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Cost Analysis to a Reliability Model for an Optical Communication Process with Bidirectional and Non-Revertible 1+1 Protection Switching Scheme

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Abstract

Cost analysis of a system having bidirectional and non-revertible 1+1 protection switching scheme in optical communication process has been analyzed in the present paper. The scheme under consideration comprises four optical lines out of which two are operative (working paths) and the other two are hot-standby (protection paths). Signals are transmitted through working path and protection path from one user to other. We may call the users as user-1 and user-2. User-1 transmits signals through working path as well as protection path which are received by user-2 from working path only, similar transmission take place from user-2 to user-1.Working and protection paths are routed through different optical pipes. If anyone working path gets failed then signals are received from the protection paths by both users. The signals continue to remain receiving from protection paths even if the working paths get repaired before the failure of protection paths and this makes the process non-revertible. After getting the protection path repaired, if the working paths are operative, the protection paths again act as a hot standby.

Keywords: Bidirectional protection scheme, optical communication process, working path, protection path, regenerative points, availability, busy period and profit analysis.

INTRODUCTION

Communication is a process by which information is transmitted and understood between two or more persons/organizations. Effective and fast communication is playing a key role for improving business processing, achieving cost effectiveness, deriving revenue growth and competitive advantages. And hence it is regarded as the foundation of any organization. Optical fiber has played a key role in stimulating the extra ordinary growth in worldwide communication and is vital in enabling the proliferating use of the internet.

Reliability and availability have widely been studied by various researchers, though the mathematical models on various protection schemes along with making comparisons between various schemes have been discussed, yet models considering various possibilities depending on failure and repair rates are still need to be developed. Keeping the above in view, cost analysis of a system having bidirectional and non-revertible 1+1 protection switching scheme in optical communication process has been analyzed in the present paper. The scheme under consideration comprises four optical lines out of which two are operative (working paths) and the other two are hot-standby (protection paths). Signals are transmitted through working path and protection path both from one user to other but received by 2nd user from working path only. And similar transmission take place from 2nd user to 1st user. Working and protection paths are routed through different optical pipes. If any one working path gets failed then signals are received from the protection paths by both users. The signals continue to remain receiving from protection paths even if the working paths get repaired before the failure of protection paths and this makes the process non-revertible. After getting the protection path repaired, if the working paths are operative, the protection paths again act as a hot standby.

UNDERTAKEN ASSUMPTIONS

- Initially working path is taken as operative and the protection path act as hot standby.
- The system becomes inoperable if working path and its corresponding protection path get failed.
- All random variables are independent.
- The failure and repair times are assumed to be exponentially distributed.
- The failures are self-announcing and switching is perfect & instantaneous.
- No more than one unit can repair at a time.
- Repairing of already undertaken unit is not left in between.

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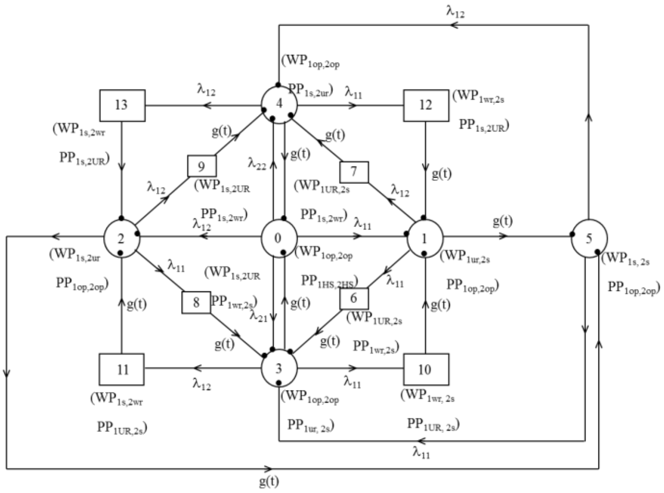
State Transition Diagram (Fig. 1)



Failed State: ☐ Op. State: ○ Regenerative Point: ●

Notations

WP_{10P} : Operative unit of 1st working path

WP_{20P} : Operative unit of 2nd working path

PP_{10P} : Operative unit of 1st protective path

PP_{20P} : Operative unit of 2nd protective path

WP_{1ur} : 1st working path is under repair

WP_{2ur} : 2nd working path is under repair

PP_{1ur} : 1st protective path is under repair

PP_{2ur} : 2nd protective path is under repair

WP_{1HS} : 1st working path is hot standby

WP_{2HS} : 2nd working path is hot standby

PP_{1HS} : 1st protective path is hot standby

PP_{2HS} : 2nd protective path is hot standby

WP_{1UR} : 1st working path is under repair from previous state

WP_{2UR}: 2nd working path is under repair from previous state

PP_{1UR} : 1st protective path is under repair from previous state

PP_{2UR} : 2nd protective path is under repair from previous state

WP_{1wr} : 1st working path is waiting for repair

WP_{2wr} : 2nd working path is waiting for repair

PP_{1wr} : 1st protective path is waiting for repair

PP_{2wr} : 2nd protective path is waiting for repair

λ_{11} : Failure rate of operative unit of 1st working path

λ_{12} : Failure rate of operative unit of 2nd working path

λ_{21} : Failure rate of hot standby unit of 1st protective path

λ_{22} : Failure rate of hot standby unit of 2nd protective path

$f(t)$: Repair rate of failed unit of working / protective path

The Transition State Probabilities

$q_{01}(t) = \lambda_{11} e^{-(\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22})t}$

$q_{02}(t) = \lambda_{12} e^{-(\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22})t}$

$q_{03}(t) = \lambda_{21} e^{-(\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22})t}$

$q_{04}(t) = \lambda_{22} e^{-(\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22})t}$

$q_{15}(t) = e^{-(\lambda_{11}+\lambda_{12})t}.\, g(t)$

$q_{16}(t) = \lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t)$

$q_{17}(t) = \lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t)$

$q_{13}{}^{(6)}(t) = [\lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t} © 1] \,.\, g(t)$

$q_{14}{}^{(7)}(t) = [\lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t} © 1] \,.\, g(t)$

$q_{25}(t) = e^{-(\lambda_{11}+\lambda_{12})t} g(t) = q_{15}(t)$

$q_{28}(t) = \lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t) = q_{16}(t)$

$q_{29}(t) = \lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t) = q_{17}(t)$

$q_{23}{}^{(8)}(t) = \left[\lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t} © 1\right].\, g(t) = q_{13}{}^{(6)}(t)$

$q_{24}{}^{(9)}(t) = \left[\lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t} © 1\right].\, g(t) = q_{14}{}^{(7)}(t)$

$q_{30}(t) = e^{-(\lambda_{11}+\lambda_{12})t} g(t) = q_{15}(t)$

$q_{3,10}(t) = \lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t) = q_{16}(t)$

$q_{3,11}(t) = \lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t) = q_{17}(t)$

$q_{31}{}^{(10)}(t) = \left[\lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t} © 1\right].\, g(t) = q_{13}{}^{(6)}(t)$

$q_{32}{}^{(11)}(t) = \left[\lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t} © 1\right].\, g(t) = q_{14}{}^{(7)}(t)$

$q_{40}(t) = e^{-(\lambda_{11}+\lambda_{12})t} g(t) = q_{15}(t)$

$q_{4,12}(t) = \lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t) = q_{16}(t)$

$q_{4,13}(t) = \lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t}.\, \overline{G}(t) = q_{17}(t)$

$q_{41}{}^{(12)}(t) = \left[\lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t} © 1\right].\, g(t) = q_{13}{}^{(6)}(t)$

$q_{42}{}^{(13)}(t) = \left[\lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t} © 1\right].\, g(t) = q_{14}{}^{(7)}(t)$

$q_{5,3}(t) = \lambda_{11} e^{-(\lambda_{11}+\lambda_{12})t}$

$q_{5,4}(t) = \lambda_{12} e^{-(\lambda_{11}+\lambda_{12})t}$

The nonzero element, p_{ij} is given by
$p_{ij} = \lim_{s\to 0} q_{ij}{}^{*}(s)$

$p_{01} + p_{02} + p_{03} + p_{04} = 1, \quad p_{15} + p_{16} + p_{17} = 1,$

$p_{15} + p_{13}{}^{(6)} + p_{14}{}^{(7)} = 1,$

$p_{25} + p_{28} + p_{29} = 1, p_{25} + p_{23}{}^{(8)} + p_{24}{}^{(9)} = 1,$
$p_{30} + p_{3,10} + p_{3,11} = 1,$

$p_{30} + p_{31}{}^{(10)} + p_{32}{}^{(11)} = 1,$ $p_{40} + p_{4,12} + p_{4,13} = 1,$
$p_{40} + p_{41}{}^{(12)} + p_{42}{}^{(13)} = 1,$ $p_{53} + p_{54} = 1$

Mean Sojourn Times

The mean sojourn time (μ_i) in the regenerative state 'i' is defined as the time of stay before transition to any other state. If μ_i denotes the mean sojourn time in the regenerative state i then

$$\mu_i = E(t)\Pr[T > t]$$

$$\mu_0 = \frac{1}{(\lambda_{11} + \lambda_{12} + \lambda_{21} + \lambda_{22})}$$

$$\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \frac{1-g^*(\lambda_{11}+\lambda_{12})}{(\lambda_{11}+\lambda_{12})}$$

Mean Time to System Failure

Recursive relation for MTSF i.e. ϕ_i (t) are:

$$\emptyset_0(t) = Q_{01}(t)Ⓢ\emptyset_1(t) + Q_{02}(t)Ⓢ\emptyset_2(t) + Q_{03}(t)Ⓢ\emptyset_3(t) + Q_{04}(t)Ⓢ\emptyset_4(t)$$

$$\emptyset_1(t) = Q_{15}(t)Ⓢ\emptyset_5(t) + Q_{16}(t) + Q_{17}(t)$$

$$\emptyset_2(t) = Q_{25}(t)Ⓢ\emptyset_5(t) + Q_{2,8}(t) + Q_{2,9}(t)$$

$$\emptyset_3(t) = Q_{30}(t)Ⓢ\emptyset_0(t) + Q_{3,10}(t) + Q_{3,11}(t)$$

$$\emptyset_4(t) = Q_{40}(t)Ⓢ\emptyset_0(t) + Q_{4,12}(t) + Q_{4,13}(t)$$

$$\emptyset_5(t) = Q_{53}(t)Ⓢ\emptyset_3(t) + Q_{54}(t)Ⓢ\emptyset_4(t)$$

Taking Laplace-Stieltjes transforms of equations and solving for $\emptyset_0{}^{**}$(s) , we get

$$\emptyset_0{}^{**}(s) = \frac{N(s)}{D(s)}$$

Where

$$D(s) = \begin{vmatrix} 1 & -Q_{01} & -Q_{02} & -Q_{03} & -Q_{04} & 0 \\ 0 & 1 & 0 & 0 & 0 & -Q_{15} \\ 0 & 0 & 1 & 0 & 0 & -Q_{25} \\ -Q_{30} & 0 & 0 & 1 & 0 & 0 \\ -Q_{40} & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -Q_{53} & -Q_{54} & 1 \end{vmatrix}$$

$$D(s) = 1 - Q_{53}Q_{15}Q_{01}Q_{30} - Q_{53}Q_{25}Q_{02}Q_{30} - Q_{30}Q_{03} - Q_{15}Q_{01}Q_{40}Q_{54} - Q_{40}Q_{04} - Q_{25}Q_{02}Q_{40}Q_{54}$$

$$N(s) = \begin{vmatrix} 1 & -Q_{01} & -Q_{02} & -Q_{03} & -Q_{04} & 0 \\ Q_{16} + Q_{17} & 1 & 0 & 0 & 0 & -Q_{15} \\ Q_{28} + Q_{29} & 0 & 1 & 0 & 0 & -Q_{25} \\ Q_{3,10} + Q_{3,11} & 0 & 0 & 1 & 0 & 0 \\ Q_{4,12} + Q_{4,13} & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -Q_{53} & -Q_{54} & 1 \end{vmatrix}$$

$$N(s) = 1 + Q_{01}Q_{16} + Q_{01}Q_{17} + Q_{02}Q_{28} + Q_{02}Q_{29} + Q_{3,10}Q_{01}Q_{53}Q_{15} + Q_{3,10}Q_{02}Q_{53}Q_{25} + Q_{3,10}Q_{03} + Q_{3,11}Q_{01}Q_{53}Q_{15} + Q_{3,11}Q_{02}Q_{53}Q_{25} + Q_{3,11}Q_{03} + Q_{4,12}Q_{01}Q_{15}Q_{54} + Q_{4,12}Q_{02}Q_{54}Q_{25} + Q_{4,12}Q_{04} + Q_{4,13}Q_{01}Q_{54}Q_{15} + Q_{4,13}Q_{02}Q_{54}Q_{25} + Q_{4,13}Q_{04}$$

The Mean Time to System Failure (MTSF) when the system starts from the state '0' is,

$$MTSF = T_0 = \lim_{s\to 0} \frac{1-\emptyset_0{}^{**}(s)}{s}$$

Using L' Hospital rule and putting the value of $\emptyset_0{}^{**}(s)$, we have

$$T_0 = \frac{N}{D}$$

$$N = \mu_0 + \mu_1 p_{01} + \mu_2 p_{02} + \mu_3(p_{01}p_{15}p_{53} + p_{02}p_{25}p_{53} + p_{03}) + \mu_4(p_{01}p_{15}p_{54} + p_{02}p_{25}p_{54} + p_{04}) + \mu_5(p_{01}p_{15} + p_{02}p_{25})$$

$$D = 1 - p_{53}p_{01}p_{15}p_{30} - p_{53}p_{02}p_{25}p_{30} - p_{30}p_{03} - p_{01}p_{15}p_{54}p_{40} - p_{40}p_{04} - p_{02}p_{25}p_{54}p_{40}$$

Availability Analysis

Recursive relations for A_i (t) are:

$$A_0(t) = M_0(t) + q_{01}(t) © A_1(t) + q_{02}(t) © A_2(t) + q_{03}(t) © A_3(t) + q_{04}(t) © A_4(t)$$

$$A_1(t) = M_1(t) + q_{15}(t) © A_5(t) + q_{13}^{(6)}(t) © A_3(t) + q_{14}^{(7)}(t) © A_4(t)$$

$$A_2(t) = M_2(t) + q_{25}(t) © A_5(t) + q_{23}^{(8)}(t) © A_3(t) + q_{24}^{(9)}(t) © A_4(t)$$

$$A_3(t) = M_3(t) + q_{30}(t) © A_0(t) + q_{31}^{(10)}(t) © A_1(t) + q_{32}^{(11)}(t) © A_2(t)$$

$$A_4(t) = M_4(t) + q_{40}(t) © A_0(t) + q_{41}^{(12)}(t) © A_1(t) + q_{42}^{(13)}(t) © A_2(t)$$

$$A_5(t) = M_5(t) + q_{53}(t) © A_3(t) + q_{54}(t) © A_4(t)$$

Where

$$M_0(t) = e^{-(\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22})t}$$
$$M_1(t) = e^{-(\lambda_{12}+\lambda_{21})t}\,\overline{G(t)}$$
$$M_2(t) = e^{-(\lambda_{12}+\lambda_{21})t}\,\overline{G(t)}$$
$$M_3(t) = e^{-(\lambda_{12}+\lambda_{21})t}\,\overline{G(t)}$$
$$M_4(t) = e^{-(\lambda_{12}+\lambda_{21})t}\,\overline{G(t)}$$
$$M_5(t) = e^{-(\lambda_{12}+\lambda_{21})t}\,\overline{G(t)}$$

The Availability of the system, in steady state is given by

$$A_0 = \lim_{s\to 0} sA_0^*(s) = \frac{N_1}{D_1},$$

$$\begin{aligned} D_1 = \mu_0 p_{15} + K_1(p_{13}^{(6)} + p_{01}\, p_{15}) + K_2(p_{14}^{(7)} + p_{02}\, p_{15}) \\ + K_3(p_{13}^{(6)} - p_{04}(p_{15})^2 p_{53} \\ + p_{03}(p_{15})^2 p_{54} + p_{15} p_{53} - p_{04} p_{15} p_{13}^{(6)} \\ + p_{03} p_{15} p_{14}^{(7)}) \\ + K_4(p_{14}^{(7)} - p_{03}(p_{15})^2 p_{54} \\ + p_{04}(p_{15})^2 p_{53} + p_{15} p_{54} - p_{03} p_{15} p_{14}^{(7)} \\ + p_{04} p_{15} p_{13}^{(6)}) + \mu_5[p_{15}(p_{13}^{(6)} + p_{14}^{(7)} \\ + p_{01}\, p_{15} + p_{02}\, p_{15} \end{aligned}$$

$$\begin{aligned} N_1 = \mu_4 + p_{01}p_{15}\mu_1 + p_{01}(p_{15})^2\mu_5 + p_{02}(p_{15})^2\mu_5 \\ + p_{02}p_{15}\mu_2 + p_{13}^{(6)}\mu_1 + p_{53}(p_{15})^2\mu_4 \\ - p_{53}(p_{15})^2\mu_3 + p_{13}^{(6)}\mu_4 p_{15} - p_{13}^{(6)}\mu_3 p_{15} \\ - (p_{15})^2\mu_5 + p_{15}\mu_0 - p_{15}\mu_2 - p_{13}^{(6)}\mu_2 + \mu_2 \\ - p_{53}p_{15}\mu_4 + p_{53}p_{15}\mu_3 - p_{03}p_{15}\mu_4 \\ + p_{03}p_{15}\mu_3 + p_{13}^{(6)}\mu_3 + p_{13}^{(6)}\mu_3 p_{01}p_{15} \\ + p_{13}^{(6)}\mu_3 p_{02}p_{15} - p_{53}p_{01}\mu_4(p_{15})^2 \\ - p_{53}p_{02}\mu_4(p_{15})^2 + p_{53}p_{01}\mu_3(p_{15})^2 \\ + p_{53}p_{02}\mu_3(p_{15})^2 - p_{13}^{(6)}\mu_4 \\ - p_{13}^{(6)}\mu_4 p_{01}p_{15} - p_{13}^{(6)}\mu_4 p_{02}p_{15} + p_{15}\mu_5 \end{aligned}$$

Busy Period Analysis of Ordinary Repairman

Recursive relations for $B_i(t)$ are:

$$B_0(t) = q_{01}(t) © B_1(t) + q_{02}(t) © B_2(t) + q_{03}(t) © B_3(t) + q_{04}(t) © B_4(t)$$

$$B_1(t) = W_1(t) + q_{15}(t) © B_5(t) + q_{13}^{(6)}(t) © B_3(t) + q_{14}^{(7)}(t) © B_4(t)$$

$$B_2(t) = W_2(t) + q_{25}(t) © B_5(t) + q_{23}^{(8)}(t) © B_3(t) + q_{24}^{(9)}(t) © B_4(t)$$

$$B_3(t) = W_3(t) + q_{30}(t) © B_0(t) + q_{31}^{(10)}(t) © B_1(t) + q_{32}^{(11)}(t) © B_2(t)$$

$$B_4(t) = W_4(t) + q_{40}(t) © B_0(t) + q_{41}^{(12)}(t) © B_1(t) + q_{42}^{(13)}(t) © B_2(t)$$

$$B_5(t) = W_5(t) + q_{53}(t) © B_3(t) + q_{54}(t) © B_4(t)$$

Where
$W_1(t) = W_2(t) = W_3(t) = W_4(t) = W_5(t) = \overline{G(t)}$

Taking Laplace transform of equations and solving them for $B_0^*(s)$. In steady-state the total fraction of the time for which the system is under repair of the repairman is given by

$$B_0 = \lim_{s\to 0} sB_0^*(s) = \frac{N_2}{D_1}$$

Where $N_2 = \mu_2 - p_{13}^{(6)}\mu_4 - p_{13}^{(6)}\mu_4 p_{01}p_{15} - p_{13}^{(6)}\mu_4 p_{02}p_{15} + p_{13}^{(6)}\mu_3 + p_{13}^{(6)}\mu_3 p_{01}p_{15} + p_{13}^{(6)}\mu_3 p_{02}p_{15} + p_{15}\mu_5 - (p_{15})^2\mu_4 p_{01}p_{53} - (p_{15})^2\mu_4 p_{02}p_{53} + (p_{15})^2\mu_3 p_{01}p_{53} + (p_{15})^2\mu_3 p_{02}p_{53} + \mu_4 + p_{13}^{(6)}\mu_4 p_{15} - p_{13}^{(6)}\mu_3 p_{15} + p_{01}p_{15}\mu_1 + p_{01}(p_{15})^2\mu_5 + p_{02}(p_{15})^2\mu_5 + p_{03}p_{15}\mu_3 - (p_{15})^2\mu_5 - p_{03}p_{15}\mu_4 + (p_{15})^2\mu_4 p_{53} + p_{13}^{(6)}\mu_1 + p_{02}p_{15}\mu_2 - (p_{15})^2\mu_3 p_{53} - p_{15}\mu_2 - p_{13}^{(6)}\mu_2 - p_{53}p_{15}\mu_4 + p_{53}p_{15}\mu_3 + p_{15}$

and D_1 is already specified

Expected Number of Visits

Recursive relations for $V_i(t)$:

$$V_0(t) = Q_{01}(t)Ⓢ[V_1(t)+1] + Q_{02}(t)Ⓢ[V_2(t)+1] + Q_{03}(t)Ⓢ[V_3(t)+1] + Q_{04}(t)Ⓢ[V_4(t)+1]$$

$$V_1(t) = Q_{15}(t)ⓈV_5(t) + Q_{13}^{(6)}(t)ⓈV_3(t) + Q_{14}^{(7)}(t)ⓈV_4(t)$$

$$V_2(t) = Q_{25}(t)ⓈV_5(t) + Q_{23}^{(8)}(t)ⓈV_3(t) + Q_{24}^{(9)}(t)ⓈV_4(t)$$

$$V_3(t) = Q_{30}(t)ⓈV_0(t) + Q_{31}^{(10)}(t)ⓈV_1(t) + Q_{32}^{(11)}(t)ⓈV_2(t)$$

$$V_4(t) = Q_{40}(t)ⓈV_0(t) + Q_{41}^{(12)}(t)ⓈV_1(t) + Q_{42}^{(13)}(t)ⓈV_2(t)$$

$$V_5(t) = Q_{53}(t)ⓈV_3(t) + Q_{54}(t)ⓈV_4(t)$$

Taking Laplace transforms of equations and solving them for $V_0^*(s)$. In study-state the expected no. of visits of expert repairman is given by $V_0 = \lim_{s\to 0} sV_0^*(s) = \frac{N_3}{D_1}$, Where $N_3 = p_{15}$ and D_1 is already specified.

Profit Analysis

Expected profit incurred to system is given by

$$Profit\ (P) = C_0A_0 - C_1B_0 - C_2V_0$$

Where
C_0 = Revenue per unit up time
C_1 = Cost per unit up time for which the repairman is busy for repair
C_2 = Cost per visit of repairman

Numerical Results and Discussion

Considering $g(t) = \alpha e^{-\alpha t}$
We have $p_{01} = \frac{\lambda_{11}}{\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22}}$
$p_{02} = \frac{\lambda_{12}}{\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22}}$
$p_{03} = \frac{\lambda_{21}}{\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22}}$
$p_{04} = \frac{\lambda_{22}}{\lambda_{11}+\lambda_{12}+\lambda_{21}+\lambda_{22}}$
$p_{15} = p_{25} = p_{30} = p_{40} = \frac{\alpha}{\lambda_{11}+\lambda_{12}+\alpha}$,
$p_{16} = p_{28} = p_{3,10} = p_{4,12} = \frac{\lambda_{11}}{\lambda_{11}+\lambda_{12}+\alpha}$,
$p_{17} = p_{29} = p_{3,11} = p_{4,13} = \frac{\lambda_{12}}{\lambda_{11}+\lambda_{12}+\alpha}$,
$p_{53} = \frac{\lambda_{11}}{\lambda_{11}+\lambda_{12}}$, $p_{54} = \frac{\lambda_{12}}{\lambda_{11}+\lambda_{12}}$
$p_{13}^{(6)} = p_{23}^{(8)} = p_{31}^{(10)} = p_{41}^{(12)} = \frac{\lambda_{11}}{\lambda_{11}+\lambda_{12}+\alpha}$,

$$p_{14}^{(7)} = p_{24}^{(9)} = p_{32}^{(11)} = p_{42}^{(13)} = \frac{\lambda_{12}}{\lambda_{11}+\lambda_{12}+\alpha}$$

Fig. 2 shows the behavior of MTSF with respect to Repair Rate (α) for different value of failure rate (λ_{11}).The graph reveals that MTSF get increased with the increase in the values of repair rate (α) but have lower values for higher values of λ_{11}.

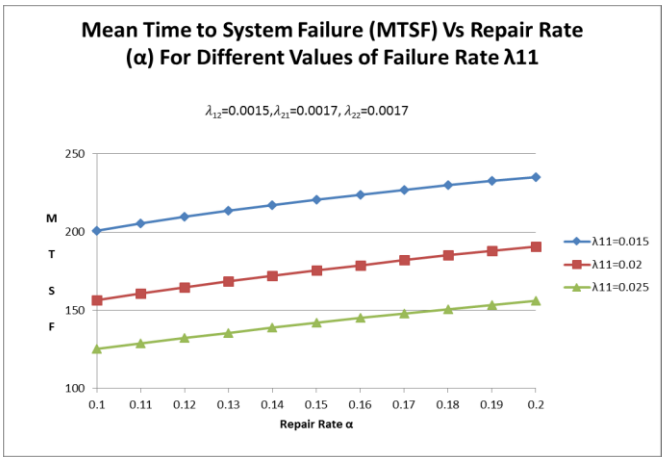


Fig. 2

Fig. 3 shows the behavior of Availability (A_0) with respect to repair rate (α) for different value of Failure Rate, λ_{11}. The graph reveals that Availability (A_0) get increased with the increase in the values of repair rate (α) but have lower values for higher values of λ_{11}.

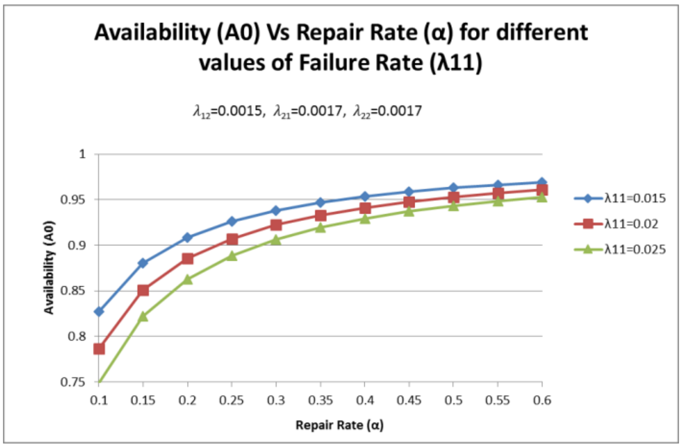


Fig. 3

Fig. 4 represents the behavior of profit (P) with respect to Failure Rate (λ_{11}) for different values Failure Rate (λ_{21}). It is observed from the graphs:

The profit decreases with the increase in the values of Failure Rate (λ_{11}) and has higher for lower values of λ_{21}.

i. For λ_{21} = 0.0010, the profit is positive or zero or negative according as Failure Rate (λ_{11}) < or = or > 0.0030 and hence failure rate should not be greater than 0.00295.

ii. For λ_{21} = 0.0015, the profit is positive or zero or negative according as Failure Rate (λ_{11}) < or = or > 0.0028 and hence failure rate should not be greater than 0.00275.

iii. For λ_{21} = 0.0020, the profit is positive or zero or negative according as Failure Rate (λ_{11}) < or = or > 0.0025 and hence failure rate should not be greater than 0.00245

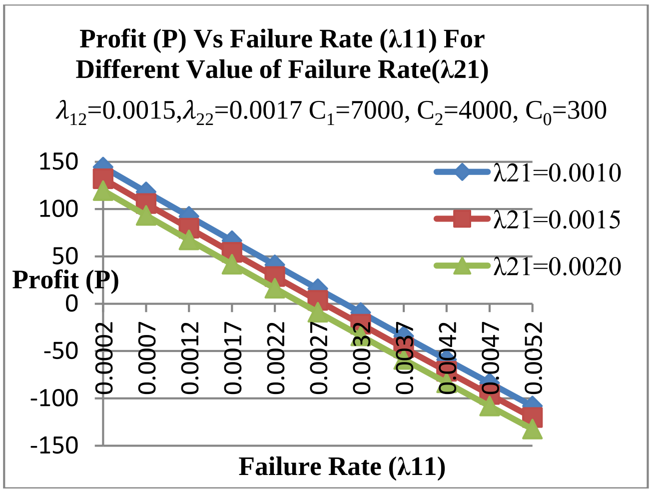


Fig. 4

Fig.5 depicts the behavior of profit (P) with respect to revenue per unit up time (C_0) for different values Failure Rate (λ_{11}). It is observed from the graphs:

The profit increases with the increase in the values of C_0 and has higher for lower values of λ_{11}

i. For λ_{11} = 0.0010, the profit is positive or zero or negative according as C_0> or = or <214.3333 and hence revenue per unit up time should be fixed not less than 214.3333.

ii. For λ_{11} = 0.0015, the profit is positive or zero or negative according as C_0> or = or < 240.133 and hence revenue per unit up time should be fixed not less than 240.133.

iii. For λ_{11} = 0.0020, the profit is positive or zero or negative according as C_0> or = or < 265.8123 and hence revenue per unit up time should be fixed not less than 265.8123.

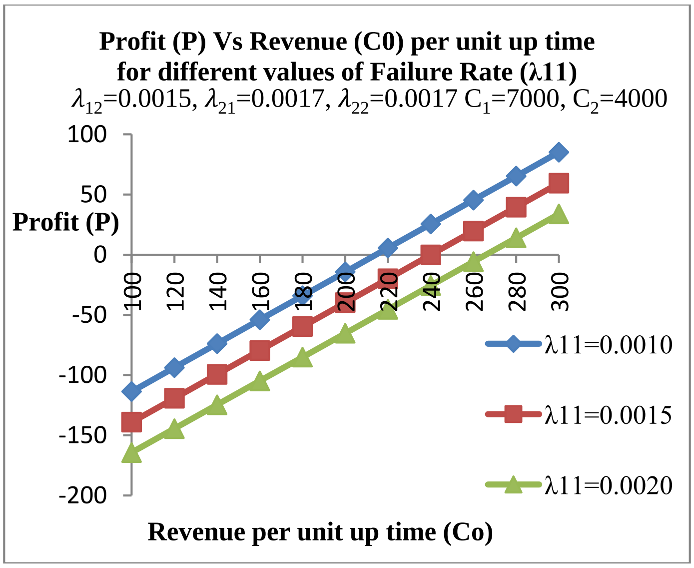


Fig. 5

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