CHAPTER-3

STOCHASTIC ANALYSIS OF SYSTEM WITH DIFFERENT TYPES OF FAILURE UNDER INSPECTION POLICY

INTRODUCTION

In the previous chapter we have analyzed the two models consisting of identical units having similar kind of failure. However such two unit identical systems are also frequently used by many industries. In the field of reliability, large number of researchers had analyzed many systems with two types of failure. Garg [119], Goel et al. [120-123], Gupta et al. [124-125] and Damcese et al. [126] had analyzed the cold standby system with two types of failure using exponential distribution. Kumar [127] had analyzed the two identical units system having degraded being inspecting at its failure by single server to see the feasibility of repair. In 2012, Kumar [128] had again considered the cold standby system subject to inspection, degradation and priority.

In reliability analysis of system using discrete distribution, Bhardwaj [129-130] had studied the redundant system having imperfect switching and connection time. He had also analyzed the identical parallel standby systems possessing two different failure. Gupta [131] had used concept of two phase repair and geometric distributions of the events for warm standby system. But, in all researches no one had given any importance for inspection of different types of failure.

Keeping the above things in view, this chapter aims to analyze the two identical standby systems by introducing the concept of inspection policy to detect the two types of failure. Initially, one unit is in operative and other is in standby state. Inspection policy is being introduced to scrutinize the one out of different failures. It proves to be helpful repairman to repair a true failure of the failed unit. Minor failure will be given a preference to be repaired as compared to the major one as the repair time taken by minor is less than major.

Using regenerative point technique various important measures of system effectiveness are obtained. Graphs were also been drawn to analyzed the behaviour of mean time to system failure and profit function with respect to failure/repair rate.
3.2 MODEL DESCRIPTION

The following assumptions have been associated with model:

- A system consists of two identical automatic units have been arranged parallel. Initially, one unit is in operative condition and the other is in standby.
- Upon the failure of an automatic unit, the standby unit gets operative instantaneously.
- System is assumed to be in failed state when both units fall together in failed state.
- Inspection policy is being introduced for inspecting the failed automatic unit before being repaired by repairman.
- A single repair facility is available to repair both kind of failed unit with preference to minor failure.
- The repaired unit’s operate as good as new.

3.2.1 NOMENCLATURE

<table>
<thead>
<tr>
<th>O/S</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/S</td>
<td>Automatic unit is in operative/standby mode.</td>
</tr>
<tr>
<td>a/b</td>
<td>Probability of unit’s to get into failed state with major/minor failure.</td>
</tr>
<tr>
<td>F&lt;sub&gt;i&lt;/sub&gt;/F&lt;sub&gt;iw&lt;/sub&gt;</td>
<td>Automatic unit is in failure mode and is under inspection/waiting for inspection.</td>
</tr>
<tr>
<td>F&lt;sub&gt;Mr&lt;/sub&gt;/F&lt;sub&gt;Mw&lt;/sub&gt;</td>
<td>Unit is in major failure mode and is under repair/waiting for repair.</td>
</tr>
<tr>
<td>F&lt;sub&gt;mr&lt;/sub&gt;/F&lt;sub&gt;mw&lt;/sub&gt;</td>
<td>Unit is in minor failure mode and is under repair/waiting for repair.</td>
</tr>
<tr>
<td>p&lt;sub&gt;1&lt;/sub&gt;/q&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Probability of an automatic unit to get into failed state or not.</td>
</tr>
<tr>
<td>p&lt;sub&gt;2&lt;/sub&gt;/q&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Probability of the failed unit to be inspected satisfactory or not.</td>
</tr>
<tr>
<td>r</td>
<td>Repair rate of a failed automatic unit.</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
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<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>$q_{ij}(t)/Q_{ij}(t)$</td>
<td>Probability and cumulative density function of first passage time from regenerative state ‘$i$’ to ‘$j$’.</td>
</tr>
<tr>
<td>$P_{ij}(t)$</td>
<td>Steady state transition probability from state $S_i$ to $S_j$.</td>
</tr>
<tr>
<td>$\mu_i$</td>
<td>Mean sojourn time in state $S_i$.</td>
</tr>
<tr>
<td>$\otimes$</td>
<td>Convolution of the two functions of non-negative variable.</td>
</tr>
</tbody>
</table>

Table 3.1: Nomenclature

Figure 3.1: Transition Diagram

**Up States**
- $S_0 = (O, S)$, $S_1 = (F_i, O)$,
- $S_2 = (F_{mr}, O)$, $S_3 = (F_mr, O)$.

**Down State**
- $S_4 = (F_i, F_{iw})$, $S_5 = (F_{mr}, F_i)$,
- $S_6 = (F_{mr}, F_i)$, $S_7 = (F_{mr}, F_{mw})$,
- $S_8 = S_{10} = (F_{mw}, F_{mr})$, $S_9 = (F_{mr}, F_{mw})$. 
### 3.3 TRANSITION PROBABILITIES AND SOJOURN TIMES

Since the system undergoes discrete failures so the number of failures preceding the first success follows the geometric distribution. The cumulative density function of first passage time from regenerative state 'i' to 'j' has been defined by:

\[
Q_{11}(t) = \frac{p_i[1-q_i^{(r+1)}]}{1-q_i} \quad Q_{12}(t) = \frac{ap_2q_i[1-q_1q_2^{(r+1)}]}{1-q_1q_2}
\]
\[
Q_{13}(t) = \frac{bp_2q_i[1-q_1q_2^{(r+1)}]}{1-q_1q_2} \quad Q_{14}(t) = \frac{p_1q_2[1-q_1q_2^{(r+1)}]}{1-q_1q_2}
\]
\[
Q_{15}(t) = \frac{ap_1p_2[1-q_1q_2^{(r+1)}]}{1-q_1q_2} \quad Q_{16}(t) = \frac{bp_1p_2[1-q_1q_2^{(r+1)}]}{1-q_1q_2}
\]
\[
Q_{20}(t) = Q_{30}(t) = \frac{rq_1[1-(q_1s)^{r+1}]}{1-q_1s} \quad Q_{21}(t) = Q_{31}(t) = \frac{rp_1[1-(qs_1)^{r+1}]}{1 sq_1}
\]
\[
Q_{25}(t) = Q_{36}(t) = \frac{sp_1[1-(qs_1)^{r+1}]}{1 sq_1} \quad Q_{25}(t) = \frac{ap_1[1-(q_2)^{r+1}]}{1-q_2}
\]
\[
Q_{46}(t) = \frac{bp_2[1-(q_2)^{r+1}]}{1-q_2} \quad Q_{46}(t) = \frac{rq_2[1-(q_2s)^{r+1}]}{1-q_2s}
\]
\[
Q_{52}(t) = Q_{62}(t) = \frac{arp_2[1-(q_2s)^{r+1}]}{1-q_2s} \quad Q_{53}(t) = Q_{63}(t) = \frac{brp_2[1-(q_2s)^{r+1}]}{1-q_2s}
\]
\[
Q_{57}(t) = Q_{8,10}(t) = \frac{asp_2[1-(q_2s)^{r+1}]}{1-q_2s} \quad Q_{58}(t) = Q_{8,9}(t) = \frac{bsp_2[1-(q_2s)^{r+1}]}{1-q_2s}
\]
\[
Q_{52}(t) = Q_{62}(t) = Q_{93}(t) = Q_{10,2}(t) = \frac{r[1-s^{(1+1)}]}{1-s} \quad \text{(3.1-3.17)}
\]

The steady state transition probabilities from state $S_i$ to $S_j$ can be obtained from

\[ P_{ij} = \lim_{t \to \infty} Q_{ij} \]

It can be verified that

\[
P_{01} = 1, \quad P_{12} = P_{13} + P_{14} + P_{15} + P_{16} = 1,
\]
\[
P_{20} = P_{21} + P_{25} = 1, \quad P_{30} + P_{31} + P_{36} = 1,
\]
\[
P_{45} + P_{46} = 1, \quad P_{51} + P_{52} + P_{53} + P_{57} + P_{58} = 1,
\]
\[
P_{61} + P_{62} + P_{63} + P_{6,10} + P_{69} = 1, \quad P_{72} = P_{82} = P_{93} = P_{10,2} = 1
\]

\[ \text{(3.18-3.25)} \]
3.3.1 MEAN SOJOURN TIMES

Let \( T'_i \) be the sojourn time in state \( S_i = (i = 0,1,2,3,4,5,6,7,8,9,10) \), then “mean sojourn time” in state \( S_i \) is obtained by:

\[
\mu_i = E(T'_i) = \sum_{i=0}^{\infty} P(T'_i > t)
\]

so that

\[
\mu_0 = \frac{1}{1-q_1} \quad \mu_1 = \frac{1}{1-q_1q_2} \quad \mu_2 = \mu_3 = \frac{1}{1-sq_1} \\
\mu_4 = \frac{1}{1-q_2} \quad \mu_5 = \mu_6 = \frac{1}{1-sq_2} \quad \mu_7 = \mu_8 = \mu_9 = \mu_{10} = \frac{1}{1-s}
\]

(3.26-3.31)

Mean sojourn time \( (m_{ij}) \) of the system in state \( S_i \) when the system is to transit into \( S_j \) is given by:

\[
m_{ij} = \sum_{i=0}^{\infty} t q_{ij}(t)
\]

\[
m_{01} = q_1 \mu_0 \\
m_{12} + m_{13} + m_{14} + m_{15} + m_{16} = q_1q_2 \mu_1 \\
m_{20} + m_{21} + m_{25} = m_{30} + m_{31} + m_{36} = sq_1 \mu_2 \\
m_{45} + m_{46} = q_2 \mu_4 \\
m_{51} + m_{52} + m_{53} + m_{57} + m_{58} = m_{61} + m_{62} + m_{63} + m_{6,10} + m_{69} = sq_2 \mu_5 \\
m_{72} = m_{82} = m_{93} = m_{10,2} = s \mu_7
\]

(3.32-3.37)

The value of transition probabilities and mean sojourn time are used to calculate the results for reliability, availability of the system, and busy time period of inspection and repairman.

3.4 RELIABILITY AND MEAN TIME TO SYSTEM FAILURE

The time taken by the system before its failure is known to be first passage time to the failed state or life time of the system. If random variable \( T \) denotes the life time of the system then its expected value provides the mean time to system failure.
Let $R_i(t)$ denotes the probability of system that perform satisfactorily for atleast ‘t’ epochs, when it begin initially from operative regenerative state $S_i$ $(i = 0, 1, 2, 3)$. The reliability analysis of the system is obtained by analyzing the mean time to system failure of system by the solving the following equation:

\[
\begin{align*}
R_0(t) &= Z_0(t) + q_{01}(t-1) \odot R_1(t-1) \\
R_1(t) &= Z_1(t) + q_{12}(t-1) \odot R_2(t-1) + q_{13}(t-1) \odot R_3(t-1) \\
R_2(t) &= Z_2(t) + q_{20}(t-1) \odot R_0(t-1) + q_{21}(t-1) \odot R_1(t-1) \\
R_3(t) &= Z_3(t) + q_{30}(t-1) \odot R_0(t-1) + q_{31}(t-1) \odot R_1(t-1) \\
R_4(t) &= Z_4(t) + q_{40}(t-1) \odot R_0(t-1) + q_{41}(t-1) \odot R_1(t-1)
\end{align*}
\]

(3.38-3.41)

By taking Geometric transformation and solving the above equations, we get

\[
R_0(h) = \frac{N_1(h)}{D_1(h)}
\]

The MTSF (mean time to system failure) is:

\[
\mu_i = \lim_{h \to 1} \frac{N_1(h)}{D_1(h)} - 1 = \frac{N_1}{D_1}
\]

where

\[
\begin{align*}
N_1 &= \mu_0[1 - (P_{12} + P_{13}P_{21})] + P_{01}[\mu_1 + (P_{12} + P_{13})\mu_2] \\
D_1 &= 1 - (P_{12} + P_{13})[P_{21} + P_{20}P_{01}]
\end{align*}
\]

(3.42-3.43)

3.5 AVAILABILITY ANALYSIS

The percentage of time that the equipment is under operation is called steady-state availability. It characterizes the mean behavior of the unit. The availability function $A(t)$ is defined as the probability that the unit is operating at time $t$.

Let $A_i(t)$ denotes the probability of system to be in upstate at epoch ‘t’ when it started initially from regenerative state $S_i$. Using simple probabilistic argument, the following recurrence expressions has been obtained:

\[
\begin{align*}
A_0(t) &= Z_0(t) + q_{01}(t-1) \odot A_1(t-1) \\
A_1(t) &= Z_1(t) + q_{12}(t-1) \odot A_2(t-1) + q_{13}(t-1) \odot A_3(t-1) + q_{14}(t-1) \odot A_4(t-1) \\
&\quad + q_{15}(t-1) \odot A_5(t-1) + q_{16}(t-1) \odot A_6(t-1) \\
A_2(t) &= Z_2(t) + q_{20}(t-1) \odot A_0(t-1) + q_{21}(t-1) \odot A_1(t-1) + q_{23}(t-1) \odot A_3(t-1) \\
A_3(t) &= Z_3(t) + q_{30}(t-1) \odot A_0(t-1) + q_{31}(t-1) \odot A_1(t-1) + q_{32}(t-1) \odot A_2(t-1) \\
A_4(t) &= q_{45}(t-1) \odot A_5(t-1) + q_{46}(t-1) \odot A_6(t-1)
\end{align*}
\]
\[ A_5(t) = q_{51}(t-1)A_0(t-1) + q_{52}(t-1)A_2(t-1) + q_{53}(t-1)A_3(t-1) + q_{57}(t-1)A_7(t-1) + q_{58}(t-1)A_8(t-1) \]
\[ A_6(t) = q_{61}(t-1)A_0(t-1) + q_{62}(t-1)A_2(t-1) + q_{63}(t-1)A_3(t-1) + q_{68}(t-1)A_8(t-1) + q_{69}(t-1)A_9(t-1) \]
\[ A_7(t) = q_{72}(t-1)A_3(t-1) \]
\[ A_8(t) = q_{82}(t-1)A_2(t-1) \]
\[ A_9(t) = q_{93}(t-1)A_2(t-1) \]

By taking Geometric transformation and solving the above equations, we get

\[ A_o(h) = \frac{N_2(h)}{D_2(h)} \]

and

\[ Z_i(h) = \mu_i \]

The steady state availability of system is obtained by:

\[ A_0 = \lim_{t \to \infty} A_0(t) \]

After applying ‘L’ Hospital Rule, we obtained:

\[ A_0 = -\frac{N_2(1)}{D_2'(1)} \]

where

\[ N_2(1) = \mu_0P_{20}[1 - P_{51}(P_{14} + P_{15} + P_{16})] + \mu_1P_{01}(1 - P_{25} + P_{25}P_{51}) + \mu_2P_{01}[1 - P_{51}(P_{14} + P_{15} + P_{16})] \]

\[ D_2'(1) = -\{ q_1\mu_0P_{20}[1 - P_{51}(P_{14} + P_{15} + P_{16})] + P_{01}(1 - P_{25} + P_{25}P_{51}) \}
\[ (q_1q_2\mu_1 + q_2\mu_2P_{14}) + sq_1\mu_2P_{01}[1 - P_{51}(P_{14} + P_{15} + P_{16})] + P_{01}(sq_2\mu_5 + sq_7P_{01})(P_{57} + P_{58})[1 - (P_{12} + P_{13})(1 - P_{25})] \}

3.6 BUSY PERIOD ANALYSIS

3.6.1 BUSY PERIOD OF INSPECTOR

Let \( B_3(t) \) be the probability of the inspector that inspects the failure of a failed unit, before it get repaired by repairman. Using simple probabilistic argument, the following recurrence expressions has been obtained:
\[ B_0(t) = q_0(t-1) \cap B_1(t-1) \]
\[ B_1(t) = Z_i(t) + q_{12}(t-1) \cap B_2(t-1) + q_{13}(t-1) \cap B_3(t-1) + q_{14}(t-1) \cap B_4(t-1) \]
\[ B_4(t) = q_{20}(t-1) \cap B_5(t-1) + q_{21}(t-1) \cap B_6(t-1) + q_{25}(t-1) \cap B_8(t-1) \]
\[ B_2(t) = q_{30}(t-1) \cap B_6(t-1) + q_{31}(t-1) \cap B_4(t-1) + q_{36}(t-1) \cap B_6(t-1) \]
\[ B_4(t) = Z_i(t) + q_{45}(t-1) \cap B_5(t-1) + q_{46}(t-1) \cap B_6(t-1) \]
\[ B_5(t) = Z_i(t) + q_{51}(t-1) \cap B_6(t-1) + q_{52}(t-1) \cap B_2(t-1) + q_{53}(t-1) \cap B_3(t-1) + q_{57}(t-1) \cap B_7(t-1) + q_{58}(t-1) \cap B_8(t-1) \]
\[ B_6(t) = Z_i(t) + q_{61}(t-1) \cap B_6(t-1) + q_{62}(t-1) \cap B_2(t-1) + q_{63}(t-1) \cap B_3(t-1) + q_{68}(t-1) \cap B_8(t-1) + q_{69}(t-1) \cap B_9(t-1) \]
\[ B_7(t) = q_{72}(t-1) \cap B_2(t-1) \]
\[ B_8(t) = q_{82}(t-1) \cap B_2(t-1) \]
\[ B_9(t) = q_{93}(t-1) \cap B_3(t-1) \]  (3.56-3.65)

By taking Geometric transformation and solving the above equations, we get

\[ B_0(h) = \frac{N_3(h)}{D_2(h)} \]

The probability of inspection facility involved in inspecting the failed unit is obtained by:

\[ B_0 = \lim_{t \to \infty} B_0(t) \]

After applying ‘L’ Hospital Rule, we obtained:

\[ B_0 = -\frac{N_3(1)}{D'_2(1)} \]

where

\[ N_3(1) = (1 - P_{25} + P_{23}P_{51}) (\mu_1 + \mu_4 P_{14}) + \mu_5 [1 - (P_{12} + P_{13}) (1 - P_{25})] \]

(3.66)

and \( D'_2(1) \) is same as in availability analysis.

### 3.6.2 BUSY PERIOD OF REPAIRMAN

Let \( B'_i(t) \) be the probability of repair facility being involved to repair the failed unit, when system starts initially from regenerative state \( S_i \). Using
simple probabilistic argument, the following recurrence expressions has been obtained:

\[ B_0'(t) = q_{01}(t-1) \odot B_1'(t - 1) \]
\[ B_1'(t) = q_{12}(t-1) \odot B_2'(t - 1) + q_{13}(t-1) \odot B_3'(t - 1) + q_{14}(t-1) \odot B_4'(t - 1) + q_{15}(t-1) \odot B_5'(t - 1) + q_{16}(t-1) \odot B_6'(t - 1) \]
\[ B_2'(t) = Z_2(t) + q_{21}(t-1) \odot B_0'(t - 1) + q_{22}(t-1) \odot B_1'(t - 1) + q_{23}(t-1) \odot B_2'(t - 1) + q_{24}(t-1) \odot B_3'(t - 1) + q_{25}(t-1) \odot B_4'(t - 1) \]
\[ B_3'(t) = Z_3(t) + q_{31}(t-1) \odot B_0'(t - 1) + q_{32}(t-1) \odot B_1'(t - 1) + q_{33}(t-1) \odot B_2'(t - 1) + q_{34}(t-1) \odot B_3'(t - 1) + q_{35}(t-1) \odot B_4'(t - 1) + q_{36}(t-1) \odot B_5'(t - 1) \]
\[ B_4'(t) = q_{41}(t-1) \odot B_0'(t - 1) + q_{42}(t-1) \odot B_1'(t - 1) + q_{43}(t-1) \odot B_2'(t - 1) + q_{44}(t-1) \odot B_3'(t - 1) + q_{45}(t-1) \odot B_4'(t - 1) + q_{46}(t-1) \odot B_5'(t - 1) \]
\[ B_5'(t) = Z_5(t) + q_{51}(t-1) \odot B_0'(t - 1) + q_{52}(t-1) \odot B_1'(t - 1) + q_{53}(t-1) \odot B_2'(t - 1) + q_{54}(t-1) \odot B_3'(t - 1) + q_{55}(t-1) \odot B_4'(t - 1) + q_{56}(t-1) \odot B_5'(t - 1) \]
\[ B_6'(t) = Z_6(t) + q_{61}(t-1) \odot B_0'(t - 1) + q_{62}(t-1) \odot B_1'(t - 1) + q_{63}(t-1) \odot B_2'(t - 1) + q_{64}(t-1) \odot B_3'(t - 1) + q_{65}(t-1) \odot B_4'(t - 1) + q_{66}(t-1) \odot B_5'(t - 1) + q_{67}(t-1) \odot B_6'(t - 1) \]
\[ B_7'(t) = Z_7(t) + q_{71}(t-1) \odot B_0'(t - 1) + q_{72}(t-1) \odot B_1'(t - 1) \]
\[ B_8'(t) = Z_8(t) + q_{81}(t-1) \odot B_0'(t - 1) + q_{82}(t-1) \odot B_1'(t - 1) \]
\[ B_9'(t) = Z_9(t) + q_{91}(t-1) \odot B_0'(t - 1) + q_{92}(t-1) \odot B_1'(t - 1) \]

By taking Geometric transformation and solving the above equation, we get

\[ B_0'(h) = \frac{N_4(h)}{D_2(h)} \]

The probability of repair facility involved in repair of failed unit is obtained by:

\[ B_0' = \lim_{t \to \infty} B_0'(t) \]

After applying ‘L’ Hospital Rule, we obtained:

\[ B_0' = - \frac{N_3(1)}{D_2'(1)} \]

where

\[ N_4(1) = \mu_2 P_{01} [1 - P_{31} (P_{14} + P_{15} + P_{16})] + \mu_3 P_{01} [1 - (P_{12} + P_{13})(P_{21} + P_{20} P_{01})] + \mu_7 P_{01} (P_{37} + P_{58}) [1 - (P_{12} + P_{13})(1 - P_{25})] \]

(3.77)
and \( D'_2(1) \) is same as in availability analysis.

### 3.7 GRAPHICAL INTERPRETATION AND PROFIT FUNCTION ANALYSIS

The expected profit for steady-state is obtained by:

\[
P = C_0 A_0 - C_1 B_0 - C_2 B'_0
\]

(3.78)

where

- \( C_0 \): be per unit operative time revenue by the system.
- \( C_1 \) & \( C_2 \): be per unit failed time expenditure on the system.

According to the data analysis of this particular real life situation, the behavior of the profit function has been studied through graphs by the fixed values of certain parameters \( r, p_1, p_2, a, C_0, C_1 \) and \( C_2 \) as

\[
r = 0.4, p_1 = 0.2, p_2 = 0.6, a = 0.4, C_0 = 800, C_1 = 200 \text{ and } C_2 = 400.
\]

The reliability measures of system effectiveness for above values are obtained as:

**Mean time to system failure (MTSF)** = 32.88889

**Availability** (\( A_0 \)) = 0.916869

**Busy period of Inspector** (\( B_0 \)) = 0.240156

**Busy period of repairman** (\( B'_0 \)) = 0.360233

**Profit** (\( P \)) = 270.6855

**Figure: 3.2** A graph reflects the behavior of mean time to system failure with respect to failure rate (\( p_1 \)) for different values of repair rate (\( r \)) i.e. mean time to system failure decrease with increase in failure rate.

**Figure: 3.3** A graph reflects the behavior of mean time to system failure with respect to repair rate (\( r \)) for different values of failure rate (\( p_1 \)) i.e. mean time to system failure increases with increase in repair rate.

**Figure: 3.4** A graph reflects the behavior of Profit function with respect to failure rate (\( p_1 \)) for different values of repair rate (\( r \)) i.e. Profit decreases with increase in failure rate.
Figure: 3.5  A graph reflects the behavior of Profit function with respect to repair rate \((r)\) for different values of failure rate \((p_1)\) i.e. Profit increases with increase in repair rate.

3.8 CONCLUSION

By the means of this model following observations have been observed for profit function w.r.t different repair and failure rate:

Profit w.r.t Failure rate:
- For \(r = 0.3\), profit function \(P > or = or < 0\) as the failure rate \(p_1 < or = or > 0.7201\). So, the system is valid and useful, if its failure rate is less than 0.7201.
- For \(r = 0.35\), profit function \(P > or = or < 0\) as the failure rate \(p_1 < or = or > 0.8084\). So, the system is valid and useful, if its failure rate is less than 0.8084.
- For \(r = 0.4\), profit function \(P > or = or < 0\) as the failure rate \(p_1 < or = or > 0.958\). So, the system is valid and useful, if its failure rate is less than 0.958.

Profit w.r.t Repair rate:
- For \(p_1 = 0.2\), profit function \(P > or = or < 0\) as the repair rate \(r > or = or < 0.0956\). So, the system is valid and useful, if its repair rate is greater than 0.0956.
- For \(p_1 = 0.3\), profit function \(P > or = or < 0\) as the repair rate \(r > or = or < 0.1309\). So, the system is valid and useful, if its repair rate is greater than 0.1309.
- For \(p_1 = 0.4\), profit function \(P > or = or < 0\) as the repair rate \(r > or = or < 0.1516\). So, the system is valid and useful, if its repair rate is greater than 0.1516.

This chapter concluded with the result that the preventive maintenance of units will increase the availability and profit of the system.
Figure: 3.2: MTSF vs FAILURE RATE

Figure: 3.3: MTSF vs REPAIR RATE
Figure 3.4: PROFIT vs FAILURE RATE

Figure 3.5: PROFIT vs REPAIR RATE