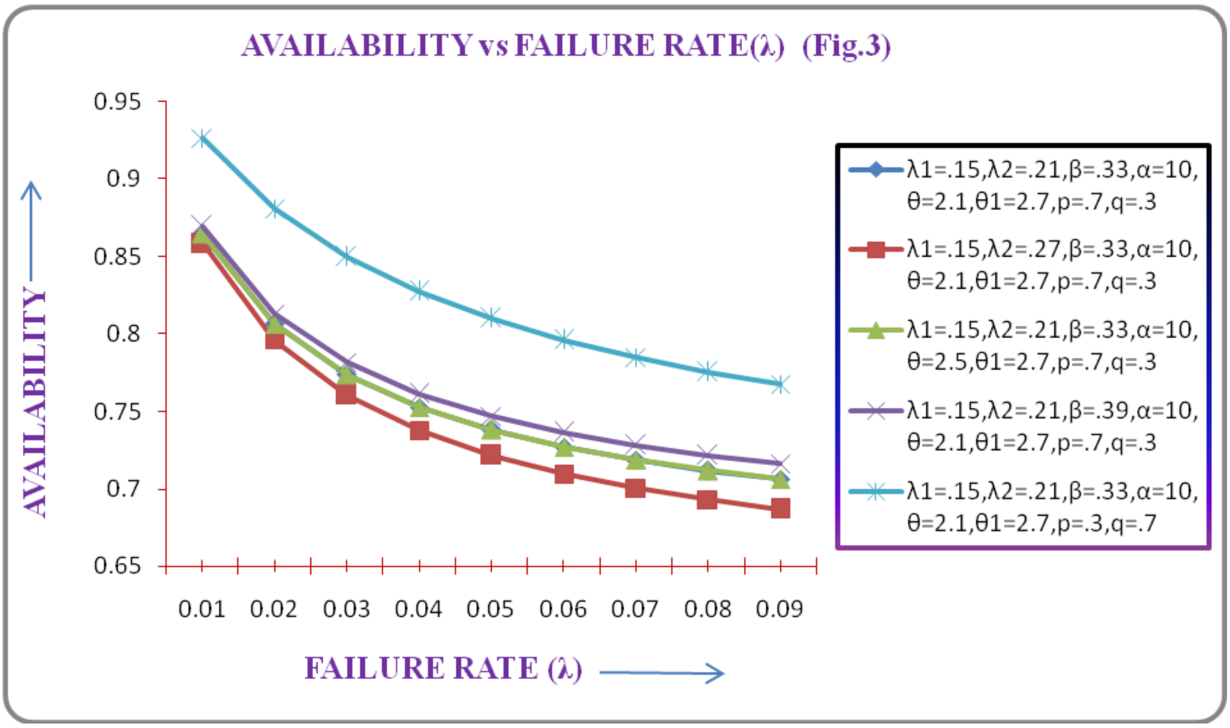
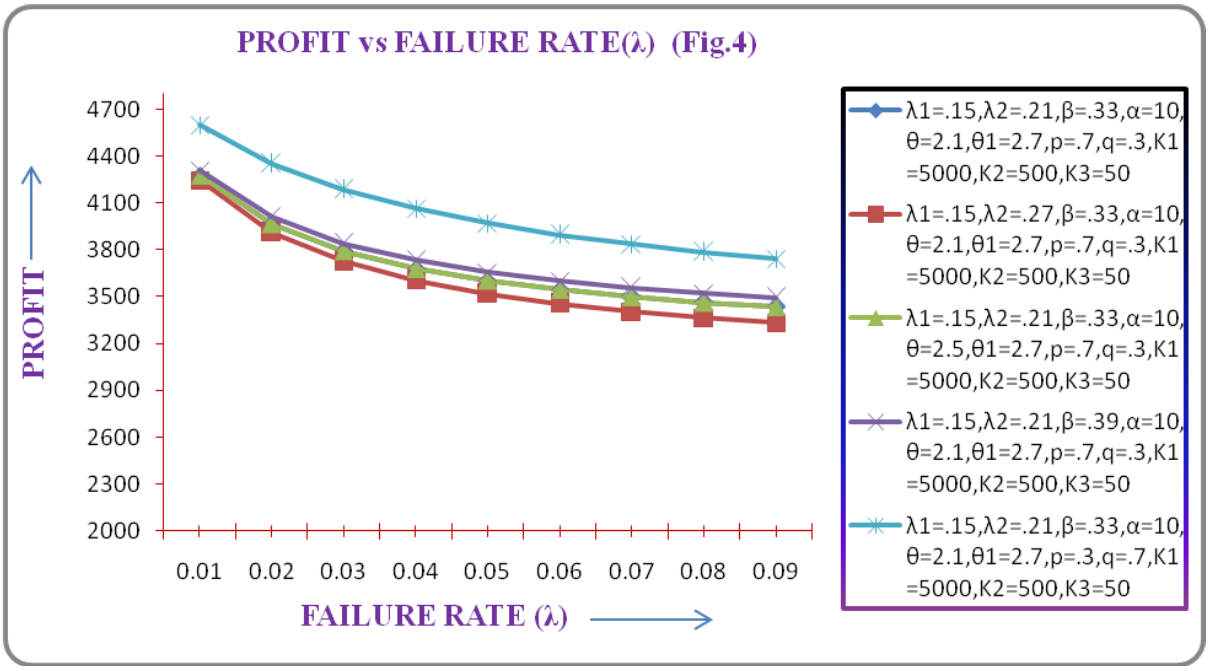
State Transition Diagram (Fig.1)




MTSF vs FAILURE RATE(λ) (Fig.2)
MTSF
FAILURE RATE (λ)
λ1=.15,λ2=.21,β=.33,α=10, θ=2.1,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.27,β=.33,α=10, θ=2.1,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.21,β=.33,α=10, θ=2.5,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.21,β=.39,α=10, θ=2.1,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.21,β=.33,α=10, θ=2.1,θ1=2.7,p=.3,q=.7


AVAILABILITY vs FAILURE RATE(λ) (Fig.3)
AVAILABILITY
FAILURE RATE (λ)
λ1=.15,λ2=.21,β=.33,α=10, θ=2.1,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.27,β=.33,α=10, θ=2.1,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.21,β=.33,α=10, θ=2.5,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.21,β=.39,α=10, θ=2.1,θ1=2.7,p=.7,q=.3
λ1=.15,λ2=.21,β=.33,α=10, θ=2.1,θ1=2.7,p=.3,q=.7


PROFIT vs FAILURE RATE(λ) (Fig.4)
PROFIT
FAILURE RATE (λ)
4700
4400
4100
3800
3500
3200
2900
2600
2300
2000
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
λ1=.15,λ2=.21,β=.33,α=10,θ=2.1,θ1=2.7,p=.7,q=.3,K1=5000,K2=500,K3=50
λ1=.15,λ2=.27,β=.33,α=10,θ=2.1,θ1=2.7,p=.7,q=.3,K1=5000,K2=500,K3=50
λ1=.15,λ2=.21,β=.33,α=10,θ=2.5,θ1=2.7,p=.7,q=.3,K1=5000,K2=500,K3=50
λ1=.15,λ2=.21,β=.39,α=10,θ=2.1,θ1=2.7,p=.7,q=.3,K1=5000,K2=500,K3=50
λ1=.15,λ2=.21,β=.33,α=10,θ=2.1,θ1=2.7,p=.3,q=.7,K1=5000,K2=500,K3=50