

STUDY OF MODELS IN RELIABILITY WITH SUSTAINABILITY AND DEGRADATION

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Abstract :

The revive (repair) and sustainance aspects of a two-unit cold standby system are examined in this model. The idea of a rest period is taken into account, meaning that if the repairman has to take a break before finishing the unit that has failed, another repairman may be brought in to continue the work. While the distribution for repair, rest, and patience durations is assumed to be arbitrary with various probability density functions, the failure time follows an exponential distribution. Semi-Markov processes are used to calculate a number of dependability metrics, including mean time to system failure (MTSF), steady-state availability, busy period, and projected number of server visits.

keywords: Failed unit, repaired unit, repairman, patience time, MTSF, Availability.

1. Introduction

Due to the growing need in the modern business, a great deal of effort has been done on different kinds of one- or two-unit redundant systems. The employment of extra parts in addition to the primary unit to increase system dependability is referred to as "redundant components." These spare parts are stored so they may be utilized in the event that the

primary unit malfunctions. Standby units come in two varieties: heated standby units and cold standby units.

Warm standby units have the potential to fail while waiting in the standby state, whereas cold standby units cannot fail while they are waiting. The ideas of redundant systems, including repair time, operation and rest time, availability, busy period, and failures owing to various types of mistake, have been the subject of several studies.

S.K. Barak, M.S. Barak, and S.C. Malik (2016) investigated a two-unit cold standby system using preventive maintenance and repair. The possibility of repairing the failed unit is evaluated following inspection. They graphed the trend for various reliability metrics computed using the semi-Markov process and the regenerating point approach for arbitrary parameter and cost values.

Renu and P. Bhatia (2019) studied two high-pressure die casting machines where the secondary units functioned for the maximum permissible time, with two maintenance facilities. Various dependability metrics were investigated in every potential circumstan

C. Aggarwal and S.C. Malik (2020) considered a repairable standby system that could continue to operate while the server was being fixed. They conducted a thorough examination of a cold standby repairable system consisting of two identical units, taking into consideration the stochastic idea of server rest intervals between repairs. The expressions for Mean Time to System Failure (MTSF), availability, server busy period due to repair, projected number of repairs, and profit function were calculated using the semi-Markov process and regenerating point approach. The profit of the system model was calculated using changes in income per unit time, server downtime expenses, and repair expenditures per unit time.

C. Aggarwal, N. Ahlawat, and S.C. Malik (2021) studied the profitability of a cold standby system in which preventative maintenance was prioritized above repair. They studied one server that was permitted to rest after each repair but not after preventative maintenance. To conduct the profit analysis, the revenue per unit uptime and cost functions associated with repair activities were considered

In this research, we examined a two-unit cold standby system from the perspectives of revival and sustainability. We define revive as fixing the failing unit, and the same repairing facility is regarded. There may be times when the repairman has to rest before fixing the failing

device, or the repair may be completed without rest. If the failing unit is left unattended during the repairman's rest interval, another repairman takes up the repair.

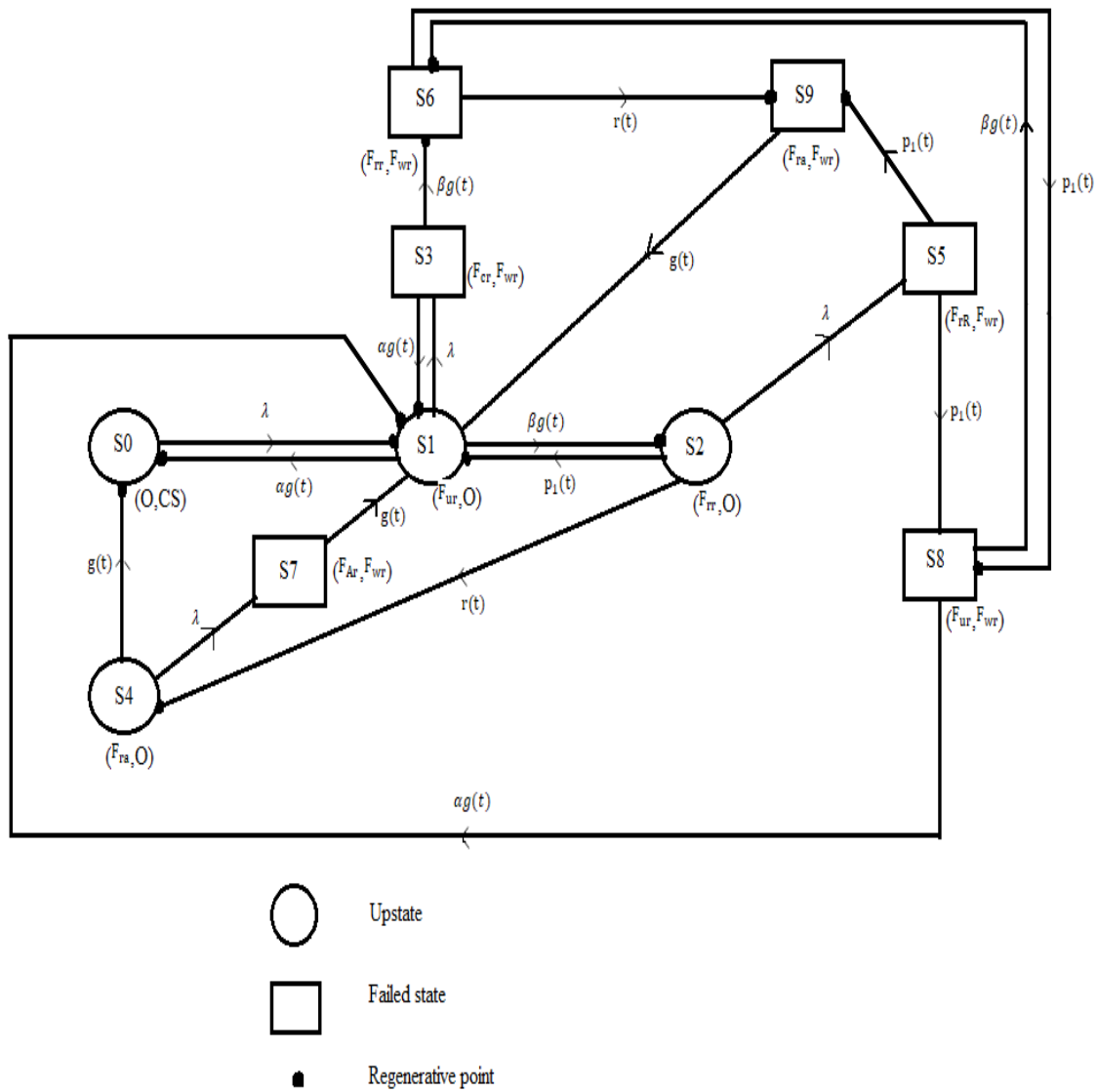
2. Description of model and Assumptions:

- i.The system consists of two identical units. One unit is operational, and the other is maintained on cold standby.
 - ii.If one unit fails, the backup unit will take over immediately, while the failing unit is repaired.
 - iii.If both units fail, the system fails.
 - iv.After repair, the failed item will act as if it were new.
 - v.Each unit's time to failure follows an exponential distribution, but repair and patience times follow an arbitrary distribution.
- All random variables are mutually independent.

3. Nomenclature

α	probability that the repairman does not need rest before repair is over
β	probability that the repairman does need rest before repair is over
λ	constant failure rate of the operative unit
O	operative state of unit
CS	unit is in cold standby
$g(t)$	p.d.f. of repair time of unit
$G(t)$	c.d.f. of repair time of unit

$r(t)$	p.d.f. of rest time of unit
$R(t)$	c.d.f. of rest time of unit
$p_1(t)$	p.d.f. of patience time of unit
$P_1(t)$	c.d.f. of patience time of unit
F_{ur}	failed unit under the repair of repairman
F_{cr}	repair of the failed unit is continuing from the previous state
F_{rr}	repairman is at rest and failed unit is waiting for repair
F_{rR}	rest of the repairman is continuing from previous state while failed unit is waiting for repair
F_{wr}	failed unit is waiting for repair
F_{ra}	failed unit under repair of another repairman who resumes repair
F_{Ar}	repair by another repairman is continuing from previous state



4. Transition probabilities

The transition probabilities are:

$$dQ_{01}(t) = \lambda e^{-\lambda t} dt$$

$$dQ_{10}(t) = \alpha e^{-\lambda t} g(t) dt$$

$$dQ_{12}(t) = \beta e^{-\lambda t} g(t) dt$$

$$dQ_{13}(t) = \lambda e^{-\lambda t} \overline{G(t)} dt$$

$$dQ_{16}^{(3)}(t) = (\lambda e^{-\lambda t} \odot \beta) g(t) dt = \beta (1 - e^{-\lambda t}) g(t) dt$$

$$dQ_{11}^{(3)}(t) = (\lambda e^{-\lambda t} \odot \alpha) g(t) dt = \alpha (1 - e^{-\lambda t}) g(t) dt$$

$$dQ_{21}(t) = e^{-\lambda t} r(t) \overline{P_1(t)} dt = e^{-\lambda t} E_1(t) dt$$

$$\begin{aligned}
&\text{where } E_1(t) = r(t)\overline{P_1(t)} \quad . \\
&dQ_{24}(t) = e^{-\lambda t} p_1(t)\overline{R(t)} dt = e^{-\lambda t} E_2(t) dt \\
&\text{where } E_2(t) = p_1(t)\overline{R(t)} \quad . \\
&dQ_{25}(t) = \lambda e^{-\lambda t} \overline{R(t)} \overline{P_1(t)} = e^{-\lambda t} E_3(t) dt \\
&\text{where } E_3(t) = \overline{R(t)} \overline{P_1(t)} \quad . \\
&dQ_{28}^{(5)}(t) = (\lambda e^{-\lambda t} \odot 1) r(t)\overline{P_1(t)} dt = (1 - e^{-\lambda t}) E_1(t) dt \\
&dQ_{29}^{(5)}(t) = (\lambda e^{-\lambda t} \odot 1) p_1(t)\overline{R(t)} dt = (1 - e^{-\lambda t}) E_2(t) dt \\
&dQ_{40}(t) = e^{-\lambda t} g(t) dt \\
&dQ_{47}(t) = \lambda e^{-\lambda t} \overline{G(t)} dt \\
&dQ_{41}^{(7)}(t) = (\lambda e^{-\lambda t} \odot 1) g(t) dt = (1 - e^{-\lambda t}) g(t) dt \\
&dQ_{68}(t) = r(t)\overline{P_1(t)} dt = e^{-\lambda t} E_1(t) dt \\
&dQ_{69}(t) = p_1(t)\overline{R(t)} dt = e^{-\lambda t} E_2(t) dt \\
&dQ_{81}(t) = \alpha g(t) dt \\
&dQ_{86}(t) = \beta g(t) dt \\
&dQ_{91}(t) = g(t) dt \quad \dots\dots(1-19)
\end{aligned}$$

The non-zero elements p_{ij} of transition state probabilities are as follows:

$$\begin{aligned}
p_{01} &= 1, p_{10} = \alpha g^*(\lambda), p_{12} = \beta g^*(\lambda), p_{13} = 1 - g^*(\lambda), p_{16}^{(3)} = \beta(1 - g^*(\lambda)), \\
p_{11}^{(3)} &= \alpha(1 - g^*(\lambda)), p_{21} = E_1^*(\lambda), p_{24} = E_2^*(\lambda), p_{25} = \lambda E_3^*(\lambda), p_{28}^{(5)} = E_1^*(0) - E_1^*(\lambda), \\
p_{29}^{(5)} &= E_2^*(0) - E_2^*(\lambda), p_{40} = g^*(\lambda), p_{47} = 1 - g^*(\lambda), p_{41}^{(7)} = 1 - g^*(\lambda), p_{68} = E_1^*(0), \\
p_{69} &= E_2^*(0), p_{81} = \alpha, p_{86} = \beta, p_{91} = 1
\end{aligned}$$

By using above transition state probabilities, it can be verified that

$$\begin{aligned}
p_{01} &= 1 \\
p_{10} + p_{12} + p_{13} &= p_{10} + p_{12} + p_{16}^{(3)} + p_{11}^{(3)} = 1 \\
p_{21} + p_{24} + p_{25} &= p_{21} + p_{24} + p_{28}^{(5)} + p_{29}^{(5)} = 1 \\
p_{40} + p_{47} &= p_{40} + p_{41}^{(7)} = 1 \\
p_{68} + p_{69} &= p_{81} + p_{86} = p_{91} = 1 \quad \dots\dots(20-24)
\end{aligned}$$

5. Mean Sojourn Time

If T denotes mean sojourn time in state 0, then

$$\begin{aligned}\mu_0 &= \int P(T > t)dt = \frac{1}{\lambda}, \mu_1 = \frac{1-g^*(\lambda)}{\lambda}, \mu_2 = E_3^*(\lambda), \mu_4 = \mu_1 = \frac{1-g^*(\lambda)}{\lambda}, \mu_6 = E_3^*(0), \\ \mu_9 &= \mu_8 = \int_0^\infty \overline{G(t)}dt \\ &\dots\dots\dots(25)\end{aligned}$$

The unconditional mean time taken by the system to transit to any regenerative state when counting from the epoch of entry into that stage is, mathematically, expressed as

$$m_{ij} = \int_0^\infty t dQ_{ij}(t) = -\frac{d}{ds} q_{ij}^*|_{s=0} \dots\dots\dots(26)$$

Thus, $m_{01} = \mu_0$, $m_{10} + m_{12} + m_{13} = m_{40} + m_{47} = \mu_1$,

$$m_{10} + m_{12} + m_{11}^{(3)} + m_{16}^{(3)} = m_{81} + m_{86} = m_{91} = \mu_8$$

$$m_{21} + m_{24} + m_{25} = \int_0^\infty t e^{-\lambda t} [E_1(t) + E_2(t) + \lambda E_3(t)] dt = \xi_1$$

$$m_{21} + m_{24} + m_{28}^{(5)} + m_{29}^{(5)} = \int_0^\infty t e^{-\lambda t} [E_1(t) + E_2(t)] dt = m_{68} + m_{69} = \xi_2 \dots\dots\dots(27)$$

6. Mean time to system failure

Let us suppose the failed states as absorbing states. Also, by employing the arguments used for regenerative processes, we will obtain the following relations from:

$$\phi_0(t) = Q_{01}(t) \otimes \phi_1(t)$$

$$\phi_1(t) = Q_{13}(t) + Q_{10}(t) \otimes \phi_0(t) + Q_{12}(t) \otimes \phi_2(t)$$

$$\phi_2(t) = Q_{25}(t) + Q_{24}(t) \otimes \phi_4(t) + Q_{21}(t) \otimes \phi_1(t)$$

$$\phi_4(t) = Q_{47}(t) + Q_{40}(t) \otimes \phi_0(t) \dots\dots\dots(28-31)$$

Taking the L.S.T. of the above equations (28-31) and solving for $\phi_0^{**}(s)$, we will get

$$\begin{aligned}\phi_0^{**}(s) &= \frac{Q_{01}^{**}(s)[Q_{12}^{**}(s)\{Q_{25}^{**}(s)+Q_{24}^{**}(s)Q_{47}^{**}(s)\}+Q_{12}^{**}(s)]}{1-Q_{01}^{**}(s)[Q_{10}^{**}(s)+Q_{12}^{**}(s)Q_{24}^{**}(s)Q_{40}^{**}(s)]-Q_{12}^{**}(s)Q_{21}^{**}(s)} \\ &\dots\dots\dots(32)\end{aligned}$$

Now, the MTSF when the system starts from state 0 is

$$T_0 = \lim_{s \rightarrow 0} \frac{1 - \phi_0^{**}(s)}{s} = \frac{N}{D}$$

.....(33)

$$\text{Where } N = \mu_0 + \mu_1(1 + P_{12}p_{24}) + k_2P_{12} \quad \text{.....(34)}$$

$$\text{and } D = p_{12}(p_{24}p_{47} + p_{25}) + p_{12}$$

.....(35)

7. Availability Analysis

$M_i(t)$ denotes the probability that the system starting in up regenerative state is up at time t without passing through any regenerative state. Thus, we have

$$M_0(t) = e^{-\lambda t}, \quad M_1(t) = e^{-\lambda t} \overline{G(t)}, \quad M_2(t) = e^{-\lambda t} \overline{E_3(t)}, \quad M_4(t) = e^{-\lambda t} \overline{G(t)}$$

.....(36)

Using the arguments of the theory of regenerative processes, the availability $A_i(t)$ is seen to satisfy

$$\begin{aligned} A_0(t) &= M_0(t) + q_{01}(t) \odot A_1(t) \\ A_1(t) &= M_1(t) + q_{10}(t) \odot A_0(t) + q_{12}(t) \odot A_2(t) + q_{11}^{(3)}(t) \odot A_1(t) + q_{16}^{(3)}(t) \odot A_6(t) \\ A_2(t) &= M_2(t) + q_{21}(t) \odot A_1(t) + q_{24}(t) \odot A_4(t) + q_{28}^{(5)}(t) \odot A_8(t) + q_{29}^{(5)}(t) \odot A_9(t) \\ A_4(t) &= M_4(t) + q_{40}(t) \odot A_0(t) + q_{41}^{(7)}(t) \odot A_1(t) \\ A_6(t) &= q_{68}(t) \odot A_8(t) + q_{69}(t) \odot A_9(t) \\ A_8(t) &= q_{81}(t) \odot A_1(t) + q_{86}(t) \odot A_6(t) \\ A_9(t) &= q_{91}(t) \odot A_1(t) \end{aligned}$$

.....(37-43)

Taking Laplace transform of equation (36) and taking $\lim s \rightarrow 0$, we will get

$$M_0^*(0) = \mu_0, \quad M_1^*(0) = \mu_1, \quad M_2^*(0) = \mu_2, \quad M_4^*(0) = \mu_4$$

.....(44)

The steady state availability of the system is given by

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

.....(45)

$$\text{Where } N_1 = (1 - p_{68}p_{86})[\mu_0(p_{10} + p_{12}p_{24}p_{40}) + \mu_1(1 + p_{12}p_{24}) + \mu_2p_{12} \dots\dots\dots(46)$$

$$\text{and } D_1 = \mu_0(1 - p_{68}p_{86})(p_{10} + p_{12}p_{24}p_{40}) + (1 + p_{12}p_{24})[\mu_8 + p_{12}\xi_2] + \xi_2(p_{16}^{(3)} + p_{12}p_{28}^{(5)}p_{86}) + \mu_8[p_{12}(p_{28}^{(5)} + p_{69}p_{86}) + p_{16}^{(3)}p_{68} + p_{81}(p_{12}p_{29}^{(5)} + p_{16}^{(3)})]$$

.....(47)

8. Busy period analysis

Busy period of the repairman:

$$\begin{aligned} B_0(t) &= q_{01}(t) \odot B_1(t) \\ B_1(t) &= W_1(t) + q_{10}(t) \odot B_0(t) + q_{12}(t) \odot B_2(t) + q_{11}^{(3)}(t) \odot B_1(t) + q_{16}^{(3)}(t) \odot B_6(t) \\ B_2(t) &= q_{21}(t) \odot B_1(t) + q_{24}(t) \odot B_4(t) + q_{28}^{(5)}(t) \odot B_8(t) + q_{29}^{(5)}(t) \odot B_9(t) \\ B_4(t) &= W_4(t) + q_{40}(t) \odot B_0(t) + q_{41}^{(7)}(t) \odot B_1(t) \\ B_6(t) &= q_{68}(t) \odot B_8(t) + q_{69}(t) \odot B_9(t) \\ B_8(t) &= W_8(t) + q_{81}(t) \odot B_1(t) + q_{86}(t) \odot B_6(t) \\ B_9(t) &= W_9(t) + q_{91}(t) \odot B_1(t) \end{aligned}$$

.....(48-54)

$$\text{Where } W_1(t) = W_4(t) = e^{-\lambda t} \overline{G(t)} + [\lambda e^{-\lambda t} \odot 1] \overline{G(t)}, \quad W_8(t) = W_9(t) = \overline{G(t)} \dots\dots\dots(55)$$

Taking Laplace transform of equation (55) and taking $s \rightarrow 0$, we will get

$$W_1^*(0) = W_4^*(0) = W_8^*(0) = \mu_8$$

.....(56)

In steady-state, the total fraction of time under which system is under repair is given by

$$B_0 = \lim_{s \rightarrow 0} s B_0^* = \frac{N_2}{D_1}$$

.....(57)

Where
$$N_2 = (1 - p_{68}p_{86})(p_{12} + \mu_8) + \mu_8 p_{16}^{(3)}$$
(58)

And D_1 is same as in equation (47).

Rest Period:

At time $t = 0$, where system entered into regenerative state. Let us define probability of repairman is at rest by $R_i(t)$, then we have

$$\begin{aligned} R_0(t) &= q_{01}(t) \odot R_1(t) \\ R_1(t) &= q_{10}(t) \odot R_0(t) + q_{12}(t) \odot R_2(t) + q_{11}^{(3)}(t) \odot R_1(t) + q_{16}^{(3)}(t) \odot R_6(t) \\ R_2(t) &= W_2(t) + q_{21}(t) \odot R_1(t) + q_{24}(t) \odot R_4(t) + q_{28}^{(5)}(t) \odot R_8(t) + q_{29}^{(5)}(t) \odot R_9(t) \\ R_4(t) &= q_{40}(t) \odot R_0(t) + q_{41}^{(7)}(t) \odot R_1(t) \\ R_6(t) &= W_6(t) + q_{68}(t) \odot R_8(t) + q_{69}(t) \odot R_9(t) \\ R_8(t) &= q_{81}(t) \odot R_1(t) + q_{86}(t) \odot R_6(t) \\ R_9(t) &= q_{91}(t) \odot R_1(t) \end{aligned} \quad \dots\dots(59-65)$$

Where
$$W_2(t) = e^{-\lambda t} E_3(t) + [\lambda e^{-\lambda t} \odot 1] E_3(t), \quad W_6(t) = E_3(t)$$
(66)

Taking Laplace transform of equation (66) and solving for $s \rightarrow 0$, we get

$$W_2^*(0) = W_6^*(0) = \mu_6$$
(67)

In steady-state solution, the total fraction of time for which the repairman is at rest is given by

$$R_0 = \lim_{s \rightarrow 0} s R_0^* = \frac{N_3}{D_1}$$
(68)

Where
$$N_3 = \mu_6 [p_{12}(1 - p_{68}p_{86}) + p_{28}^{(5)} p_{86} + p_{16}^{(3)}]$$
(69)

And D_1 is same as in equation (47).

9. Expected number of visits by expert repairman

$$\begin{aligned}
 V_0(t) &= Q_{01}(t) \otimes [1 + V_1(t)] \\
 V_1(t) &= Q_{10}(t) \otimes V_0(t) + Q_{12}(t) \otimes V_2(t) + Q_{16}^{(3)}(t) \otimes [1 + V_6(t)] + Q_{11}^{(3)}(t) \otimes V_1(t) \\
 V_2(t) &= Q_{21}(t) \otimes V_1(t) + Q_{24}(t) \otimes [1 + V_4(t)] + Q_{28}^{(5)}(t) \otimes V_8(t) + Q_{29}^{(5)}(t) \otimes V_9(t) \\
 V_4(t) &= Q_{40}(t) \otimes V_0(t) + Q_{41}^{(7)}(t) \otimes V_1(t) \\
 V_6(t) &= Q_{68}(t) \otimes V_8(t) + Q_{69}(t) \otimes [1 + V_9(t)] \\
 V_8(t) &= Q_{81}(t) \otimes V_1(t) + Q_{86}(t) \otimes V_6(t) \\
 V_9(t) &= Q_{91}(t) \otimes V_1(t) \quad \dots\dots(70-76)
 \end{aligned}$$

In steady-state, the number of visits per unit time is given by taking $s \rightarrow 0$ and $t \rightarrow \infty$

$$V_0 = \lim_{t \rightarrow \infty} \frac{V_0(t)}{t} = \lim_{s \rightarrow \infty} [sV_0^{**}(s)] = \frac{N_4}{D_1} \quad \dots\dots(77)$$

$$\begin{aligned}
 \text{Where } N_4 &= (1 - p_{68}p_{86}) \left[1 - p_{11}^{(3)} - p_{12}p_{21} + p_{12}p_{24}p_{40} \right] - p_{12} \left(p_{28}^{(5)}p_{81} + p_{29}^{(5)} \right) - \\
 & p_{28}^{(5)}p_{69}p_{86}(1 - p_{12}) + p_{68} \left(p_{29}^{(5)}p_{86} - p_{16}^{(3)}p_{81} \right) \quad \dots\dots(78)
 \end{aligned}$$

And D_1 is same as in equation (47).

10. Cost-Benefit analysis

The expected total profit in steady state is given by

$$P_2 = C_0A_0 - C_1B_0 - C_2R_0 - C_3V_0 \quad \dots\dots(79)$$

Where C_0 is revenue per unit time of the system.

C_1 is cost per unit time for which the repairman is busy.

C_2 is cost per unit time for which the repairman is at rest.

C_3 is cost per visit of the repairman.

11. Comparison Analysis

MTSF vs. Failure Rate of the Main Unit with Initial State S0

The MTSF was calculated using various failure rate (λ) values for the operating unit, as stated in Table 1.1. Figure 1 depicts the related graphs. This has been done by taking particular values of the likelihood of the system that requires repair (p_{12}) and replacement (p_{24}) for the distinct circumstances. (i) $p_{12} > p_{24}$ ($p_{12} = 0.75$; $p_{24} = 0.25$), (ii) $p_{12} = p_{24}$ ($p_{12} = 0.50$; $p_{24} = 0.50$), or (iii) $p_{12} < p_{24}$ ($p_{12} = 0.25$; $p_{24} = 0.75$).

Table 1.1 and Figure 1 illustrate that increasing the operational unit's failure rate (λ) decreases the system's MTSF (T_0) for a fixed value of p_{12}/p_{24} . Changing λ from 0.0015 to 0.0095 results in a 75% to 18% drop in MTSF. Notably, the percentage decline in MTSF is practically equal in all three cases. For a particular operating unit failure rate (λ), MTSF decreases as the chance of system repair decreases or increases. When p_{12} is reduced from 0.75 to 0.25, the MTSF value decreases by 26.34% for $\lambda = 0.0095$ and 28.22% for $\lambda = 0.001$.

TABLE- 1.1

MTSF T_0 vs. Failure Rate λ				
Sr. No.	λ	T_0 $p_{12} = 0.75$; $p_{24} = 0.25$	T_0 $p_{12} = 0.50$; $p_{24} = 0.50$	T_0 $p_{12} = 0.25$; $p_{24} = 0.75$
1	0.0015	210617.5000	175999.0313	151193.4063

2	0.0025	53185.5743	44518.4922	38300.5469
3	0.0035	23876.4190	20018.9805	17248.0626
4	0.0045	13565.8604	11393.0938	9830.2969
5	0.0055	8769.6768	7377.1919	6374.3794
6	0.0065	6151.4351	5183.1207	4484.8975
7	0.0075	4564.9668	3852.5879	3338.2757
8	0.0085	3530.2581	2984.1128	2589.3250
9	0.0095	2817.4273	2385.3301	2072.5977

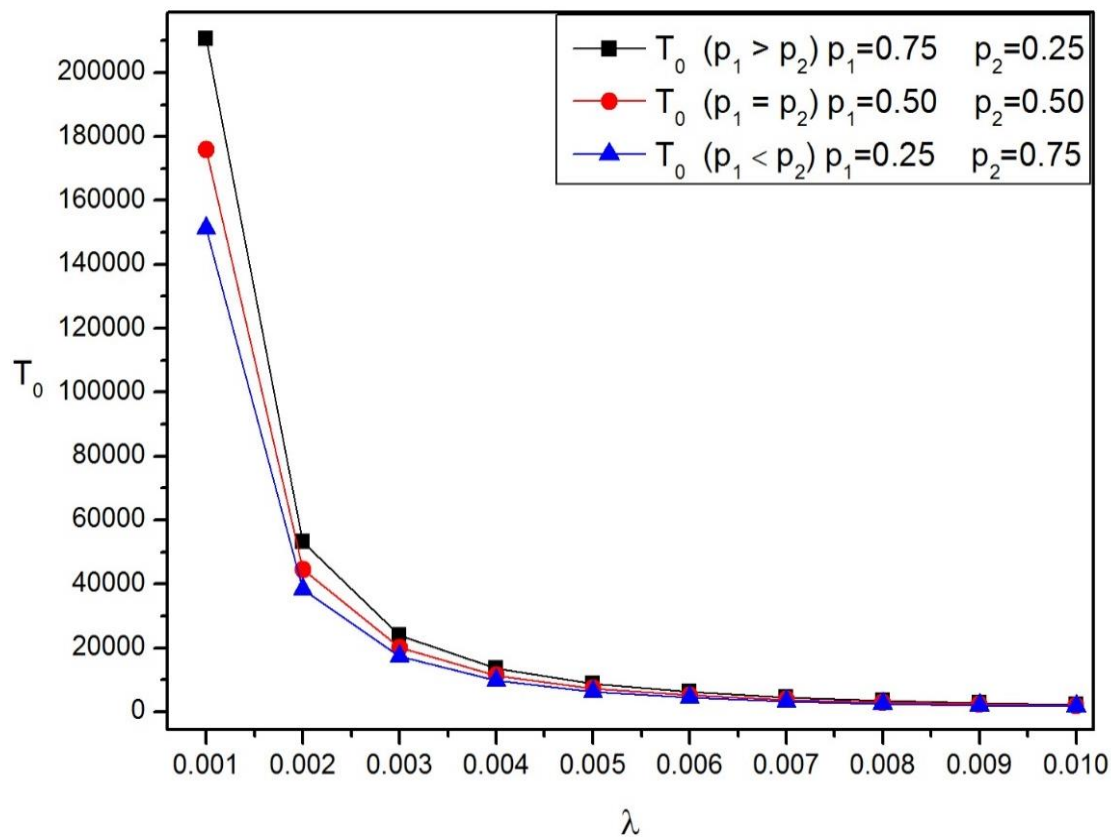


Figure 1 (MTSF T_0 vs. Failure Rate of the system)

MTSF vs. Failure Rate of the Main Unit with Initial State S1

Table 1.2 shows an assessment of the MTSF for different operating unit failure rate values (λ) based on the system's repair (p12) and replacement (p24) scenarios. Figure 2 displays the related graphs for these cases.

Table 1.2 and Figure 2 show that at a given value of p12/p24, the system's MTSF (T_1) decreases fast when the operating unit's failure rate (λ) increases. When λ varies between 0.0015 and 0.0095, the percentage drop in MTSF ranges from 74.85% to 18.51%. The percentage decrease in T_1 is essentially comparable in all three scenarios.

T_1 reduces for a given λ as p12 lowers or p24 increases. T_1 reduces by 27.54% at $\lambda = 0.0095$ and 28.35% at $\lambda = 0.0015$ when p12 declines from 0.75 to 0.25. At higher failure rates (λ), the MTSF (T_1) fluctuates less for a given variance in p12.

TABLE- 1.2

MTSF T_1 vs. Failure Rate λ				
Sr. No.	λ	T_1 $p_{12} = 0.75; p_{24} = 0.25$	T_1 $p_{12} = 0.50; p_{24} = 0.50$	T_1 $p_{12} = 0.25; p_{24} = 0.75$
1	0.0015	209919.1563	175277.5626	150448.1719
2	0.0025	52897.3282	44303.6641	37983.8282
3	0.0035	23721.5333	19853.0391	16974.1778
4	0.0045	13477.6543	11296.5928	9627.8311
5	0.0055	8621.4795	7222.3571	6214.7637
6	0.0065	6029.9097	5056.0621	4353.8492
7	0.0075	4462.4932	3745.3702	3327.6326
8	0.0085	3442.0740	2891.7757	2493.9849

9	0.0095	2740.3570	2404.5665	1989.1618
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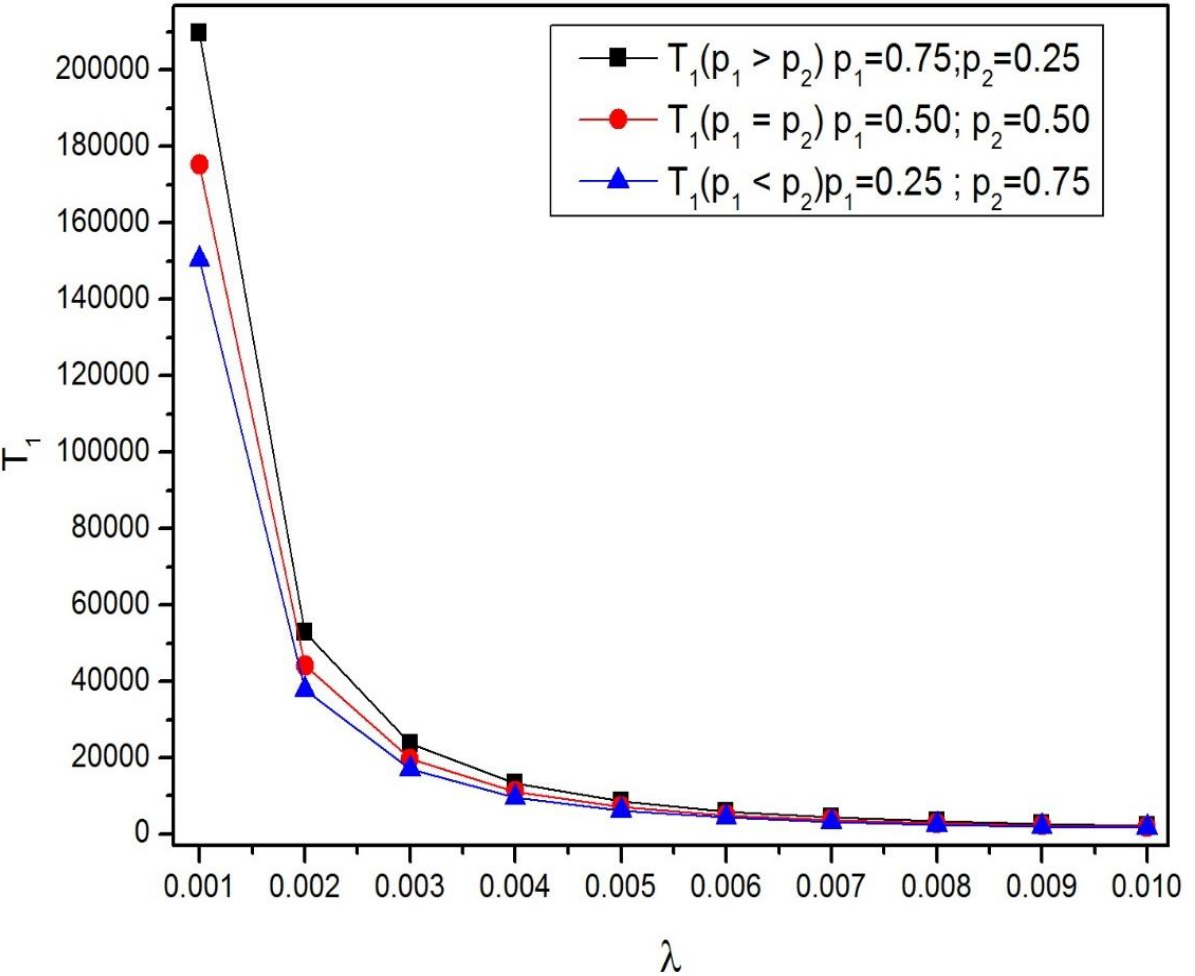


Figure 2 (MTSF T_1 vs. Failure Rate λ of the Main Unit)

12. Conclusion

Using route analysis, the MTSF and availability of the two-unit cold standby system were quickly and readily estimated. As a positional metric, MTSF has been shown to be reliant on the beginning state. On the other hand, by supposing the beginning states to be S0 and S1, it is established that MTSF is dependent on the starting state. On the other hand, by setting the beginning states to S0 and S1, it was observed that the system's steady state availability,

which is the global measure, is the same, even when measured independently.

Observations from the system analysis show that, for any fixed value of the probability of minor or major failures and the inspection, replacement, and repair rates, all of the MTSF of the system with respect to S_0 , S_1 (the initial states) decrease rapidly with the increase in the operating unit's failure rate (λ).

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