Availability and Profit Analysis of Power Cables Used as a Two Unit Hot Standby System with Inspection in Metro Railways Network

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ABSTRACT: Metro railways network becomes an integral part of our life. The failure-resistant network which uses power cables of different capacities for supplying energy to the metro system. The study of the metro network system facilitates carrying out reliability modelling and profit analysis of this energising power system through power cables. The cables are laid in loops for feeding supply to substations from each station. Initially, one cable is in working state, and the other cable of same voltage capacity is taken as a hot standby. In case of failure, the second cable can be made operative without delay. Inspections have been carried out at each failure to check whether the system is repairable or not. The calculations to measure System Effectiveness and Profit Analysis are done using "Semi-Markov Processes" and "Regenerative Point Technique". The results obtained through calculations have been showcased and verified through different graphs with discussions and conclusion.

Keywords: Metro Railways, Power Cables, Profit Analysis, Semi-Markov Processes, Regenerative Point Technique, System Effectiveness.

1. INTRODUCTION

The paper demonstrates reliability study results towards taking recourse for effective utilisation and timely maintenance of different industrial engineering systems. Extensive work on reliability and profit analysis has been carried out on different types of redundant standby systems by many researchers including [1-4]. B. Parashar and G. Taneja [5] analysed a PLC system based upon real data collected from industry. S.M. Rizwan et al. [6] studied the reliability of an industrial system taking hot standby. Z. Zhang et al. [7] and G. Taneja [9] discussed aspects of maintenance and variation in demand of different systems. B. Parashar and A. Naithani [8 & 13] discussed a system of ID fans in a thermal plant under different conditions such as at full/reduced capacity. R. Malhotra and G. Taneja [11] extended the work on a cable manufacturing plant of a two-unit cold standby system considered to be operative depending upon the demand. S.Z. Taj et al. [15] dealt in electrical cables manufacturing plant with minor and major preventive measures. A. Monacha and G. Taneja [12] worked on a two-unit cold standby system with arbitrary distribution for life, repair and waiting times. Ranu Pandey et al. [14] discussed a system of power cables of two unit cold standby systems in Metro Railways based upon real data collected. Sheetal et al. [16] discussed profit analysis of a fabric manufacturing company system with the effect of temperature. Electricity is central to modern life. Conductors facilitate the flow of electrical energy. Cables are conductors covered by insulating material and act as, "energy transportation nerves." To maintain system efficiency it is critical that any failure, due to cable manufacturing defects or system malfunctioning, is reduced to its lowest levels [10]. However, to assess and predict the failure or breakdown, mathematical modelling tools come handy. The probability analysis is thought to critically delve into the problem of "FAILURE" and achieve near reality solution. The reduction in break-downs to a minimum level contributes to the higher availability of the Electrical System in considered Metro trains and transportation becomes smooth and public at large gets motivated with better confidence.

There are various power cables with different capacities of 220, 132, 66, 33, 25 KV are used in supplying power for the functioning of the metro network system. The failure data of eight years have been collected for the power cable with the capacity of 33KV. These cables are laid in loops for feeding supply to the substation at each station. So in order to overcome the damage of 33 KV power cables due to numerous factors that include manufacturing defects, external defects etc., maintenance of the power cables are of prime concern as it has a direct impact on the functioning of the metro railways system. The aim of the study is to analyse the reliability by considering an inspection in two unit hot standby identical parallel power cable of 33KV capacity. The following measures of the system effectiveness are analysed by making use of "Semi-Markov Processes" and "Regenerative Point Technique":

- Mean Time to System Failure
- The steady-state Availability Analysis
- The busy period of the repairman for Inspection, repair and replacements of the power cable at $t=0$
- Repairman expected number of visits at $t=0$
- Expected number of replacements

- Expected profit gained to the system

2. SYMBOLS AND NOTATIONS

O	Power cable in an operative state
O_{hs}	Hot Standby Unit of the power cable
λ	The failure rate of the operative power cable
p	The probability of failure (repairable) of the unit
q	The probability of replacement (irreparable) of the unit
r	The probability of the unit found Ok
F_{ui}	The unit is under inspection in case of failure
F_r	The unit is under repair
F_{rp}	The unit is under replacement
F_{Ui}	The state continues under the inspection of failure from its former state.
F_R	The state continues under repair of failure from its former state.
F_{RP}	The state continues under replacement from its former state.
F_{wi}	No longer working unit waiting for inspection
γ	Constant rate of inspection
α	Constant rate of repairable failure
β	Constant rate of replacement failure
$g(t), G(t)$	p.d.f and c.d.f. of repair-time of failed unit
$h(t), H(t)$	p.d.f. and c.d.f. of replacement-time of failed unit
$h_1(t), H_1(t)$	p.d.f. and c.d.f. of inspection-time of failed unit
$w(t), W(t)$	p.d.f. and c.d.f. of waiting-time of failed unit
$q_{ij}(t), Q_{ij}(t)$	p.d.f. and c.d.f. for the first passage of time from a regenerative state "i" to "j" or to a failed state "j" without visiting any other regenerative state in $(0,t]$
p_{ij}	Transition probability from regenerative-state "i" to regenerative state "j"
$M_i(t)$	Probability that system up initially in regenerative state "i" is up at time "t" without passing through any other regenerative state
m_{ij}	Contribution to mean sojourn-time in regenerative state "i" before transiting to regenerative-state "j" without visiting to any other state
$\mu_i(t)$	Mean sojourn-time in regenerative-state before transiting to any other state
©, $\otimes$	Symbols for 'Laplace' and 'Laplace-Stieltje's' convolution
*, **	Symbols for 'Laplace' and 'Laplace-Stieltje's' transforms
C_0	Indicates revenue per unit up-time
C_1	Represent cost per unit up-time for which the repairman is busy for repair
C_2	Represent cost per unit up-time for the repairman busy in replacement
C_3	Represent cost per unit up-time for the repairman busy in inspection
C_4	Represent cost per visit of the repairman
C_5	Represent cost per unit replacement
A_0	Steady-state availability of the system
B_0	The busy period of the repairman for repair at $t=0$
BR_0	The busy period of the repairman for replacement at $t=0$
BR_{i0}	The busy period of the repairman for inspection at $t=0$
V_0	Repairman expected number of visits at $t=0$

R_0 Expected number of replacements

3. **DATA SUMMARY**

The following values have been obtained from the collected data:

- The estimated value of failure rate (λ) =.000015 per hour
- The estimated value of repair rate (α) =.067per hour
- The estimated value of replacement rate (β) =.002 per hour
- The estimated value of inspection rate (γ) =1 per hour
- The probability of repairable failure (p) =.69
- The probability of replaceable failure (q) =.16
- The probability of unit found ok (r) =.15
- The expected cost of Revenue up time (C_0) = 30000
- The expected cost of repairman during repair (C_1) = 3000
- The expected cost of repairman during replacement (C_2) = 250
- The expected cost of repairman per visit during inspection (C_3) = 600 per hour
- The expected cost of repairman per visit (C_4) = 500 per hour
- The expected cost of cable replacement (C_5) = 150000

(All costs are in INR)

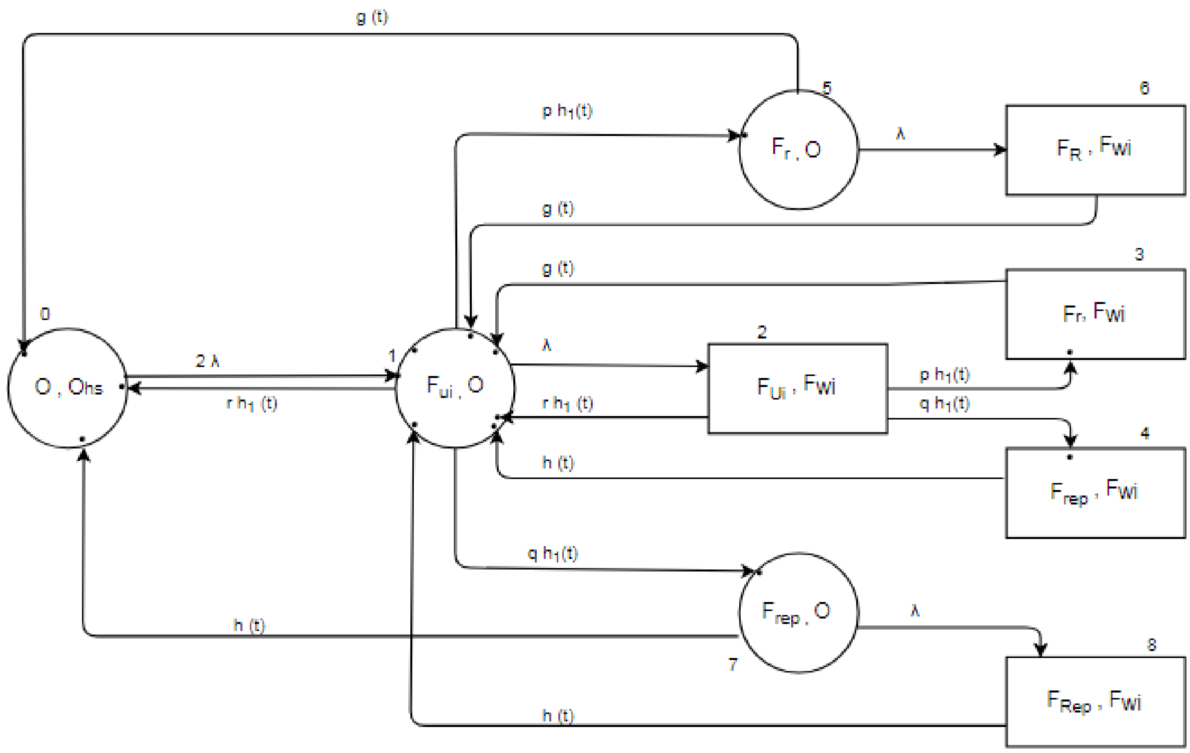
4. MODEL DESCRIPTION AND ASSUMTIONS

The assumptions used in the probabilistic model are given below:

1) Initially, the system is operative at full capacity with two power cables; one is operative, and another one is used as a hot standby
2) The two power cables are identical and constitute a parallel system.
3) If one unit is failed, the standby unit becomes operative immediately.
4) As the unit fails, it is undertaken for inspection.
5) The failure rate of hot standby unit is same as that of an operative unit.
6) Failure, repair and inspection times are assumed to follow an exponential and general time distribution respectively.
7) The repairman is available for inspection and is common for repair as well as for replacement.
8) The repaired unit works as good as a new one.
9) The system will be in the failed state when both units are not working.
10) All the random variables are independent.

5. TRANSITION DIAGRAM

A state transition diagram showing all the possible states of the system under consideration as shown in the Fig.1. The span of entry into states 0, 1, 3, 4, 5, 7 are regeneration points, and thus these are called regenerative states. The states 0, 1, 5, 7 are up states whereas 2, 3, 4, 6, 8 are failed states.



- Regeneration Point
- ◯ System in Operative State
- ▭ System in Failed State

Fig.1: State Transition Diagram

6. TRANSITION PROBABILITIES AND MEAN SOJOURN TIME

The steady-state transition probabilities are

$$dQ_{01}(t) = 2\lambda e^{-2\lambda t} dt\,,$$

$$dQ_{12}(t) = \lambda e^{-\lambda t}\, \bar{H}_1\, dt,$$

$$dQ_{10}(t) = re^{-\lambda t} h_1(t)dt,$$

$$dQ_{15}(t) = pe^{-\lambda t} h_1(t)dt,$$

$$dQ_{17}(t) = qe^{-\lambda t} h_1(t)dt,$$

$$dQ_{11}^{2}(t) = r(1-e^{-\lambda t})\mathrm{h}_1(t)dt,$$

$$dQ_{14}^{2}(t) = q(1-e^{-\lambda t})h_1(t)dt,$$

$$dQ_{13}^{2}(t) = p(1-e^{-\lambda t})h_1(t)dt,$$

$$dQ_{50}(t) = e^{-\lambda t}\mathrm{g}(t)dt,$$

$dQ_{56}(t) = \lambda e^{-\lambda t}\bar{G}(t)dt,$

$dQ_{51}^{6}(t) = (\lambda e^{-\lambda t} © 1)g(t)dt,$

$dQ_{71}^{8}(t) = (\lambda e^{-\lambda t} © 1)h(t)dt,$

$dQ_{70}(t) = e^{-\lambda t}h(t)dt,$

$dQ_{78}(t) = \lambda e^{-\lambda t}\bar{H}(t)dt,$

$dQ_{31}(t) = g(t)dt,$

$dQ_{41}(t) = h(t)dt$

(1)

The non-zero elements $p_{ij} = \lim_{s\to 0} q_{ij}^{*}(s)$ can be obtained as

$p_{01} = 1,$

$p_{31} = 1,$

$p_{41} = 1,$

$p_{10} = rh_1^{*}(\lambda),$

$p_{15} = ph_1^{*}(\lambda),$

$p_{17} = qh_1^{*}(\lambda),$

$p_{11}^{2} = r[1 - h_1^{*}(\lambda)],$

$p_{12} = [1 - h_1^{*}(\lambda)],$

$p_{13}^{2} = p[1 - h_1^{*}(\lambda)],$

$p_{14}^{2} = q[1 - h_1^{*}(\lambda)],$

$p_{51}^{6} = [1 - g^{*}(\lambda)],$

$p_{50} = g^{*}(\lambda),$

$p_{56} = [1 - g^{*}(\lambda)],$

$p_{70} = h^{*}(\lambda),$

$p_{78} = [1 - h^{*}(\lambda)],$

$p_{71}^{8} = [1 - h^{*}(\lambda)],$

(2)

From the above steady-state transition probabilities, it can be verified that

$$p_{01} = p_{31} = p_{41} = 1,$$

$$p_{10} + p_{12} + p_{15} + p_{17} = p_{10} + p_{15} + p_{17} + p_{13}^{2} + p_{14}^{2} + p_{11}^{2} = 1,$$

$$p_{50} + p_{56} = p_{50} + p_{51}^{6} = p_{70} + p_{78} = p_{70} + p_{71}^{8} = 1.$$
(3)

The mean sojourn time (μ_i) in the regenerative state "i" is

$$\mu_0 = \frac{1}{2\lambda},$$

$$\mu_1 = \frac{1 - h_1^*(\lambda)}{\lambda},$$

$$\mu_3 = \int_0^\infty t g(t) dt,$$

$$\mu_4 = \int_0^\infty t h(t) dt,$$

$$\mu_5 = \frac{1 - g^*(\lambda)}{\lambda},$$

$$\mu_7 = \frac{1 - h^*(\lambda)}{\lambda},$$

$$\kappa_1 = \int_0^\infty t h_1(t) dt,$$
(4)

The unconditional mean time for the system to transit for any regenerative state "j" when it is counted from the starting point of entrance into state "i" is mathematically stated as

$$m_{ij} = \int_0^\infty t dQ_{ij}(t) = -q_{ij}^{*'}(0).$$
(5)

Thus,

$$m_{01} = \mu_0,$$

$$m_{31} = m_{50} + m_{51}^{6} = \mu_3,$$

$$m_{50} + m_{56} = \mu_5,$$

$$m_{10} + m_{12} + m_{15} + m_{17} = \mu_1,$$

$$m_{70} + m_{78} = \mu_7,$$

$$m_{70} + m_{71}^{8} = m_{41} = \mu_4,$$

$$m_{10} + m_{15} + m_{17} + m_{13}^{2} + m_{14}^{2} + m_{11}^{2} = \kappa_1. \qquad (6)$$

where,

$$\kappa_1 = \int_0^\infty \bar{H}_1(t)dt = \int_0^\infty th_1(t)dt,$$

$$\mu_3 = \int_0^\infty \bar{G}(t)dt = \int_0^\infty tg(t)dt,$$

$$\mu_4 = \int_0^\infty \bar{H}(t)dt = \int_0^\infty th(t)dt.$$

7. MEASURES OF SYSTEM EFFECTIVENESS

7.1. Mean Time to System Failure (MTSF). Taking failed state of the system as absorbing state, Let $\phi_i(t)$, be the cumulative distribution function of first passage time from i^{th} state to a failed state where i =0,1,2,3,4,5,6,7,8. MTSF of the system can be determined by the following recursive relations for $\phi_i(t)$

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

$$\phi_1(t) = Q_{10}(t) \otimes \phi_0(t) + Q_{15}(t) \otimes \phi_5(t) + Q_{17}(t) \otimes \phi_7(t) + Q_{12}(t),$$

$$\phi_5(t) = Q_{50}(t) \otimes \phi_0(t) + Q_{56}(t),$$

$$\phi_7(t) = Q_{70}(t) \otimes \phi_0(t) + Q_{78}(t). \qquad (7)$$

Taking Laplace-Stieltjes Transform (L.S.T.) of the above relations given by (7) on both the sides and solving them for $\phi_0^{**}(s)$, we obtain

$\phi_0^{**}(s) = \dfrac{N_0(s)}{D_0(s)}$, $\phi_0^{**}(s)$ represents the Laplace-Stieltjes Transform of $\phi_0(s)$.

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

$$MTSF = \lim_{s \to 0} \frac{1-\phi_0^{**}(s)}{s} = \frac{D_0^{'}(0) - N_0^{'}(0)}{D_0(0)} = \frac{N}{D},$$

Where,

$$N = \mu_0 + \mu_1 + p_{15}\mu_5 + p_{17}\mu_7,$$

$$D = 1 - p_{10} - p_{15}p_{50} - p_{17}p_{70}. \qquad (8)$$

7.2. Availability Analysis

Let $A_i(t)$ be the probability that the system is working at the instant time "t", given that the system entered regenerative state "i" at $t = 0$.

Then,

$$A_0(t) = M_0(t) + q_{01}(t) © A_1(t),$$

$$A_1(t) = M_1(t) + q_{10}(t) © A_0(t) + q_{15}(t) © A_5(t) + q_{17}(t) © A_7(t) + q_{11}^2(t) © A_1(t) + q_{13}^2(t) © A_3 + q_{14}^2(t) © A_4(t),$$

$$A_3(t) = q_{31}(t) © A_1(t),$$

$$A_4(t) = q_{41}(t) © A_1(t),$$

$$A_5(t) = M_5(t) + q_{51}^6(t) © A_1(t) + q_{50}(t) © A_0(t),$$

$$A_7(t) = M_7(t) + q_{71}^8(t) © A_1(t) + q_{70}(t) © A_0(t).$$

(9)

Where,

$$M_0(t) = e^{-2\lambda t}, M_1(t) = e^{-\lambda t} \bar{H}_1(t), M_5(t) = e^{-\lambda t} \bar{G}(t), M_7(t) = e^{-\lambda t} \bar{H}(t).$$

Taking Laplace transforms of above equations and solving them for $A_0^*(s)$, we get

$$A_0^*(s) = \frac{N_1(s)}{D_1(s)},$$

The availability A_0 in steady-state of the present system is defined as

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

Where,

$$N_1 = \mu_0(1 - p_{11}^2 - p_{13}^2 p_{31} - p_{41} p_{14}^2 - p_{15} p_{51}^6 - p_{71}^8 p_{17}) + \mu_1 + \mu_5 p_{15} + \mu_7 p_{17},$$
$$D_1 = 1 + p_{17}\mu_4 + p_{13}^2 \mu_3 + \mu_4 p_{14}^2 + p_{15}\mu_3 + \mu_0(p_{15} p_{50} + p_{17} p_{70} + p_{10}).$$

(10)

7.3. Busy Period Analysis of Repairman (Repair only)

The total fraction of the time $B_0^*(s)$ for which the system is under repair of the repairman is calculated by the following recursive relation

$$B_0(t) = q_{01}(t) © B_1(t),$$

$$B_1(t) = q_{10}(t) © B_0(t) + q_{15}(t) © B_5(t) + q_{17}(t) © B_7(t) + q_{11}^2(t) © B_1(t) + q_{13}^2(t) © B_3(t) + q_{14}^2(t) © B_4(t),$$

$$B_3(t) = W_3(t) + q_{31}(t) © B_1(t),$$

$$B_4(t) = q_{41}(t) © B_1(t),$$

$$B_5(t) = W_5(t) + q_{50}(t) © B_0(t) + q_{51}^{6}(t) © \mathrm{B}_1(t),$$

$$B_7(t) = q_{70}(t) © B_0(t) + q_{71}^{8}(t) © \mathrm{B}_1(t),$$

(11)

Where,

$$W_3(t) = \bar{G}(t), W_5(t) = \bar{G}(t).$$

Taking Laplace transforms of above equations and solving them for $B_0^*(s)$, we get

$$B_0^*(s) = \frac{N_2(s)}{D_1(s)},$$

In steady-state, the busy period of the repairman is given by,

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

Where,

$$N_2 = \mu_3(p_{15} + p_{13}^{2}),$$
(12)

Moreover, $D_1(s)$ is already calculated.

7.4. Busy Period Analysis of Repairman (Replacement only)

$$BR_3(t) = q_{31}(t) © BR_1(t),$$

$$BR_4(t) = W_4(t) + q_{41}(t) © BR_1(t),$$

$$BR_5(t) = q_{50}(t) © BR_0(t) + q_{51}^{6}(t) © \mathrm{BR}_1(t),$$

$$BR_7(t) = W_7(t) + q_{70}(t) © BR_0(t) + q_{71}^{8}(t) © \mathrm{BR}_1(t),$$
(13)

Where,

$$W_4(t) = \bar{H}(t), W_7(t) = \bar{H}(t).$$

Taking Laplace transforms of above equations and solving them for $BR_0^*(s)$, we get

$$BR_0^*(s) = \frac{N_3(s)}{D_1(s)},$$

In steady-state, the busy period of the repairman is given by,

$$BR_0 = \lim_{s \to 0} s.BR_0^*(s) = \frac{N_3}{D_1},$$

Where,

$$N_3 = (p_{17} + p_{14}^2)(p_{01}\mu_4)\,, \qquad (14)$$

And moreover, $D_1(s)$ is already specified.

7.5. Busy Period Analysis of Repairman (Inspection time only)

$$BR_{i0}(t) = q_{01}(t) © BR_{i1}(t),$$

$$BR_{i1}(t) = W_1(t) + q_{10}(t) © \mathrm{BR}_{i0}(t) + q_{15}(t) © BR_{i5}(t) + q_{17}(t) © BR_{i7}(t) + q_{11}^2(t) © BR_{i1}(t) + q_{13}^2(t) © BR_{i3}(t) + q_{14}^2(t) © BR_{i4}(t),$$

$$BR_{i3}(t) = q_{31}(t) © BR_{i1}(t),$$

$$BR_{i4}(t) = q_{41}(t) © BR_{i1}(t),$$

$$BR_{i5}(t) = q_{50}(t) © BR_{i0}(t) + q_{51}^6(t) © \mathrm{BR}_{i1}(t),$$

$$BR_{i7}(t) = q_{70}(t) © BR_{i0}(t) + q_{71}^8(t) © \mathrm{BR}_{i1}(t), \qquad (15)$$

Where,

$$W_2(t) = \bar{H}_1(t).$$

Taking Laplace transforms of above equations and solving them for $BR_0^*(s)$, we get

$$BR_{i0}^*(s) = \frac{N_4(s)}{D_1(s)},$$

In steady-state, the busy period of the repairman is given by,

$$BR_{i0} = \lim_{s \to 0} s.BR_{i0}^*(s) = \frac{N_4}{D_1},$$

Where,

$$N_4 = \kappa_1 p_{01}\,, \qquad (16)$$

Moreover, $D_1(s)$ is already specified.

7.6. Expected Number of Visits by the Repairman

$$V_0(t) = Q_{01}(t) \otimes [1 + V_1(t)],$$

$$V_1(t) = Q_{10}(t) \otimes \mathrm{V}_0(t) + Q_{15}(t) \otimes V_5(t) + Q_{17}(t) \otimes V_7(t) + Q_{11}^2(t) \otimes V_1(t) + Q_{13}^2(t) \otimes V_3(t) + Q_{14}^2(t) \otimes V_4(t),$$

$$V_3(t) = Q_{31}(t) \otimes V_1(t),$$

$$V_4(t)=Q_{41}(t)\otimes V_1(t),$$

$$V_5(t)=Q_{50}(t)\otimes V_0(t)+Q_{51}^{6}(t)\otimes \mathrm{V}_1(t),$$

$$V_7(t)=Q_{70}(t)\otimes V_0(t)+Q_{71}^{8}(t)\otimes \mathrm{V}_1(t). \tag{17}$$

Taking Laplace-Stieltjes Transforms (L.S.T.) of above equations on both the sides and solving them for $V_0^{**}(s)$, we get

$$V_0^{**}(s)=\frac{N_5(s)}{D_1(s)},$$

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

$$V_0=\lim_{s\to 0} s.V_0^{**}(s)=\frac{N_5}{D_1},$$

Where,

$$N_5=p_{01}(1-p_{17}p_{71}^{8}-p_{15}p_{51}^{6}-p_{11}^{2}-p_{31}p_{13}^{2}-p_{41}p_{14}^{2}) \tag{18}$$

and $D_1(s)$ is already specified.

7.7. Expected Number of Replacements.

$$R_0(t)=Q_{01}(t)\otimes R_1(t),$$

$$R_1(t)=Q_{10}(t)\otimes \mathrm{R}_0(t)+Q_{15}(t)\otimes R_5(t)+Q_{17}(t)\otimes[1+R_7(t)]+Q_{11}^{2}(t)\otimes R_1(t)+Q_{13}^{2}(t)\otimes R_3(t)$$
$$+Q_{14}^{2}(t)\otimes[1+R_4(t)],$$

$$R_3(t)=Q_{31}(t)\otimes R_1(t),$$

$$R_4(t)=Q_{41}(t)\otimes R_1(t),$$

$$R_5(t)=Q_{50}(t)\otimes R_0(t)+Q_{51}^{6}(t)\otimes \mathrm{R}_1(t),$$

$$R_7(t)=Q_{70}(t)\otimes R_0(t)+Q_{71}^{8}(t)\otimes \mathrm{R}_1(t). \tag{19}$$

Taking Laplace-Stieltjes Transforms (L.S.T.) of above equations on both the sides and solving them for $R_0^{**}(s)$, we get

$$R_0^{**}(s)=\frac{N_6(s)}{D_1(s)},$$

In steady-state, the expected number of replacements is given by,

$$R_0=\lim_{s\to 0} s.R_0^{**}(s)=\frac{N_6}{D_1},$$

Where,

$N_6 = (p_{17} + p_{14}^2)p_{01}$,
(20)

And moreover, $D_1(s)$ is already specified.

8. PROFIT ANALYSIS

The total expected profit P of the system at steady state can be calculated by expected total revenue in $(0,t]$ minus expected total costs of repair, replacement and inspection in $(0,t]$ minus expected cost of visits by repairman in $(0,t]$minus the cost of the number of replacements in $(0,t]$. Hence, the overall profit in $(0,t]$ is given by

$$P = C_0 A_0 - C_1 B_0 - C_2 BR_0 - C_3 BR_{i0} - C_4 V_0 - C_5 R_0 ,$$
(21)

9. Particular Case

For the particular case, the inspection, repair and replacement rate are assumed to be exponentially distributed, let us take $g(t) = \alpha e^{-\alpha t}; h(t) = \beta e^{-\beta t}; h_1(t) = \gamma e^{-\gamma t}$

Using the values, as estimated in section 3, of various probabilities and repairable/replaceable/inspection rates the following measures of system effectiveness are obtained as:

Mean Time to System Failure: 24567649.7782hours

Availability of the system A_0: .9999820

Expected busy period for repairable failures by the repairman B_0: .000308

Expected busy period of the repairman for replaceable failure BR_0: .00239

Expected busy period for inspection of a failure by the repairman BR_{i0}: .000301

Expected number of visits by the repairman V_0 : .0000299

Expected number of replacement R_0: .0000048

10. Figures

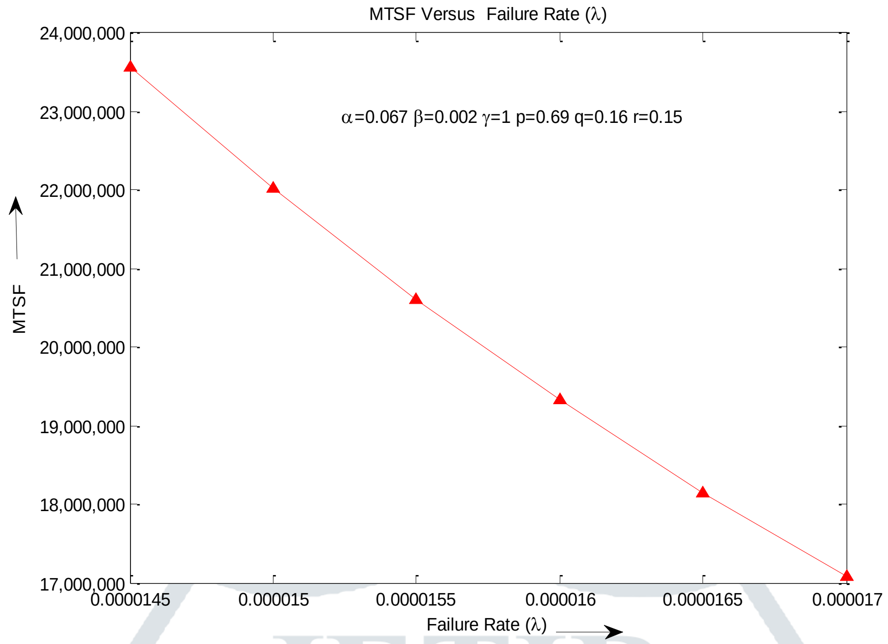


Fig. 2: MTSF versus Failure rate

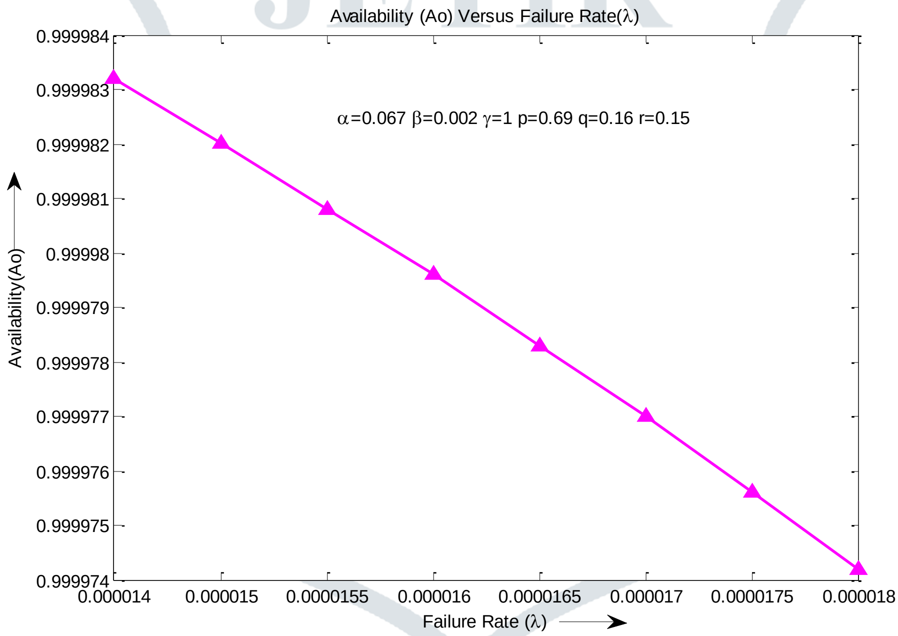


Fig. 3: Availability versus Failure rate

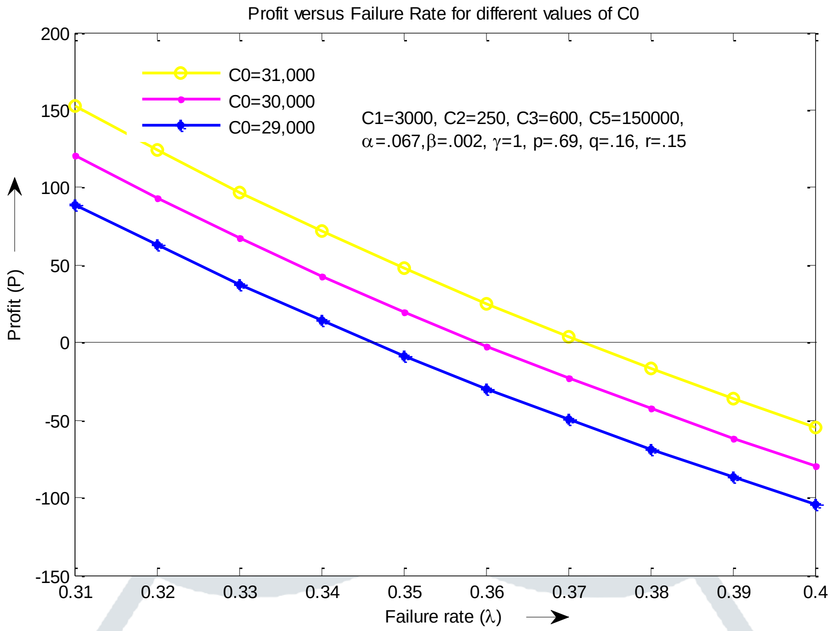


Fig. 4: Profit (P) Versus Failure rate λ for different values of the revenue per unit up time (C0)

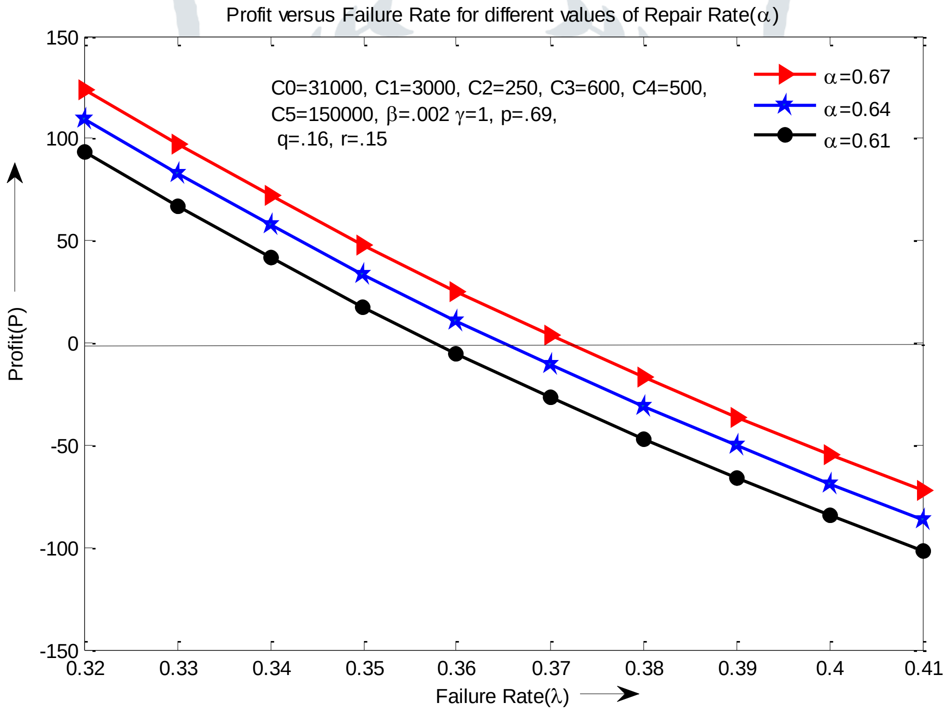


Fig. 5: Profit (P) versus Failure rate λ for different values of Repair Rate (α)

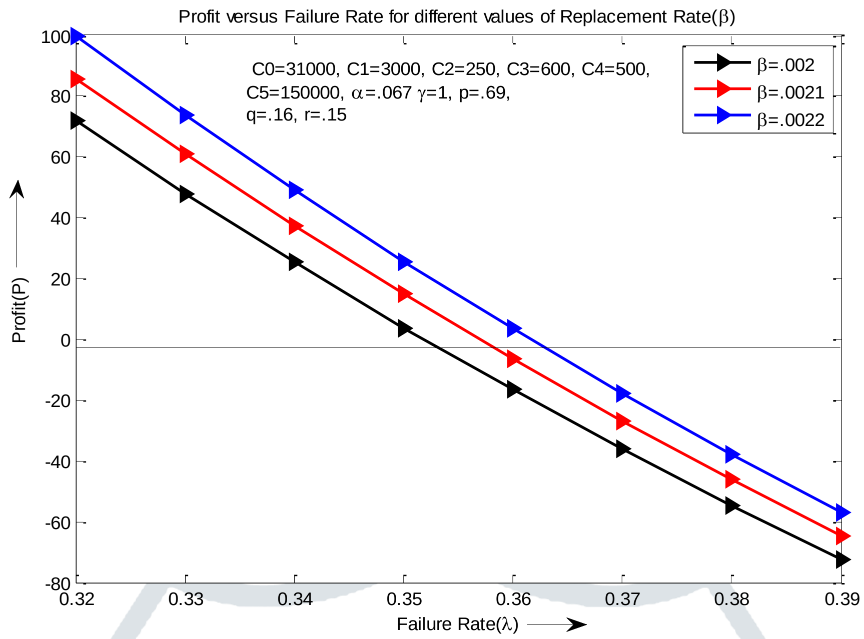


Fig. 6: Profit (P) versus Failure rate λ for different values of Replacement Rate (β)

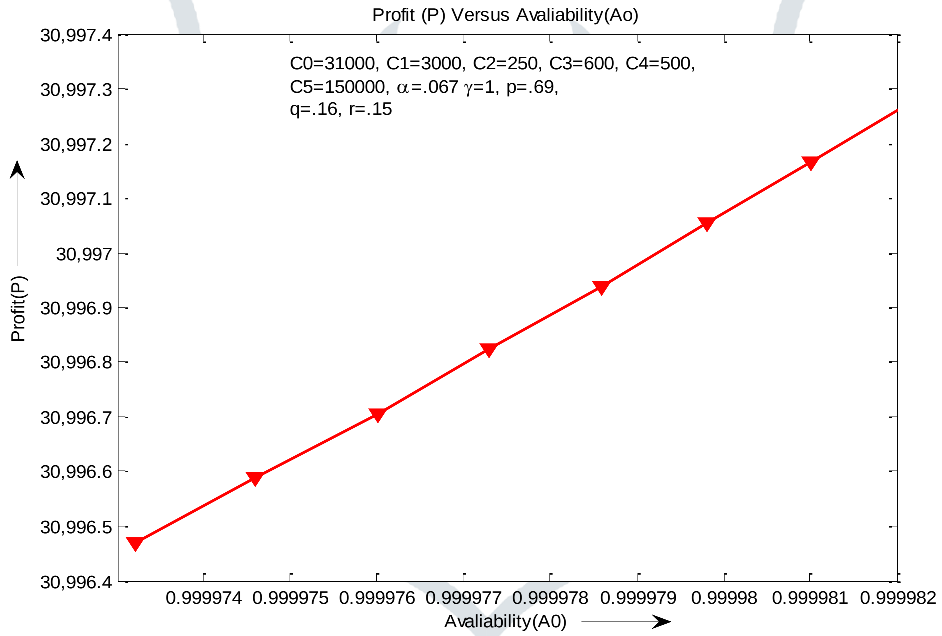


Fig. 7: Profit (P) versus Availability (A0)

Conclusions have been made from the graphs as follows:

Figure 2 depicts the decrease in MTSF concerning the increase of failure rate λ .

Figure 3 displays the Availability of the system decreases with an increase in the failure rate λ .

Figure 4 analysis shows that the profit decreases with an increase in the failure rate λ for different values of revenue per unit up time (C0). It is concluded that if C0=29000 then P >or=or<0 accordingly as failure rate λ <or=or>.3467. So, for the system to be beneficial for C0=29000, failure rate λ should be less than .3467. Similarly, for C0=30000 and 31000 the values of failure rate λ should be less than .3594 and .3723 respectively.

Figure 5 depicts that the profit decreases with an increase in the failure rate λ for different values of repair rate α if repair rate α =.067 then P >or=or<0 accordingly as failure rate λ <or=or>.3743. For the system benefit, failure rate λ must be less than .3743.Similarly, if repair rate α =.064 and .061 the cut-off points of failure rate λ must be less than .3656 and .3595 respectively.

Figure 6 shows that the profit decreases with an increase in the failure rate λ for different values of replacement rate β if replacement rate β =.002 then P >or=or<0 accordingly as failure rate λ <or=or>.3543. For the system benefit, failure rate λ must be less than .3543 similarly, if replacement rate β =.0021 and .0022 the cut-off points of failure rate λ must be less than .3596 and .3634 respectively.

Figure 7 shows that the profit P increases when the availability $A0$ of the system increases.

11. DISCUSSIONS & CONCLUSION

To make the system effectively dependable and near failure-proof, variant measures have been thoughtfully considered and accordingly the calculations made to compute system mean time to system failure, predict reliability and availability in the concerned system. Graphical representations have also been made for markup of cut-off points. This will directly result in modifying the system intending to achieve greater profitability and concurrently minimize the losses. This present paper will prove beneficial in the target optimization of the existing system.

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