TWO UNIT COLD STANDBY SYSTEM WITH WARRANTY

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ABSTRACT

The Present paper deals with the analysis of a two unit standby system with warranty concept. In this system there is an assumption that the operating unit fails under warranty period due to bad assembling then it is sent for repair. But if it fails due to failure of any component in the warranty period then it is sent for replacement. Failure time distributions of operating unit under warranty and after warranty are exponential. Repair and replacement time distributions are general. Using the regenerative point technique in Markov renewal process, the various reliability characteristics of the system model under study are obtained.

Kew words : Markov Renewal Process, Warranty, Availability, Busy period**.**

INTRODUCTION

Various authors [2, 5, 7, 10] have analysed several reliability models in which failed units are repaired. But in the present study the idea of warranty period and replacement is incorporated . Keeping this idea in mind we develop an engineering system which consist of two units with configuration that one is operative and other as cold standby. If the operative unit fails in the warranty period due to bad assembling, then it is sent for repair. But if operative unit fails due to failure of any component in the warranty period then it is sent for replacement which is free of cost. If operative unit fails due to any types after warranty period, then it is sent for repair. A single repair facility is used for repair and replacement policies and using regenerative point technique in Marokov renewal process, the following reliability measures are obtained.

(i) Transient and steady state transition probabilities.

(ii) Mean sojourn time

(iii) Mean time to system failure

(iv) Pointwise and steady state availability of the system

(v) Expected busy period of the repairman in time interval (o, t]

(vi) Expected number of visits by the repairman in (o, t]

(vii) Profit analysis of the system.

MODEL DESCRIPTION AND ASSUMPTIONS

(i) The system consists of two identical units initially one unit is operative and the other as cold standby.

(ii) Upon a failure of an operative unit, cold standby unit takes a random amount of time to become operative.

(iii) If the operatiove unit fails due to bad assembling, it is sent for repair.

(iv) If the operative unit fails due to failure of any component in the warranty period, it is sent for replacement.

(v) If the operative unit fails due to failure of any component after warranty period, it is sent for repair.

(vi) The repair and replacement time distribution for failed unit are general.

(vii) Failure rate of operative unit are constant.

(viii) A single repairman facility is used for repair and replacement.

NOTATIONS AND STATES

α_1, α_2, α_3 — constant failure rates of the operative unit when it fails due to bad assembling, component fails in warranty period and after warranty period respectively.

f (.), F (.) — P.d.f and c.d.f. of time to complete the repair of bad assembling.

g (.), G (.) — P.d.f. and c.d.f of time to complete the replacement.

h (.), H (.) — P.d.f. and c.d.f of time to complete the repair after warranty period.

m_1, m_2, m_3 — Mean time for repair of bad assembling, replacement and repair after warranty period respectively.

N_O — Normal unit kept as operative.

N_S — Normal unit kept as cold standby.

F_{r_1} — Failed unit caused by bad assembling is under repair.

F_{r_2} — Failed unit caused by failure of any component in the warranty period is under replacement.

F_{r_3} — Failed unit caused by failure of any component after warranty period is under repair.

F_{wr_1} — Failed unit caused by bad assembling is waiting for repair.

F_{wr_2} Failed unit caused by failure of any component in the warranty period is waiting for replacement.

F_{wr_3} Failed unit caused by failure of any component after warranty period is waiting for repair.

F_{R_1} Repair of failed unit caused by bad assembling is continued from earlier state.

F_{R_2} Replacement of failed unit caused by failure of any component in the warranty period is continued from earlier state.

F_{R_3} Repair of failed unit caused by failure of any component after warranty period is continued from earlier state.

Using above notations and assumptions the possible states of the system are.

UP States

S_0 : (N_o, N_s) , S_1 : (N_o, F_{r_1})

S_2 : (N_o, N_{r_2}) , S_3 : (N_o, F_{r_3})

Down States

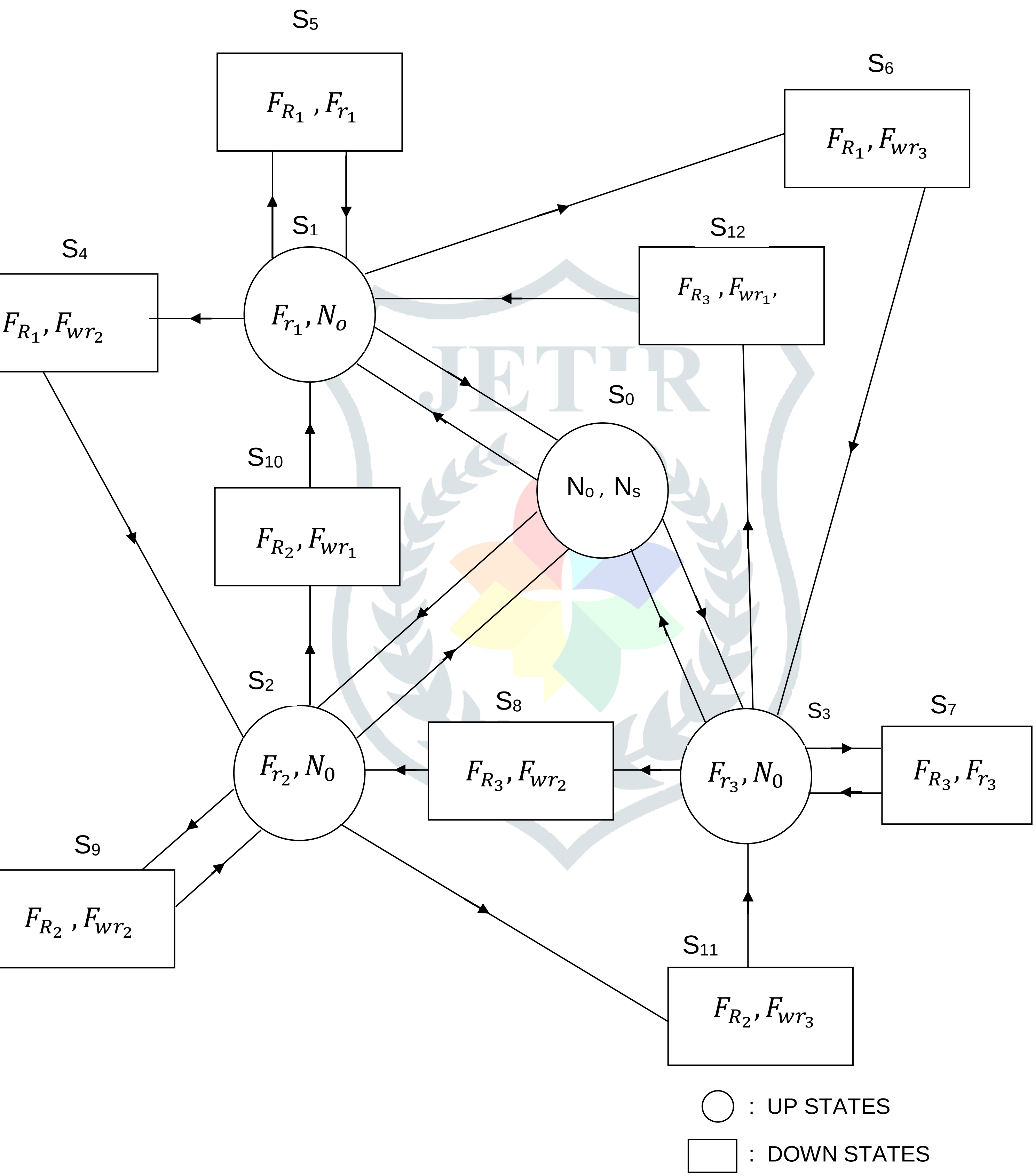
S_4 : (F_{R_1}, F_{r_2}) , S_5 : (F_{R_1}, F_{wr_1}) , S_6 : (F_{R_1}, F_{wr_3})

S_7 : (F_{R_3}, F_{wr_3}) , S_8 : (F_{R_3}, F_{wr_2}) , S_9 : (F_{R_2}, F_{wr_2})

S_{10} : (F_{R_2}, F_{wr_1}) , S_{11} : (F_{R_2}, F_{wr_3}) , S_{12} : (F_{R3}, F_{wr_1})

The states S_0, S_1, S_2 and S_3, are regenerative while S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11} and S_{12}, are non-regenerative states. The possible states and transitions between them are shown in the following figure.

Transition Diagram



TRANSITION AND STEADY STATE PROBABILITIES

The non zero elements of the transition probability, $P = (P_{ij})$ are given as under

$$P_{01} = \frac{\alpha_1}{\alpha_1+\alpha_2+\alpha_3} = \frac{\alpha_1}{\sum \alpha_i}, \qquad \because \sum \alpha_i = \alpha_1 + \alpha_2 + \alpha_3$$

$$P_{02} = \frac{\alpha_2}{\sum \alpha_i}, \quad P_{03} = \frac{\alpha_3}{\sum \alpha_i}, \quad P_{10} = f^*(\sum \alpha_i)$$

$$P_{14} = \frac{\alpha_2}{\sum \alpha_i}[1 - f^*(\sum \alpha_i)] = P_{12}^{(4)}$$

$$P_{15} = \frac{\alpha_1}{\sum \alpha_i}[1 - f^*(\sum \alpha_i)] = P_{11}^{(5)}$$

$$P_{16} = \frac{\alpha_3}{\sum \alpha_i}[1 - f^*(\sum \alpha_i)] = P_{13}^{(6)}$$

$$P_{20} = g^*(\sum \alpha_i), \quad P_{29} = \frac{\alpha_2}{\sum \alpha_i}[1 - g^*(\sum \alpha_i)] = P_{22}^{(10)}$$

$$P_{2,10} = \frac{\alpha_1}{\sum \alpha_i}[1 - g^*(\sum \alpha_i)] = P_{21}^{(10)}$$

$$P_{2,11} = \frac{\alpha_3}{\sum \alpha_i}[1 - g^*(\sum \alpha_i)] = P_{23}^{(11)}$$

$$P_{30} = h^*(\sum \alpha_i), \qquad P_{37} = \frac{\alpha_3}{\sum \alpha_i}[1 - h^*(\sum \alpha_i)] = P_{33}^{(7)}$$

$$P_{38} = \frac{\alpha_2}{\sum \alpha_i}[1 - h^*(\sum \alpha_i)] = P_{32}^{(8)}$$

$$P_{3,12} = \frac{\alpha_1}{\sum \alpha_i}[1 - h^*(\sum \alpha_i)] = P_{31}^{(12)}$$

$$P_{42} = P_{51} = P_{61} = P_{73} = P_{82} = P_{92} = 1$$

$$P_{10,1} = P_{11,3} = P_{12,1} = 1$$

The above probabilities satisfies the following relations :

$$P_{01} + P_{02} + P_{03} = 1$$

$$P_{10} + P_{14} + P_{15} + P_{16} = 1 = P_{10} + P_{11}^{(5)} + P_{12}^{(4)} + P_{13}^{(6)}$$

$$P_{20} + P_{29} + P_{2,10} + P_{2,11} = 1 = P_{20} + P_{21}^{(10)} + P_{22}^{(9)} + P_{23}^{(11)}$$

$$P_{30} + P_{37} + P_{38} + P_{3,12} = 1 = P_{30} + P_{31}^{(12)} + P_{32}^{(8)} + P_{33}^{(7)}$$

Mean Sojourn Time

Mean sojourn time μ_i in state $S_i \in E$ is defined as the expected time for which the system stays in state S_i before transiting to any other state. If T_i denotes the sojourn time in state S_i , then the mean sojourn time is given by

$$\mu_i = E[T] = \int P\,[T_i > t]dt$$

Thus, the mean sojourn time in regenerative state i are,

$$\mu_0 = \frac{1}{\sum \alpha_i} \quad , \quad \mu_1 = \frac{1}{\sum \alpha_i} \; [1 - f^*(\textstyle\sum \alpha_i)]$$

$$\mu_2 = \frac{1}{\sum \alpha_i} \; [1 - g^*(\textstyle\sum \alpha_i)]$$

$$\mu_3 = \frac{1}{\sum \alpha_i} \; [1 - h^*(\textstyle\sum \alpha_i)]$$

The conditional mean sojourn time in state S_i , given that the system is to transit to state S_j , we mathematically define as

$$m_{ij} = \int tdQ(t)$$

Thus, we have

$$m_{01} = \frac{\alpha_1}{(\sum \alpha_i)^2} \;,\; m_{02} = \frac{\alpha_2}{(\sum \alpha_i)^2} \;,\; m_{03} = \frac{\alpha_3}{(\sum \alpha_i)^2} \;,$$

$$m_{10} = \int te^{-(\sum \alpha_i)t}\, dF(t)$$

$$m_{14} = \frac{\alpha_2}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dF(t) - \frac{f^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{15} = \frac{\alpha_1}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dF(t) - \frac{f^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{16} = \frac{\alpha_3}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dF(t) - \frac{f^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{20} = \int te^{-(\sum \alpha_i)t}\, dG(t)$$

$$m_{29} = \frac{\alpha_2}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dG(t) - \frac{g^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{2,10} = \frac{\alpha_1}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dG(t) - \frac{g^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{2,11} = \frac{\alpha_3}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dG(t) - \frac{g^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{30} = \int te^{-(\sum \alpha_i)t}\, dH(t)$$

$$m_{37} = \frac{\alpha_3}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dH(t) - \frac{h^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{38} = \frac{\alpha_2}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dH(t) - \frac{h^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

$$m_{3,12} = \frac{\alpha_1}{\sum \alpha_i}\left[\frac{1}{\sum \alpha_i} - \int te^{-(\sum \alpha_i)t}\, dH(t) - \frac{h^*(\sum \alpha_i)}{\sum \alpha_i}\right]$$

It can be easily verified that

$$m_{01} + m_{02} + m_{03} = \mu_0$$

$$m_{10} + m_{14} + m_{15} + m_{16} = \mu_1$$

$$m_{10} + m_{11}^{(5)} + m_{12}^{(4)} + m_{13}^{(6)} = m_1$$

$$m_{20} + m_{29} + m_{2,10} + m_{2,11} = \mu_2$$

$$m_{20} + m_{21}^{(10)} + m_{22}^{(9)} + m_{23}^{(11)} = m_2$$

$$m_{30} + m_{37} + m_{38} + m_{3,12} = \mu_3$$

$$m_{30} + m_{31}^{(12)} + m_{32}^{(8)} + m_{33}^{(7)} = m_3$$

MEAN TIME TO SYSTEM FAILURE

To investigate the distribution function $\pi_i(t)$ of the time to system failure with starting state S_i , we regard the failed states as absorbing. By using the probabilistic arguments, the recursive relations among $\pi_i\,(t)$ are :

$$\pi_o\,(t) = Q_{01}(t)\$\,\pi_1(t) + Q_{02}(t)\$\,\pi_2(t) + Q_{03}(t)\$\,\pi_3(t)$$

$$\pi_1\,(t) = Q_{10}(t)\$\,\pi_0(t) + Q_{14}(t) + Q_{15}(t) + Q_{16}(t)$$

$$\pi_2\,(t) = Q_{20}(t)\$\,\pi_0(t) + Q_{29}(t) + Q_{2,10}(t) + Q_{2,11}(t)$$

$$\pi_3\,(t) = Q_{30}(t)\$\,\pi_0(t) + Q_{37}(t) + Q_{38}(t) + Q_{3,12}(t)$$

(1 – 4)

Taking Laplace – Stieltjes transform of (1 – 4) and solving them for $\tilde{\pi}_0(s)$ by omithing the arguments 's' for brevity, we get

$$MTSF = E(T) = \left.\frac{d\tilde{\pi}_o(s)}{ds}\right|_{S=0} = \frac{N_1}{D_1} \quad (5)$$

Where

$$N_1 = \mu_0 + P_{01}\,\mu_1 + P_{02}\,\mu_{02} + P_{03}\,\mu_3$$

and

$$D_1 = 1 - (P_{01}P_{10} + P_{02}P_{20} + P_{03}P_{30}) \quad (6-7)$$

AVAILABILITY ANALYSIS

If $M_i(i)$ defines the probability that the system is in a regenerative state, S_i remains up at least for time t without transiting to any other regenerative state, then

$$M_o(t) = e^{-(\sum \alpha_i)t}\,, \qquad M_1(t) = e^{-(\sum \alpha_i)t}\,\bar{F}(t)$$

$$M_2(t) = e^{-(\sum \alpha_i)t}\,\bar{G}(t), \quad M_3(t) = e^{-(\sum \alpha_i)t}\,\bar{H}(t)$$

By using the arguments of the theory of regenerative process, the pointwise availability $A_i(t)$ is satisfy the following recursive relations :

$$A_0(t) = M_0(t) + q_{01}(t)© A_1(t) + q_{02}(t)© A_2(t) + q_{03}(t)© A_3(t)$$

$$A_1(t) = M_1(t) + q_{10}(t)© A_0(t) + q_{11}^{(5)}(t)© A_1(t) + q_{12}^{(4)}(t)© A_2(t)$$

$$+q_{13}^{(6)}(t)©\, A_3(t)$$

$$A_2(t) = M_2(t) + q_{20}(t)©\, A_0(t) + q_{21}^{(10)}(t)©\, A_1(t) + q_{22}^{(9)}(t)©\, A_2(t)$$

$$+q_{23}^{(11)}(t)©\, A_3(t)$$

$$A_3(t) = M_3(t) + q_{30}(t)©\, A_0(t) + q_{31}^{(12)}(t)©\, A_1(t) + q_{32}^{(8)}(t)©\, A_2(t)$$

$$+q_{33}^{(7)}(t)©\, A_3(t)$$

(8 - 11)

Taking the Laplace Transform of the above relation (8 – 11) and solving for $A_0^*(s)$. By omitting the arguments 's' for brevity, we have

$$A_0^*(s) = \frac{N_2(s)}{D_2(s)} \qquad (9)$$

The steady state availability of the system is given by

$$A_0 = \lim_{s \to 0} s\, A_0^*(s) = \frac{N_2(0)}{D_2'(0)} = \frac{N_2}{D_2} \qquad (10)$$

Where

$$N_2 = \mu_0 \left[\left(1 - P_{21}^{(5)}\right)\left\{\left(1 - P_{22}^{(9)}\right)\left(1 - P_{33}^{(7)}\right) - P_{23}^{(11)}\, P_{32}^{(8)}\right\} - P_{12}^{(4)} \times\right.$$

$$\left.\left\{P_{21}^{(10)}\left(1 - P_{33}^{(7)}\right) - P_{23}^{(11)} P_{31}^{(12)}\right\} - P_{13}^{(6)}\left\{P_{32}^{(8)} P_{21}^{(10)} + P_{31}^{(12)}\left(1 - P_{22}^{(9)}\right)\right\}\right]$$

$$+ \mu_1 \left[P_{01}\left\{\left(1 - P_{22}^{(9)}\right)\left(1 - P_{33}^{(7)}\right) - P_{23}^{(11)}\, P_{32}^{(8)}\right\}\right.$$

$$+ P_{02}\left\{P_{21}^{(10)}\left(1 - P_{33}^{(7)}\right) - P_{23}^{(11)}\, P_{31}^{(12)}\right\}$$

$$+ P_{03} \left\{ P_{32}^{(8)} P_{21}^{(10)} + P_{31}^{(12)} \left(1 - P_{22}^{(9)}\right) \right\} \Big]$$

$$+ \mu_2 \Big[P_{01} P_{12}^{(4)} (1 - P_{33}^{(7)}) + P_{01} P_{13}^{(6)} P_{32}^{(8)}$$

$$+ P_{02} \left(1 - P_{11}^{(5)}\right) \left(1 - P_{33}^{(7)}\right) + P_{02} P_{13}^{(6)} P_{31}^{(12)}$$

$$+ P_{03} \left(1 - P_{11}^{(5)}\right) P_{32}^{(8)} + P_{03} P_{31}^{(12)} P_{12}^{(4)} \Big]$$

$$+ \mu_3 \Big[P_{01} P_{12}^{(4)} P_{23}^{(11)} + P_{01} P_{13}^{(6)} \left(1 - P_{22}^{(9)}\right)$$

$$+ P_{02} P_{23}^{(11)} \left(1 - P_{11}^{(5)}\right) + P_{02} P_{13}^{(6)} P_{21}^{(10)}$$

$$+ P_{03} \left(1 - P_{11}^{(5)}\right) \left(1 - P_{22}^{(10)}\right) - P_{03} P_{12}^{(4)} P_{21}^{(10)} \Big]$$

and

$$D_2 = \mu_0 \Big[\left(1 - P_{33}^{(7)}\right) \left\{ P_{10} \left(1 - P_{22}^{(9)}\right) + P_{12}^{(4)} P_{20} \right\}$$

$$+ P_{13}^{(6)} \left\{ P_{30} \left(1 - P_{22}^{(9)}\right) + P_{32}^{(8)} P_{20} \right\}$$

$$+ P_{23}^{(11)} \left(P_{12}^{(4)} P_{30} - P_{10} P_{32}^{(8)} \right) \Big]$$

$$+ m_1 \Big[\left(1 - P_{22}^{(9)}\right) \left(1 - P_{33}^{(7)} - P_{03} P_{30}\right)$$

$$- P_{02} P_{20} \left(1 - P_{33}^{(7)}\right) - P_{32}^{(8)} \left(P_{23}^{(11)} + P_{03} P_{20} \right) - P_{02} P_{23}^{(11)} P_{30} \Big]$$

$$+ m_2 \Big[\left(1 - P_{33}^{(7)}\right) \left(P_{12}^{(4)} + P_{02} P_{10} \right)$$

$$+ P_{03} \left(P_{10} P_{32}^{(8)} - P_{12}^{(4)} P_{30} \right) + P_{13}^{(6)} \left(P_{32}^{(8)} - P_{02} P_{03} \right) \Big]$$

$$+ m_3 \left[\left(1 - P_{22}^{(9)}\right)\left(P_{13}^{(6)} + P_{03}\,P_{10}\right)\right.$$

$$\left. + P_{12}^{(4)}\left(P_{23}^{(11)} + P_{03}\,P_{20}\right) + P_{02}\left(P_{10}\,P_{23}^{(11)} - P_{13}^{(6)}\,P_{20}\right)\right]$$

BUSY PERIOD ANALYSIS

$B_i(i)$ is defined as the probability that the repairman is busy at epoch t starting from $S_i \in E$. From elementary probabilistic arguments , we get $B_0\,(t) = q_{01}(t)©B_1(t) + q_{02}(t)©B_2(t) + q_{03}(t)©B_3(t)$

$$B_1\,(t) = W_1(t) + q_{10}(t)©B_0(t) + q_{11}^{(5)}(t)©B_1(t) + q_{12}^{(4)}(t)©B_2(t)$$

$$+q_{13}^{(6)}(t)©B_3(t)$$

$$B_2\,(t) = W_2(t) + q_{20}(t)©B_0(t) + q_{21}^{(10)}(t)©B_1(t) + q_{22}^{(9)}(t)©B_2(t)$$

$$+ q_{23}^{(11)}(t)©B_3(t)$$

$$B_3\,(t) = W_3(t) + q_{30}(t)©B_0(t) + q_{31}^{(12)}(t)©B_1(t) + q_{32}^{(8)}(t)©B_2(t)$$

$$+ q_{33}^{(7)}(t)©B_3(t)$$

(11 – 14)

Where

$$W_1(t) = e^{-(\sum \alpha_i)t}\bar{F}(t) \quad , \quad W_2(t) = e^{-(\sum \alpha_i)t}\bar{G}(t)$$

$$W_3(t) = e^{-(\sum \alpha_i)t}\bar{H}(t)$$

Taking the Laplace Transform of the above equations (11 – 14) and solving for $B_0^*(s)$. By omitting the argument 's' for brevity, we obtain

$$B_0^*(s) = \frac{N_3\,(s)}{D_2\,(s)} \qquad (15)$$

The steady state busy period, when the system starts from S_i , is obtained as followes

$$B_0 = \lim_{s\to 0} s\, B_0^*(s) = \frac{N_3(o)}{D_2(o)} = \frac{N_3}{D_2} \tag{16}$$

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$$N_3 = \mu_1 \Big[\left(1 - P_{22}^{(9)}\right)\left\{\left(1 - P_{33}^{(7)}\right) - P_{03}P_{30}\right\} - P_{02}P_{20}\left(1 - P_{33}^{(7)}\right)$$

$$- P_{32}^{(8)} \left(P_{23}^{(11)} + P_{03}P_{20}\right) - P_{02}\, P_{30}\, P_{23}^{(11)}\Big]$$

$$+\mu_2 \Big[\left(1 - P_{33}^{(7)}\right) \left(P_{12}^{(4)} + P_{02}P_{10}\right) + P_{32}^{(8)}\left(P_{13}^{(6)} + P_{10}P_{03}\right)$$

$$+ P_{30} \left(P_{02}\ P_{13}^{(6)} - P_{03}\ P_{12}^{(4)}\right)\Big]$$

$$+\mu_3 \Big[\left(1 - P_{22}^{(9)}\right) \left(P_{13}^{(6)} + P_{03}P_{10}\right) + P_{23}^{(11)}\left(P_{12}^{(4)} + P_{02}P_{10}\right)$$

$$+ P_{20} \left(P_{03}\ P_{12}^{(4)} - P_{02}\ P_{13}^{(6)}\right)\Big]$$

And $D_2$is defined as availability analysis.

EXPECTED NUMBER OF VISITS BY THE REPAIRMAN

$V_i(t)$ is defined as the expected number of visits by the repairman in (0 , t] , given that the system initially starts from regenerative state S_i. Using Probabilistic arguments, we get the following recursive equations:

$$V_0\,(t) = Q_{01}(t) \,\$\, [1 + V_1(t)] + Q_{02}(t) \,\$\, [1 + V_2(t)] + Q_{03}(t) \,\$\, [1 + V_3(t)]$$

$$V_1(t) = Q_{10}(t) \,\$\, V_0(t) + Q_{11}^{(5)}(t) \,\$\, V_1(t) + Q_{12}^{(4)}(t) \,\$\, V_2(t) + Q_{13}^{(6)}(t) \,\$\, V_3(t)$$

$$V_2(t) = Q_{20}(t) \,\$\, V_0(t) + Q_{21}^{(10)}(t) \,\$\, V_1(t) + Q_{22}^{(9)}(t) \,\$\, V_2(t) + Q_{23}^{(11)}(t) \,\$\, V_3(t)$$

$$V_3(t) = Q_{30}(t) \,\$\, V_0(t) + Q_{31}^{(12)}(t) \,\$\, V_1(t) + Q_{32}^{(8)}(t) \,\$\, V_2(t) + Q_{33}^{(7)}(t) \,\$\, V_3(t)$$

(17 – 20)

Taking Laplace – Stieltjes transform of (17 – 20) and solving them for $\tilde{V}_0(s)$ by omitting 's' for brevity, we get

$$\tilde{V}_0(s) = \frac{N_4(S)}{D_2(S)} \tag{21}$$

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

$$V_0 = \lim_{t\to\infty}\left(\frac{V_0(t)}{t}\right) = \lim_{s\to 0} s\,\tilde{V}_0(s) = \frac{N_4}{D_2} \tag{22}$$

Where

$$N_4 = \left(1 - P_{11}^{(5)}\right)\left[\left(1 - P_{22}^{(9)}\right)\left(1 - P_{33}^{(7)}\right) - P_{23}^{(11)}\ P_{32}^{(8)}\right]$$

$$- P_{12}^{(4)}\left[P_{21}^{(10)}\left(1 - P_{33}^{(7)}\right) + P_{23}^{(11)} P_{31}^{(12)}\right]$$

$$- P_{13}^{(6)}\left[P_{32}^{(8)} P_{21}^{(10)} + P_{31}^{(12)}\left(1 - P_{22}^{(9)}\right)\right]$$

and

D_2 is the same as in availability analysis.

PROFIT ANALYSIS

The profit obtained to the system model in steady state can be obtained as

$$P = \mathrm{K}_0\,\mathrm{A}_0 - \mathrm{K}_1\,\mathrm{B}_0 - \mathrm{K}_2\,\mathrm{V}_0 \tag{23}$$

Where

K_0 = Revenue per unit up time of the system

K_1 = Cost per unit time for which the repairman is busy

K_2 = Cost per visiti by the repairman.

CONCLUSION

In the previous study it was assumed that the operative unit fails then it was sent for repair. But in the present study the concept of warranty period is used. For making the system more effective, it is considered that the operative unit fails due to failure of any component under warranty period then it is sent for replacement in stead of repair. The optimum results are obtained which are in the equation (5) , (10) , (16), (22), and (23).

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