

Stochastic Analysis of Compound Redundant System under Perfect Switching with Human Error

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Abstract: This Paper investigate the stochastic behaviour of compound redundant system under perfect switching with human error in terms of various aspect such as reliability, availability etc. In this paper the investigations have been carried out for the evaluation of reliability and MTSF of complex system.

Keywords: Stochastic analysis, MTSF, availability, reliability, standby redundancy, compound redundant system.

1. Introduction

The word Redundancy is generally addressed to forecast the replacement of a unit or part by another unit in case of failure. Redundancy is a very general technique used to improve the performance and reliability of the system. The need for and importance of reliability have been reflected in the constantly increases emphasis on reliability by both government and commercial industry. From an economic point of view, highly reliability is always needed to reduce overall costs. In this paper the investigation have been carried out for the evaluation of reliability and MTSF of a complex system¹⁻⁶, comprising of two subsystems designated A and B connected in series with a single repair facility with the concept of perfect switching. The subsystem A consists of two identical units in parallel and failure of either units reduces the efficiency of the system. The subsystem B consists of two identical units connected in standby redundancy through a perfect switching over device and failure of these units brings the system into failed state. A large percentage of failure in system occurs due to critical human error. This type of failure may occur due to overloading, operational and maintenance error, overheating and design deficiency etc.

System's Configuration

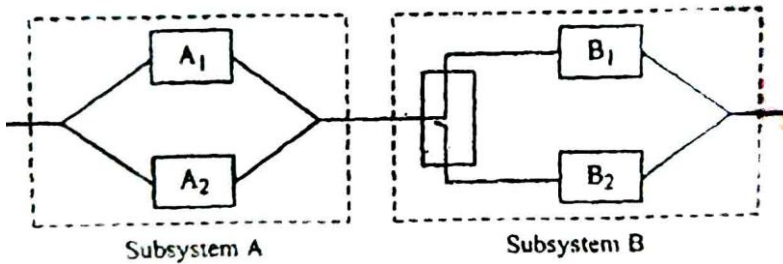


Fig. 1.1

Assumptions

1. Initially, all the units are good.
2. Repair is given only when system is failed.
3. The system fails when both units of either subsystem fail.
4. Failures follow exponential time distribution.
5. Repairs follow general time distribution
6. Switching over device for standby unit of B is perfect.
7. Residual units can't fail from failed state.
8. System/unit fails either due to its normal failure or due to critical human error⁷.
9. After repair, system/unit works like a new one.

Notations

$$D/D_x \quad - \quad \frac{\partial/\partial t}{\partial/\partial x}$$

Constant Failure rates:

- α - Constant failure rate of any unit of subsystem A
- β - Constant failure rate of any unit of subsystem B.
- λ_h - Constant failure rate due of human error.
- $P_{i,0}(y, t) i = 1, 2$ - The probability that at time t , the system is in failed state⁸ due to failure of both the units of system B and elapsed repair time lies in the interval $(y, y + \Delta)$
- $P_{i,0}(x, t) j = 1, s$ - The probability that at time t , the system is in failed state due to failure of both the units of system A and elapsed repair time lies in the interval $(x, x + \Delta)$.
- $P_h(u, t)$ - The probability that at time t , the system is in failed state due to human error and elapsed repair time lies in the interval $(u, u + \Delta)$
- $\mu(x)/v(y)/\delta(u)$ - First order probability that the failed system required in the time interval $[x, x + \Delta]/[y, y + \Delta]/[u, u + \Delta]$

Flow Diagram

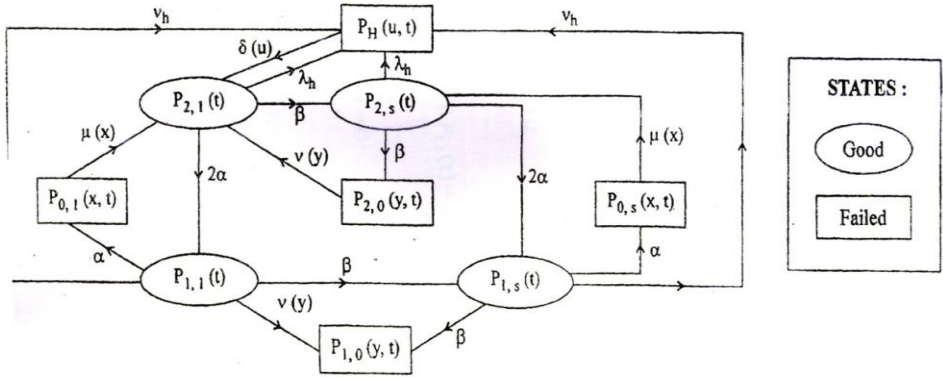


Fig. 1.2

2. Formulation of the Mathematical Model

By probabilistic consideration yield the following mathematical model⁹⁻¹¹ for the stochastic process which is continuous in time and discrete in space:

$$(2.1) \quad \left[\frac{\partial}{\partial t} + 2\alpha + \beta + v_h \right] P_{2,1}(t) = \int_0^\infty P_{2,0}(y, t) v(y) dy + \int_0^\infty P_{0,1}(x, t) \mu(x) dx + \int_0^\infty P_h(u, t) \delta(u) du$$

$$(2.2) \quad \left[\frac{\partial}{\partial t} + \beta + \alpha + v_h \right] P_{1,1}(t) = \int_0^\infty P_{1,0}(y, t) v(y) dy + 2\alpha P_{2,1}(t)$$

$$(2.3) \quad \left[\frac{\partial}{\partial t} + 2\alpha + \beta + v_h \right] P_{2,s}(t) = \int_0^\infty P_{0,s}(x, t) \mu(x) dx + \beta \cdot P_{2,1}(t)$$

$$(2.4) \quad \left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + v(y) \right] P_{1,0}(y, t) = 0$$

$$(2.5) \quad \left[\frac{\partial}{\partial t} + \alpha + \beta + v_h \right] P_{1,s}(t) = \beta \cdot P_{1,1}(t) + 2\alpha P_{2,s}(t)$$

$$(2.6) \quad \left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \mu(x) \right] P_{0,1}(x, t) = 0$$

$$(2.7) \quad \left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \mu(x) + \beta \right] P_{0,s}(x, t) = 0$$

$$(2.8) \quad \left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + v(y) \right] P_{2,0}(y, t) = 0$$

$$(2.9) \quad \left[\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \delta(u) \right] P_h(u, t) = 0$$

Boundary Conditions

$$(2.10) \quad P_{0,1}(0, t) = \beta \cdot P_{1,s}(t)$$

$$(2.11) \quad P_{0,1}(0, t) = \alpha \cdot P_{1,1}(t)$$

$$(2.12) \quad P_{0.s}(0, t) = \alpha. P_{1.s}(t)$$

$$(2.13) \quad P_{2.0}(0, t) = \beta. P_{2.s}(t)$$

$$(2.14) \quad P_h(0, t) = v_h[P_{2.1}(t) + P_{1.1}(t) + P_{2.s}(t) + P_{1.s}(t)].$$

Initial Condition

$$(2.15) \quad P_{2.1}(0) = 1 \text{ and other state probabilities are zero.}$$

Solution of the Model

Taking Laplace transform of eqn. (2.1) through (2.14) and using (2.15) one may get

$$(2.16) \quad [s+2\alpha + \beta + v_h] \bar{P}_{2.1}(s) = \int_0^\infty P_{2.0}(y, s)v(y)dy \\ + \int_0^\infty P_{0.1}(x, s)\mu(x)dx + \int_0^\infty P_h(u, s)\delta du$$

$$(2.17) \quad [s+\beta + \alpha + v_h] \bar{P}_{1.1}(s) = \int_0^\infty \bar{P}_{2.0}(y, s)v(y)dy \\ + \int_0^\infty \bar{P}_{1.0}(y, s)v(y)dy + 2\alpha \bar{P}_{2.1}(s)$$

$$(2.18) \quad [s+2\alpha + \beta + v_h] \bar{P}_{2.s}(s) = \int_0^\infty \bar{P}_{0.s}(x, s)\mu(x)dx + \beta \bar{P}_{2.1}(s)$$

$$(2.19) \quad \left[s + \frac{\partial}{\partial x} + v(y)\right] \bar{P}_{1.0}(y, s) = 0$$

$$(2.20) \quad [s + \alpha + \beta v_h] \bar{P}_{1.s}(s) = \beta \bar{P}_{1.1}(s) + 2\alpha \bar{P}_{2.s}(s)$$

$$(2.21) \quad \left[s + \frac{\partial}{\partial x} + u(x)\right] \bar{P}_{0.1}(x, s) = 0$$

$$(2.22) \quad \left[s + \frac{\partial}{\partial x} + \mu(x) + \beta\right] \bar{P}_{0.s}(x, s) = 0$$

$$(2.23) \quad \left[s + \frac{\partial}{\partial x} + v(y)\right] \bar{P}_{2.0}(y, s) = 0$$

$$(2.24) \quad \left[s + \frac{\partial}{\partial u} + \delta(u)\right] \bar{P}_h(u, s) = 0$$

$$(2.25) \quad \bar{P}_{1.0}(0, s) = \beta. \bar{P}_{1.s}(s)$$

$$(2.26) \quad \bar{P}_{0.1}(0, s) = \alpha. \bar{P}_{1.1}(s)$$

$$(2.27) \quad \bar{P}_{0.s}(0, s) = \alpha. \bar{P}_{1.s}(s)$$

$$(2.28) \quad \bar{P}_{2.0}(0, s) = \beta. \bar{P}_{2.s}(s)$$

$$(2.29) \quad \bar{P}_h(0, s) = v [\bar{P}_{2.1}(s) + \bar{P}_{1.1}(s) + \bar{P}_{2.s}(s) + \bar{P}_{1.s}(s)]$$

Solving these one may arrive at the following results:

$$(2.30) \quad \bar{P}_{2.1}(s) = \frac{1}{C(s)}$$

$$(2.31) \quad \bar{P}_{1.1}(s) = \frac{1}{s+\alpha+\beta+v_h} \left[2\alpha + \beta. \bar{S}_v(s). \frac{A(s)}{B(s)} \right] \times \frac{1}{C(s)}$$

$$(2.32) \quad \bar{P}_{1.s}(s) = \frac{A(s)}{B(s)} \times \frac{1}{C(s)}$$

$$(2.33) \quad \bar{P}_{2.s}(s) = \frac{1}{s+2\alpha+\beta+v_h} \left[\beta + \alpha \cdot \bar{S}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} \right] \times \frac{1}{C(s)}$$

$$(2.34) \quad \bar{P}_{1.0}(s) = \bar{D}_v(s) \cdot \beta \cdot \frac{A(s)}{B(s)} \times \frac{1}{C(s)}$$

$$(2.35) \quad \bar{P}_{0.1}(s) = \frac{\alpha \cdot \bar{D}_\mu(s)}{s+\alpha+\beta+v_h} \left[2\alpha + \beta \cdot \bar{S}_v(s) \cdot \frac{A(s)}{B(s)} \right] \times \frac{1}{C(s)}$$

$$(2.36) \quad \bar{P}_{0.s}(s) = \alpha \cdot \bar{D}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} \times \frac{1}{C(s)}$$

$$(2.37) \quad \bar{P}_{2.0}(s) = \frac{\beta \cdot \bar{D}_v(s)}{s+2\alpha+\beta+v_h} \left[\alpha + \bar{S}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} + \beta \right] \times \frac{1}{C(s)}$$

$$(2.38) \quad \bar{P}_h(s) = v \cdot \bar{D}_\delta(s) \left[1 + \frac{1}{s+\alpha+\beta+v_h} \left(2\alpha + \beta \cdot \bar{S}_v(s) \cdot \frac{A(s)}{B(s)} \right) \right. \\ \left. + \frac{1}{s+2\alpha+\beta+v_h} \left[\beta + \alpha \cdot \bar{S}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} \right] + \frac{A(s)}{B(s)} \right] \times \frac{1}{C(s)}$$

where

$$A(s) = 2\alpha\beta \left[\frac{1}{s+\alpha+\beta+v_h} + \frac{1}{s+2\alpha+\beta+v_h} \right]$$

$$B(s) = s + \alpha + \beta + v_h - \frac{\beta^2}{s + \alpha + \beta + v_h} \bar{S}_v(s) - \frac{2\alpha^2}{s + 2\alpha + \beta + v_h} \bar{S}_\mu(s + \beta)$$

$$C(s) = s + 2\alpha + \beta + v_h - v \bar{S}_\delta(s) - v \bar{S}_\delta(s) \frac{A(s)}{B(s)} - \frac{\beta^2 \bar{S}_v(s)}{(s + 2\alpha + \beta + v_h)} \\ - \frac{\alpha \beta \cdot \bar{S}_v(s) \cdot \bar{S}_\mu(s + \beta)}{(s + 2\alpha + \beta + v_h)} \cdot \frac{A(s)}{B(s)} - \frac{v \beta \cdot \bar{S}_\delta(s)}{(s + 2\alpha + \beta + v_h)} - \frac{v \alpha \cdot \bar{S}_\delta(s) \cdot \bar{S}_\mu(s + \beta)}{(s + 2\alpha + \beta + v_h)} \cdot \frac{A(s)}{B(s)} \\ - \frac{2\alpha^2 \bar{S}_\mu(s)}{s + \alpha + \beta + v_h} - \frac{\alpha \beta \cdot \bar{S}_\mu(s) \cdot \bar{S}_v(s)}{s + \alpha + \beta + v_h} \cdot \frac{A(s)}{B(s)} - \frac{2\alpha \cdot v \cdot \bar{S}_\delta(s)}{s + \alpha + \beta + v_h} \\ - \frac{v \beta \cdot \bar{S}_\delta(s) \cdot \bar{S}_v(s)}{s + \alpha + \beta + v_h} \cdot \frac{A(s)}{B(s)}$$

Evaluation of Up and Down state Probabilities¹²⁻¹³

$$(2.39) \quad \bar{P}_{up}(s) = \bar{P}_{2.1}(s) + \bar{P}_{1.1}(s) + \bar{P}_{1.s}(s) + \bar{P}_{2.s}(s) \\ = \frac{1}{C(s)} \left[1 + \frac{1}{s + \alpha + \beta + v_h} \left(2\alpha + \beta \cdot \bar{S}_v(s) \cdot \frac{A(s)}{B(s)} \right) \right. \\ \left. + \frac{1}{s + 2\alpha + \beta + v_h} \left(\beta + \alpha \cdot \bar{S}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} \right) + \frac{A(s)}{B(s)} \right]$$

$$(2.40) \quad \bar{P}_{down}(s) = \frac{1}{C(s)} \left[\frac{\alpha \cdot \bar{D}_\mu(s)}{s + \alpha + \beta + v_h} \left(2\alpha + \beta \cdot \bar{S}_v(s) \cdot \frac{A(s)}{B(s)} \right) + \bar{D}_v(s) \cdot \beta \cdot \frac{A(s)}{B(s)} \right. \\ \left. + \frac{\beta \cdot \bar{D}_v(s)}{s + 2\alpha + \beta + v_h} \left(\beta + \alpha \cdot \bar{S}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} \right) + \alpha \cdot \bar{D}_\mu(s + \beta) \cdot \frac{A(s)}{B(s)} \right]$$

$$\begin{aligned}
& + v. \bar{D}_\delta(s) \left\{ 1 + \frac{1}{s + 2\alpha + \beta + v_h} \left(2\alpha + \beta. \bar{S}_v(s). \frac{A(s)}{B(s)} \right) \right. \\
& + v. \bar{D}_\delta(s) \left\{ 1 + \frac{1}{s + 2\alpha + \beta + v_h} \left(2\alpha + \beta. \bar{S}_v(s). \frac{A(s)}{B(s)} \right) \right. \\
& \left. \left. + \frac{1}{s + 2\alpha + \beta + v_h} \left(\beta + \alpha. \bar{S}_\mu(s + \beta) \frac{A(s)}{B(s)} \right) + \frac{A(s)}{B(s)} \right\} \right\}
\end{aligned}$$

It is worth noticing that

$$(2.41) \quad \bar{P}_{up}(s) + \bar{P}_{down}(s) = \frac{1}{s}.$$

Ergodic Behaviour of the system

Using corollary of Abel's Lemma, viz,

$$\lim_{s \rightarrow 0} s \bar{f}(s) = \lim_{t \rightarrow \infty} f(t) = f(\text{say})$$

provided the limit on right exists, the system's steady state probabilities¹⁴⁻¹⁵ are obtained as follows:

$$(2.42) \quad P_{2.1} = \frac{1}{C'(0)}$$

$$(2.43) \quad P_{1.1} = \frac{1}{\alpha + \beta + v_h} \left[2\alpha + \beta. \bar{S}_v(0) \frac{A(0)}{B(0)} \right] \times \frac{1}{C'(0)}$$

$$(2.44) \quad P_{2.s} = \frac{1}{2\alpha + \beta + v_h} \left[\beta + \alpha. \bar{S}_\mu(\beta). \frac{A(0)}{B(0)} \right] \times \frac{1}{C'(0)}$$

$$(2.45) \quad P_{1.0} = \bar{D}_v(0). \beta \frac{A(0)}{B(0)} \times \frac{1}{C'(0)}$$

$$(2.46) \quad P_{1.s} = \frac{A(0)}{B(0)} \times \frac{1}{C'(0)}$$

$$(2.47) \quad P_{0.1} = \frac{\alpha. \bar{D}_\mu}{\alpha + \beta + v_h} \left[2\alpha + \beta. \bar{S}_v(0). \frac{A(0)}{B(0)} \right] \times \frac{1}{C'(0)}$$

$$(2.48) \quad P_{0.s} = \frac{\alpha. A(0)}{B(0)} \bar{D}_\mu(\beta) \times \frac{1}{C'(0)}$$

$$(2.49) \quad P_{2.0} = \frac{\beta. \bar{D}_\mu}{2\alpha + \beta + v_h} \left[\alpha. \bar{S}_\mu(\beta) \frac{A(0)}{B(0)} + \beta \right] \times \frac{1}{C'(0)}$$

$$\begin{aligned}
(2.50) \quad P_h = v. \bar{D}_\delta(0) & \left[1 + \frac{1}{\alpha + \beta + v_h} \left(2\alpha + \beta. \bar{S}_v(0) \frac{A(0)}{B(0)} \right) \right. \\
& \left. + \frac{1}{2\alpha + \beta + v_h} \left(\beta + \alpha. \bar{S}_\mu(\beta) \frac{A(0)}{B(0)} \right) + \frac{A(0)}{B(0)} \right] \times \frac{1}{C'(0)}
\end{aligned}$$

Up and Down State Probabilities for Steady State

$$\begin{aligned}
P_{up} = \frac{1}{C'(0)} & \left[1 + \frac{1}{\alpha + \beta + v_h} \left\{ 2\alpha + \beta. \bar{S}_v(0) \frac{A(0)}{B(0)} \right\} \right. \\
& \left. + \frac{1}{2\alpha + \beta + v_h} \left\{ \beta + \alpha. \bar{S}_\mu(\beta). \frac{A(0)}{B(0)} \right\} + \frac{A(0)}{B(0)} \right]
\end{aligned}$$

where $C'(0) = \left[\frac{d}{ds} C(s) \right]_{s=0}$

$$P_{\text{down}} = 1 - P_{\text{up}}$$

Particular Cases

When repair follow exponential time distributions:

Setting $\bar{S}_z(s) = \frac{z}{s+z}$, where $z = \mu, \delta, v$ in equation (2.30) through (2.38), one may get

$$(2.51) \quad \bar{P}_{2.1}(s) = \frac{1}{C_1(s)}$$

$$(2.52) \quad \bar{P}_{1.1}(s) = \frac{1}{s + \alpha + \beta + v_h} \left[2\alpha + \frac{\beta \cdot v}{s + v} \cdot \frac{A(s)}{B_1(s)} \right] \times \frac{1}{C_1(s)}$$

$$(2.53) \quad \bar{P}_{2.s}(s) = \frac{1}{s + \alpha + \beta + v_h} \left[\beta + \frac{\alpha \cdot \mu}{s + \beta + \mu} \cdot \frac{A(s)}{B_1(s)} \right] \times \frac{1}{C_1(s)}$$

$$(2.54) \quad \bar{P}_{1.s}(s) = \frac{A(s)}{B(s)} \times \frac{1}{C_1(0)}$$

$$(2.55) \quad \bar{P}_{1.0}(s) = \left(\frac{1}{s+v} \right) \cdot \beta \cdot \frac{A(s)}{B_1(s)} \times \frac{1}{C_1(s)}$$

$$(2.56) \quad \bar{P}_{0.1}(s) = \frac{\alpha}{s + \alpha + \beta + v_h} \cdot \frac{1}{s + v} \left[\frac{\beta \cdot v}{s + v} \cdot \frac{A(s)}{B(s)} + 2\alpha \right] \times \frac{1}{C_1(s)}$$

$$(2.57) \quad \bar{P}_{0.s}(s) = \alpha \cdot \frac{A(s)}{B_1(s)} \left[\frac{1}{s + \mu + \beta} \right] \times \frac{1}{C_1(s)}$$

$$(2.58) \quad \bar{P}_{2.0}(s) = \frac{\beta}{(s + 2\alpha + \beta + v_h)(s + v)} \left[\alpha \cdot \frac{\mu}{s + \mu + \beta} \cdot \frac{A(s)}{B_1(s)} + \beta \right] \times \frac{1}{C_1(s)}$$

$$(2.59) \quad \bar{P}_H(s) = v \cdot \frac{1}{s + \delta} \left[1 + \frac{1}{s + \alpha + \beta + v_h} \left(2\alpha + \frac{\beta \cdot v}{s + v} \cdot \frac{A(s)}{B(s)} \right) \right. \\ \left. + \frac{1}{s + 2\alpha + \beta + v_h} \left(\beta + \frac{\alpha \cdot \mu}{s + \beta + \mu} \cdot \frac{A(s)}{B_1(s)} + \frac{A(s)}{B_1(s)} \right) \times \frac{1}{C_1(s)} \right]$$

where $B_1(s) = s + \alpha + \beta + v_h - \frac{\beta^2}{(s + \alpha + \beta + v_h)} \cdot \frac{v}{s + v} - \frac{2\alpha^2}{(s + 2\alpha + \beta + v_h)} \cdot \frac{\mu}{s + \mu + \beta}$

$$C_1(s) = s + 2\alpha + \beta + v_h - \frac{v\delta}{s + \delta} - \frac{v\delta}{s + \delta} \cdot \frac{A(s)}{B_1(s)} - \frac{\beta^2}{(s + 2\alpha + \beta + v_h)} \cdot \frac{v}{s + v} \\ - \frac{\alpha\beta \cdot v\mu}{(s + 2\alpha + \beta + v_h)(s + v)(s + \mu + \beta)} \cdot \frac{A(s)}{B_1(s)} - \frac{v\beta \cdot \delta}{(s + \delta)(s + 2\alpha + \beta + v_h)} \\ - \frac{v\alpha \cdot \delta \cdot \mu}{(s + 2\alpha + \beta + v_h)(s + \delta)(s + \mu + \beta)} \cdot \frac{A(s)}{B_1(s)} - \frac{2\alpha^2 \mu}{(s + \mu)(s + \alpha + \beta + v_h)} \\ - \frac{\alpha\beta \cdot \mu \cdot v}{(s + \alpha + \beta + v_h)(s + \mu)(s + v)} \cdot \frac{A(s)}{B_1(s)} - \frac{2\alpha \cdot v \cdot \delta}{(s + \delta)(s + \alpha + \beta + v_h)} \\ - \frac{v\beta \cdot \delta \cdot v}{(s + \alpha + \beta + v_h)(s + \delta)(s + v)} \cdot \frac{A(s)}{B_1(s)}$$

Numerical Computation of Reliability and MTSF

$$(2.60) \quad \bar{R}(s) = \frac{1}{s + 2\alpha + \beta + v_h} \left[1 + \frac{2\alpha}{s + \alpha + \beta + v_h} + \frac{\beta}{s + 2\alpha + \beta + v_h} + \frac{2\alpha\beta}{(s + 2\alpha + \beta + v_h)(s + \alpha + \beta + v_h)} + \frac{2\alpha\beta}{(s + 2\alpha + \beta + v_h)^2} \right],$$

where $\bar{R}(s)$ is the Laplace transform of the reliability function. The reliability of the transit system is

$$(2.61) \quad R(t) = e^{-(\alpha + \beta + v_h)t} \left[2 + \frac{2\beta}{\alpha} \right] - \beta \cdot e^{-(2\alpha + \beta + v_h)t} \cdot t - \left[1 + \frac{2\beta}{\alpha} \right] \cdot e^{-(2\alpha + \beta + v_h)t} + 2\beta \cdot t \cdot e^{-(\alpha + \beta + v_h)t}$$

The mean time to system failure (MTSF) is given as under

$$(2.62) \quad \text{MTSF} = \lim_{s \rightarrow 0} \bar{R}(s) = \frac{1}{2\alpha + \beta + v_h} \left[1 + \frac{2\alpha}{\alpha + \beta + v_h} + \frac{\beta}{2\alpha + \beta + v_h} + \frac{2\alpha\beta}{(\alpha + \beta + v_h)(2\alpha + \beta + v_h)} + \frac{2\alpha\beta}{(\alpha + \beta + v_h)^2} \right]$$

3. Analysis

A. Reliability Analysis

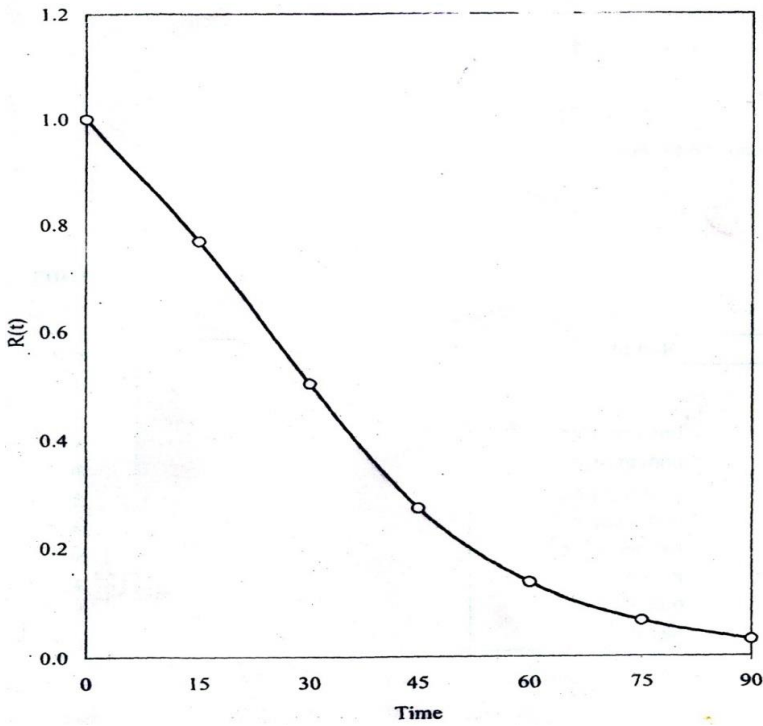
Setting $\alpha = 0.01, \beta = 0.02, v_h = 0.03$ in eqn. (1.61)

$$R(t) = 6 \times e^{-(0.06)t} - 0.02t \cdot e^{-0.07t} - 5e^{-0.07t} + 0.04e^{-0.06t} \cdot t$$

Effect of time on Reliability

Table 3.1

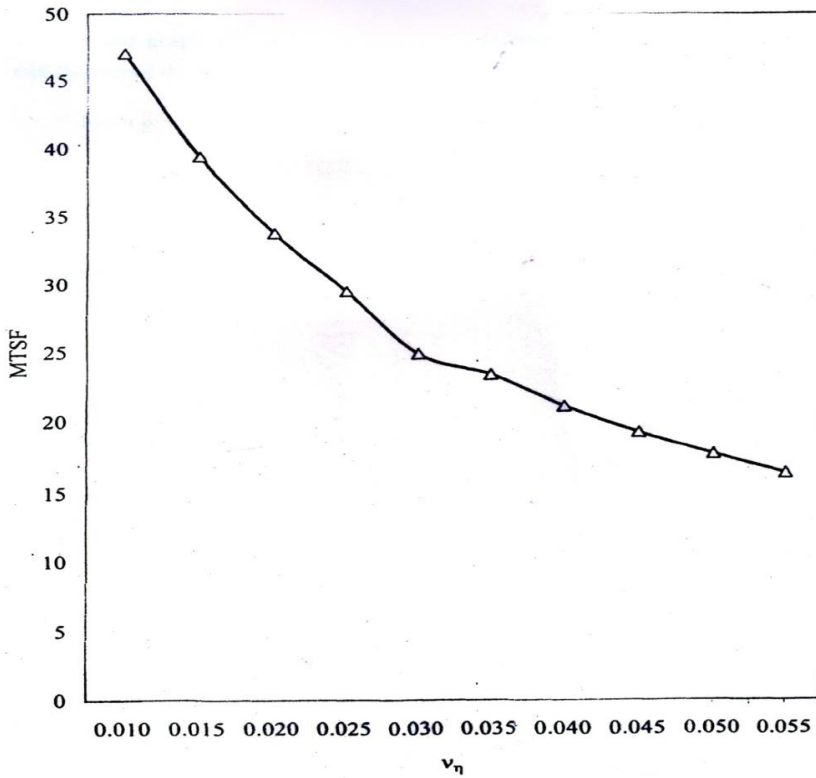
S.No.	Time	R(t)
1.	0	1.00000
2.	15	0.76867
3.	30	0.50440
4.	45	0.27138
5.	60	0.13655
6.	75	0.06587
7.	90	0.03087

**Graph 3.1****B. MTSF Analysis**

Setting different values of v_h for $\alpha = 0.01$ and $\beta = 0.02$ in eqn. (4.62) one can compute

Effect of MTSF**Table 3.2**

S.No.	v_h	MTSF
1.	0.010	47.00000000
2.	0.015	39.40413900
3.	0.020	33.77716000
4.	0.025	29.46799000
5.	0.030	24.85200000
6.	0.035	23.34780000
7.	0.040	21.10969386
8	0.045	19.24490578
9	0.050	17.66975000
10	0.055	16.32336164



Graph 3.2

4. Conclusion

From graph 3.1, it is concluded that as time t increases, $R(t)$ decreases rapidly during the early life and becomes very small in the long run. From graph 3.2, it is concluded that as v_h increases MTSF decreases.

References

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