CHAPTER - 2

Availability and Behavioral Analysis of a Dairy Plant With Priority in Repair Using RPGT

2.1 Introduction: -Now a days, manufacturers have to produce their products uninterruptedly to meet the ever increasing demands of their products. They can do so by making their production units as efficient as possible. In this chapter we discusses the Availability and Behavioral Analysis of a Dairy Plant divided into two units using Regenerative Point Graphical Technique. Mean Time to system failure, Availability, busy period of server, Number of server visits are evaluated using Regenerative Point Graphical Technique (RPGT). A profit function is also defined for analyzing the profit of the system.

Gupta, Singh and Vanita [38] defined different types of circuits / cycles like primary, secondary and tertiary circuits which are located in the transition diagram of the system and introduced the concept of base state of the system for determining the key parameters of the system using RPGT. Using RPGT Jindal [45] discussed behavior and availability analysis of industrial systems. Gupta and Singh [47] presented a new approach for availability analysis, behavior and profit analysis of process industries. Goel and Singh [46] discussed the availability analysis of the standby complex system having imperfect switch. Nidhi, Goel & Garg [69] discussed Availability Analysis of a Soap Industry Using Regenerative Point Graphical Technique (RPGT).

Here, The Dairy Plant is divided two unit ‘A’ and ‘B’ in which unit ‘A’ is milk producing unit and other subsidiary products like milk water, Cream, Ghee etc are produced by unit ‘B’. As milk is the main demand of market so unit ‘A’ is the main unit of system, so we try to keep unit ‘A’ in working as far as possible, therefore we give priority in repair to unit ‘A’ over unit ‘B’. The system is in working state if at least one unit is in working state and fails when both units fail. Nothing can fail when the system is in failed state. When both units are working the system is good otherwise it
may be working in reduced state or failed state. If any unit of the system fails the system
works in reduced capacity and the failed unit is immediately put under repair. Repairs are
perfect i.e. repair does not damage to any part of the system. The repaired unit works like
a new one. Further if both ‘A’ and ‘B’ units of system are in failed system, then repair to
unit ‘A’ is given priority in repair over ‘B’. The distributions of the failure times and
repair times are exponential and general respectively and also different for units ‘A’ and
‘B’. These are also assumed to be independent of each other.

A transition diagram of the systems is drawn to find h t primary circuit, secondary circuit,
tertiary circuit and ‘base state’. The system is discussed for steady-state conditions, Using
Regenerative Point Graphical Technique various parameters of the system are evaluated.
Expression for profit function of the system is also given. Some special cases are
discussed to depict the behavior of the system. Some particular cases, tables and graphs
followed by discussion are given.

2.2 Assumptions and Notations: - Assumptions and Notations are:

1. The system consists of two non – identical units ‘A’ and ‘B’. ‘A’ is main unit and
‘B’ unit is subsidiary.
2. A single repair facility is available for both units ‘A’ and ‘B’.
3. The distributions of failure times and repair times are exponential and general
respectively and also different for units ‘A’ and ‘B’. Failures and repairs are
statistically independent.
4. Repair is perfect i.e. it does not damage any units during repair.
5. Repaired units to be good.
6. When both units fail then the system is in failed state.
7. Nothing can fail when the system is in failed state. After the failure of any one
unit the system works in reduced state.
8. When both units ‘A’ and ‘B’ are in failed state then repairman repair unit ‘A’ on
priority basis.
9. The system is discussed for steady-state conditions.
10. Upon failure, if main unit ‘A’ is under repair and unit ‘B’ also fails it joins the
queue of the failed unit.
11. Both the units cannot fail simultaneously.

: A circuit formed through un-failed states.

m-cycle: A circuit (may be formed through regenerative or non-regenerative / failed state) whose terminals are at the regenerative state m.

m-: A circuit (may be through un-failed regenerative or non-regenerative state) whose terminals are at the regenerative m state.

( ← ) : 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.

( ← ) : 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.

: Probability factor of the state m reachable from the terminal state m of the m-.

R_j(t) : Reliability of the system at time t, given that the system entered the un-failed regenerative state ‘j’ at t = 0.

A_j(t) : Probability of the system in up time at time ‘t’, given that the system entered regenerative state ‘j’ at t = 0.

B_j(t) : Reliability that the server is busy for doing a particulars job at time ‘t’; given that the system entered regenerative state ‘j’ at t = 0.

V_j(t) : The expected no. of server visits for doing a job in (0,t] given that the system entered regenerative state ‘j’ at t = 0.

W_j(t) : Probability that the server is busy doing a particular job at time t without transiting to any other regenerative state ‘j’ through one or more non-regenerative states, given that the system entered the regenerative state ‘j’ at t = 0.

: The Mean sojourn time spent in state j, before visiting any other states;

= \int ( )
: The total un-conditional time spent before transiting to any other regenerative states, given that the system entered regenerative state ‘j’ at t=0.

: Expected waiting time spent while doing a given job, given that the system entered regenerative state ‘j’ at t=0; ( )

: Fuzziness measure of the j-state.

λ/ λ₁ : Constant failure rate of units A/ of unit B.

g(t)/G(t) / (t) : Probability density function/ Cumulative distribution function /
complement of the repair – time of unit A.

h(t)/H(t) /̅(t) : Probability density function / Cumulative distribution function /
complement of the repair time of the unit B.

A/a : Main unit in the operative state / failed state.

B/b : Operative state / failed state.
2.3 Transition Diagram:
Considering the above assumptions and notations the Diagram of the system is

![Diagram of the system]

Figure – 2.1

<table>
<thead>
<tr>
<th>State</th>
<th>Symbol</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regenerative State/Point</td>
<td>![Symbol]</td>
<td>0-3</td>
</tr>
<tr>
<td>Up-state</td>
<td>![Symbol]</td>
<td>0</td>
</tr>
<tr>
<td>Failed State</td>
<td>![Symbol]</td>
<td>2</td>
</tr>
<tr>
<td>Reduced State</td>
<td>![Symbol]</td>
<td>1,3</td>
</tr>
</tbody>
</table>

Table 2.1

The states of the system with respect to the above figure.

\[
S_0 \quad = \quad AB \\
S_1 \quad = \quad Ab \\
S_2 \quad = \quad ab \\
S_3 \quad = \quad aB
\]

States \( S_0 \), \( S_1 \), \( S_2 \), and \( S_3 \) are regenerative states.

The possible transitions between states along with transition time c. d. f’s are shown in Fig.2. 1.
Possible simple paths from state ‘i’ to reachable state ‘j’ are given in table 2.2.

**Simple Paths from State ‘i’ to the Reachable State ‘j’: P0**

<table>
<thead>
<tr>
<th>Vertex</th>
<th>j = 0</th>
<th>j = 1</th>
<th>j = 2</th>
<th>j = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(0,1,0),(0,3,0),(0,3,2,1,0)</td>
<td>(0,1),(0,3,2,1)</td>
<td>(0,1,2),(0,3,2)</td>
<td>(0,3)</td>
</tr>
<tr>
<td>1</td>
<td>(1,0)</td>
<td>(1,0,1),(1,2,1),(1,0,3,2,1)</td>
<td>(1,2),(1,0,3,2)</td>
<td>(1,0,3)</td>
</tr>
<tr>
<td>2</td>
<td>(2,1,0)</td>
<td>(2,1)</td>
<td>2,1,2),(2,1,0,3,2)</td>
<td>(2,1,0,3)</td>
</tr>
<tr>
<td>3</td>
<td>(3,0),(3,2,1,0)</td>
<td>(3,0,1),(3,2,1)</td>
<td>(3,2),(3,0,1,2)</td>
<td>(3,0,3),(3,2,1,0,3)</td>
</tr>
</tbody>
</table>

Table 2.2

Possible Primary, Secondary, Tertiary circuits at a vertex ‘i’ are given in table 2.3.

**Primary, Secondary, Tertiary Circuits at a Vertex**

<table>
<thead>
<tr>
<th>Vertex i</th>
<th>Primary (CL1)</th>
<th>Secondary (CL2)</th>
<th>Tertiary (CL3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(0,1,0)</td>
<td>(1,2,1)</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>(0,3,0)</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>(0,3,2,1,0)</td>
<td>(2,1,2)</td>
<td>Nil</td>
</tr>
<tr>
<td>1</td>
<td>(1,0,1),</td>
<td>(0,3,0)</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>(1,2,1),</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>(1,0,3,2,1)</td>
<td>(0,3,0)</td>
<td>Nil</td>
</tr>
<tr>
<td>2</td>
<td>(2,1,2),</td>
<td>(1,0,1)</td>
<td>(0,3,0)</td>
</tr>
<tr>
<td></td>
<td>(2,1,0,3,2)</td>
<td>(0,3,0)</td>
<td>Nil</td>
</tr>
<tr>
<td>3</td>
<td>(3,2,1,0,3),</td>
<td>(2,1,2)</td>
<td>(1,0,1)</td>
</tr>
<tr>
<td></td>
<td>(3,0,3)</td>
<td>(1,0,1)</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0,1,0)</td>
<td>(1,2,1)</td>
</tr>
</tbody>
</table>

Table 2.3
Analysis table of Primary, Secondary & Tertiary circuits to determine the base state is given in table 2.4

Analysis table of Primary, Secondary and Tertiary Circuits to find base state.

<table>
<thead>
<tr>
<th>Vertex i</th>
<th>No. of Primary Circuits</th>
<th>No. of Secondary Circuits</th>
<th>No. of Tertiary Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2.4

From above table we conclude that we can take ‘0’ or ‘1’ as base state. We take ‘0’ as base state.

Primary, Secondary and Tertiary circuits w.r. to simple path (‘0’ as base state) are given in table 2.5

<table>
<thead>
<tr>
<th>Vertex j</th>
<th>(S_R \rightarrow j):P0</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(S_1 \rightarrow 1):(0,1) (S_2 \rightarrow 1):</td>
<td>(1,2,1)</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>(0,1)</td>
<td>(2,1,2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(S_1 \rightarrow 2):(0,1,2) (S_2 \rightarrow 2):(0,3,2)</td>
<td>(1,2,1)</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td></td>
<td>(0,1,2)</td>
<td>(2,1,2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>(S_1 \rightarrow 3):(0,3)</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Table 2.5

Transition Probability and the Mean sojourn times.

\(q_{m,n}(t)\): The probability density function (p.d.f.) of the first passage time from a regenerative state ‘m’ to a regenerative state ‘n’ or to a failed state ‘n’ without visiting any other regenerative state in time interval (0,t].
For a regenerative process, the steady state transition probability from a regenerative state ‘m’ to a regenerative state ‘n’ without visiting any other regenerative state, is given by:

\[ p_{m,n} = (0) \]

where * denotes Laplace transformation.

The solutions of the equations for the characteristic function given by 

\[ q_{m,n}(t) = \frac{\lambda_1 e^{-(\lambda_1 + 1)t}}{\lambda_1 + 1} \]

\[ p_{m,n} = q_{m,n}^*(0) \]

are:

\[ q_{0,0}(t) = \lambda_1 e^{-(\lambda_1 + 1)t} \]
\[ q_{0,1}(t) = \lambda_1 e^{-(\lambda_1 + 1)t} \]
\[ q_{2,1}(t) = g(t) \]
\[ q_{1,0}(t) = h(t) e^{-(\lambda_1 + 1)t} \]
\[ q_{1,2}(t) = \lambda e^{-(\lambda_1 + 1)t} \]
\[ q_{3,0}(t) = g(t) e^{-(\lambda_1 + 1)t} \]
\[ q_{3,2}(t) = \lambda_1 e^{-(\lambda_1 + 1)t} \]

**Table 2.6**

\[ p_{0,1} + p_{0,3} = \frac{\lambda_1}{\lambda_1 + 1} + \frac{\lambda_1}{\lambda_1 + 1} + \frac{\lambda_1}{\lambda_1 + 1} = 1 \]
\[ p_{1,0} + p_{1,2} = h^*(\lambda) + h^*(\lambda) = 1 \]
\[ p_{2,1} = 1 \]
\[ p_{3,0} + p_{3,2} = 1 \]

Hence it is verified that for each state total state probability is 1.

**Mean Sojourn Times**

\[ R_j(t) \] : The reliability of the system at time \( t \), given that the system is in regenerative state ‘\( j \)’.

\[ \mu_j = R_j^*(0) \]

\[ R_0(t) = e^{-(\lambda_1 + 1)t} \]
\[ R_1(t) = e^{\lambda_1 t} \]
\[ R_2(t) = (t) \]
\[ R_3(t) = e^{\lambda_1 t} \]

**Table 2.7**

2.4 **Evaluation of Parameters**: - The MTSF and all the key statistical parameters of the system under steady state conditions are evaluated, applying Regenerative Point Graphical Technique (RPGT) and using ‘0’ as the base-state of the system as under:
The transition probability factors of all the reachable states from the base state ‘0’ are:
\[ V_{0,0} = \frac{(0,1,0)}{[1-(1,2,1)] + (0,3,0) + (0,3,2,1,0)} = \frac{p_{0,1}}{p_{1,0} / (1 - p_{1,2} p_{2,1})} + p_{0,3} p_{1,0} + p_{0,3} p_{3,2} p_{2,1} / (1 - p_{2,1} p_{1,2}) \]
\[ = p_{0,1} / (1 - p_{1,2}) + p_{0,3} p_{3,2} / (1 - p_{1,2}) \]
\[ V_{0,1} = \frac{(0,1)}{[1-(1,2,1)] + (0,3,2,1) / [1-(2,1,2)]] = p_{0,1} / (1 - p_{1,2} p_{2,1}) + p_{0,3} p_{3,2} p_{2,1} / (1 - p_{2,1} p_{1,2}) \]
\[ = p_{0,1} + p_{0,3} p_{3,2} p_{2,1} / (1 - p_{1,2} p_{2,1}) = p_{0,1} - p_{0,1} p_{3,2} / (1 - p_{1,2}) \]
\[ = (1 - \lambda / \lambda + \lambda_1 (g^*(\lambda_1)) h^*(\lambda) \]
\[ V_{0,2} = \frac{(0,1,2)}{[1-(1,2,1)] + (0,3,2) / [(1-(2,1,2)] = p_{0,1} p_{1,2} / (1 - p_{1,2} p_{2,1} p_{3,2}) \]
\[ = p_{0,1} p_{1,2} / (1 - p_{1,2}) + p_{0,3} p_{3,2} / (1 - p_{1,2}) \]
\[ = p_{0,1} p_{1,2} + p_{0,3} p_{3,2} / (1 - p_{1,2}) = \lambda_1 / \lambda + \lambda_1 (1 - \lambda + \lambda_1 + \lambda / \lambda + \lambda_1 [(1 - g^*(\lambda_1))] \]
\[ = \lambda_1 / \lambda + \lambda_1 \lambda_1 (1 - \lambda + \lambda_1 + \lambda h^*(\lambda)) / \lambda + \lambda_1 \lambda_1 (1 - \lambda + \lambda_1 + \lambda_1 h^*(\lambda)) / \lambda \]
\[ V_{0,3} = (0,3) = p_{0,3} = \lambda / \lambda + \lambda_1 \]

(i) MTSF(T0): From Fig.2.1, the regenerative un-failed states to which the system can transit (initial state ‘0’), before entering any failed state are: i = 0,1,3 taking ‘\( \xi \)' = ‘0’.

\[ \text{MTSF}(T_0) = \left[ \sum_{i,\xi} \left[ \frac{\{p_r(\xi^r_{i,\xi})\}}{\Pi_{m_2 \neq \xi} (1 - V_{m_2, m_2})} \right] \right] + \left[ 1 - \sum_{\xi} \left[ \frac{\{p_r(\xi^r_{i,\xi})\}}{\Pi_{m_2 \neq \xi} (1 - V_{m_2, m_2})} \right] \right] \] 2.4.1
\[ T_0 = [(0,0) \mu_0 + (0,1) \mu_1 + (0,3) \mu_3] / [1-(0,1,0) + (0,3,0)] \]

(ii) Availability of the System (A0): From figure 2.1 the regenerative states at which the system is available are j = 0,1,3, and regenerative states are i = 0-3 taking ‘\( \xi \)' = ‘0’,

\[ A_0 = \left[ \sum_{i,\xi} \left[ \frac{\{p_r(\xi^r_{i,\xi})\}}{\Pi_{m_2 \neq \xi} (1 - V_{m_2, m_2})} \right] \right] + \left[ \sum_{i,\xi} \left[ \frac{\{p_r(\xi^r_{i,\xi})\}}{\Pi_{m_2 \neq \xi} (1 - V_{m_2, m_2})} \right] \right] \] 2.4.2
\[ A_0 = \left[ \sum_{\xi} V_{\xi, \xi} f_{\xi, \xi} \right] + \left[ \sum_{\xi} \left[ V_{\xi, \xi} \mu_0 \right] \right] \]
\[ A_0 = V_{0,0} f_0 \mu_0 + V_{0,1} f_1 \mu_1 + V_{0,3} f_3 \mu_3 / V_{0,0} \mu_0 + V_{0,1} \mu_1 + V_{0,2} \mu_2 + V_{0,3} \mu_3 \]

(where \( f_j = 1, j = j \) for all j)

\[ A_0 = f_0 \mu_0 + V_{0,1} f_1 \mu_1 + p_{0,3} f_3 \mu_3 / \mu_0 + V_{0,1} \mu_1 + V_{0,2} \mu_2 + p_{0,3} \mu_3 \]
(iii). **Busy Period of the Server**: From Fig.2.1, the regenerative states where Server is busy while doing repairs are: \( j = 1, 2, 3 \) and the regenerative states are: \( i = 0, 1, 2, 3 \) taking \( \xi_j = '0' \)

\[
B_0 = \left[ \sum_{j=1}^{3} \left\{ \frac{[pf_r(t_{j-2})]}{\Pi_{m_2=1}^{m_2}} \right\} \right] + \left[ \sum_{j=1}^{3} \left\{ \frac{[pf_r(t_{j-2})]}{\Pi_{m_2=1}^{m_2}} \right\} \right]
\]

\[
= V_{01} \eta_1 + V_{02} \eta_2 + V_{03} \eta_3 / \mu_0 + V_{01} \mu_1 + V_{02} \mu_2 + V_{03} \mu_3
\]

\[
B_0 = V_{01} \eta_1 + V_{02} \eta_2 + V_{03} \eta_3 / \mu_0 + V_{01} \mu_1 + V_{02} \mu_2 + V_{03} \mu_3
\]

\[
(\text{where } \eta_j = \mu_j, \text{ for all } j)
\]

(iv). **Expected Number of Server’s Visits**: From Fig.2.1, the Regenerative States where the Server visits (afresh) for repairs of the system are: \( j = 3 \) and the Regenerative States are: \( i = 0, 1, 2, 3 \) taking \( \xi_j = '0' \), the Expected number of Server Visits per unit time is given by

\[
V_0 = \left[ \sum_{r=0}^{2} \left\{ \frac{1}{\Pi_{m_1=1}^{m_1}} \right\} \right] \left[ \sum_{r=0}^{2} \left\{ \frac{1}{\Pi_{m_1=1}^{m_1}} \right\} \right]
\]

\[
= \sum_{j=1}^{3} \sum_{r=1}^{\beta} (\text{where } \beta = \sum_j \mu_j)
\]

\[
2.5 \text{ PROFIT FUNCTION}: \text{ The profit analysis of the system can be done by using the profit function:}
\]

The profit \( P \) per unit time is as \( P = K_1 A_0 - K_2 B_0 - K_3 V_0 \)

Where \( K_1 = \text{Revenue per unit of time the system is available.} \)

\( K_2 = \text{Cost per unit time the server remains busy for the repairs.} \)

\( K_3 = \text{Cost per visit of the server.} \)

2.6 TAKING PARTICULAR CASE:

Let

\[
g(t) = we^{-wt}, \quad h(t) = wte^{-w}\frac{1}{t}
\]

We have

\[
p_{0,1} = \lambda_1 / \lambda + \lambda_1, \quad p_{1,2} = \lambda / (w_1 + \lambda), \quad p_{3,2} = \lambda_1 / (\lambda_1 + w) \quad p_{0,3} = \lambda / \lambda + \lambda_1,
\]

\[
p_{2,1} = 1, \quad p_{1,0} = w_1 / \lambda + w_1, \quad p_{3,0} = w / w + \lambda_1
\]
\[ \mu_0 = \frac{1}{\lambda + \lambda_1}, \quad \mu_1 = \frac{1}{\lambda + w}, \quad \mu_2 = \frac{1}{w}, \quad \mu_3 = \frac{1}{\lambda + w} \]

Using these results, we get the following

Tables, graphs and conclusions are obtained for

\[ \lambda = \lambda_1 \]
\[ w = w_1 \]

2.6.1 MSTF \( (T_o) \) For different values of failure and repair rates.

\[ \text{MTSF} \ (T_0) = \frac{3\ (\lambda + w)}{2\lambda^2} \]

MTSF Vs Repair and Failure Rate: - The MTSF of the system is calculated for different values of the failure rate \( (\lambda) \) by taking \( \lambda = 0.05, 0.06, 0.07 \) & \( 0.08 \) and for different values of the repair rate \( (w) \) by taking \( w = 0.80, 0.85, 0.90 \) & \( 1.00 \). The data so obtained is shown in table 2.8.

<table>
<thead>
<tr>
<th>( \Lambda )</th>
<th>( (\omega=0.80) )</th>
<th>( (\omega=0.85) )</th>
<th>( (\omega=0.90) )</th>
<th>( (\omega=1.00) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>190.000</td>
<td>200.000</td>
<td>210.000</td>
<td>230.000</td>
</tr>
<tr>
<td>0.06</td>
<td>136.111</td>
<td>143.055</td>
<td>150.000</td>
<td>163.890</td>
</tr>
<tr>
<td>0.07</td>
<td>103.061</td>
<td>108.163</td>
<td>113.265</td>
<td>123.469</td>
</tr>
<tr>
<td>0.08</td>
<td>81.250</td>
<td>85.156</td>
<td>89.063</td>
<td>96.875</td>
</tr>
</tbody>
</table>

Table 2.8

Table 2.8 shows the behavior of MTSF \( (T_o) \) Vs Repair rate \( (w) \) of the unit of the system for different values of the failure rate \( (\lambda) \). From the above table we can conclude that MTSF is increasing which should be so when the repair rate increasing and decreases when the failure rate increases which should be so in practical situations.
From figure 2.2 it can be concluded that MTSF is increasing when repair rates increase and decreasing when failure rates increasing.
### 2.6.2 Availability ($A_0$) Vs Repair Rate ($w$) and Failure Rate:

The availability of the system is calculated for different values of the failure rate ($\lambda$) by taking $\lambda = 0.05, 0.06, 0.07, 0.08, 0.09$ & $0.10$ and for different values of the repair ($w$) by taking $w = 0.80, 0.85, 0.90, 0.95$ & $1.00$. The data so obtained is shown in Table (2.9).

**Availability ($A_0$)**

\[
A_0 = \frac{1 - 2\lambda^2 (\lambda + w)}{[2\lambda^2 (2w + \lambda)]} + [w^2 (3\lambda + w)]
\]

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$w=0.80$</th>
<th>$w=0.85$</th>
<th>$w=0.90$</th>
<th>$w=0.95$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.893561</td>
<td>0.899207</td>
<td>0.904283</td>
<td>0.908873</td>
</tr>
<tr>
<td>0.06</td>
<td>0.875942</td>
<td>0.882407</td>
<td>0.888231</td>
<td>0.893506</td>
</tr>
<tr>
<td>0.07</td>
<td>0.859302</td>
<td>0.866511</td>
<td>0.873017</td>
<td>0.87892</td>
</tr>
<tr>
<td>0.08</td>
<td>0.843558</td>
<td>0.851447</td>
<td>0.858578</td>
<td>0.865056</td>
</tr>
<tr>
<td>0.09</td>
<td>0.828639</td>
<td>0.837149</td>
<td>0.844854</td>
<td>0.851864</td>
</tr>
<tr>
<td>0.10</td>
<td>0.814480</td>
<td>0.823559</td>
<td>0.831793</td>
<td>0.839293</td>
</tr>
</tbody>
</table>

**Table 2.9**

The above table shows that the availability of the system is increasing when the repair rate is increasing and decreases with the increase in failure rate, which should be actually.
From figure 2.3 it can be concluded that availability is increasing when repair rates increase and decreasing when failure rates increasing.
2.6.3 Busy Period of Server vs Repair Rate & Failure Rate: Busy period of server for different values of failure and repair rates the of time for which the server will remain busy is given in table – 2.10. The busy period of server is calculated for different values of the failure rate (λ) by taking λ = 0.05, 0.06 and 0.07 and for different values of the repair rate (w) by taking w = 0.80, 0.85, 0.90 & 0.95. The data obtained is shown in table below 2.10.

\[ B = 1 - \lambda w^2 (\lambda + w) / 2 (\lambda + w - \lambda w) [ 2\lambda (\lambda + w) + w^2 ] + \lambda w^2 (\lambda + w) \]

<table>
<thead>
<tr>
<th>( \Lambda )</th>
<th>(( \omega = 0.80 ))</th>
<th>(( \omega = 0.85 ))</th>
<th>(( \omega = 0.90 ))</th>
<th>(( \omega = 0.95 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.977365399</td>
<td>0.977199411</td>
<td>0.977050745</td>
<td>0.97691683</td>
</tr>
<tr>
<td>0.06</td>
<td>0.983367330</td>
<td>0.983133382</td>
<td>0.982923509</td>
<td>0.982734189</td>
</tr>
<tr>
<td>0.07</td>
<td>0.999530633</td>
<td>0.999219041</td>
<td>0.998939055</td>
<td>0.998686122</td>
</tr>
</tbody>
</table>

**Table 2.10**

The table shows that when we increase in repair rate then busy period of server is decreasing i.e. there is a negative relationship between repair rate and busy period of server and we increase in failure rate then busy period of server is increasing.
The above figure 2.4 shows that when we increase in repair rate then busy period of server is decreasing i.e. there is a negative relationship between repair rate and busy period of server and we increase in failure rate then busy period of server is increasing.
2.7 Conclusion: From the graphs and tables, we see that when we increase in the repair rate (w) which increases the availability of the system. The study can be extended to more than two units system; the Regenerative Point Graphical Technique is useful to evaluate the key parameters of the system in a simple way, without writing any state equations and without doing any lengthy and cumbersome calculations. In future, Researchers can evaluate the parameters, when repair rate and failure rate are variable and also discuss the cost and profit benefit analysis. Further results can also be applied to find the waiting time of units and number of server visits, as if the states where the server is on prime visit or on a secondary visit are determined separately using the formula. Since the cost of secondary visit is usually less than primary visit of server, therefore the system can be run with low maintenance cost. Various system parameters can also be evaluated taking any state as base state. Fixing the target of availability management can cost of maintenance.