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Profit Evaluation of a System having Bath-tub Curved Failure Pattern and Some Components under Warranty

Rajeev Kumar[1], Vinod Kumar[2] and Reena[3]

Department of Mathematics, M. D. University, Rohtak (Haryana) India.

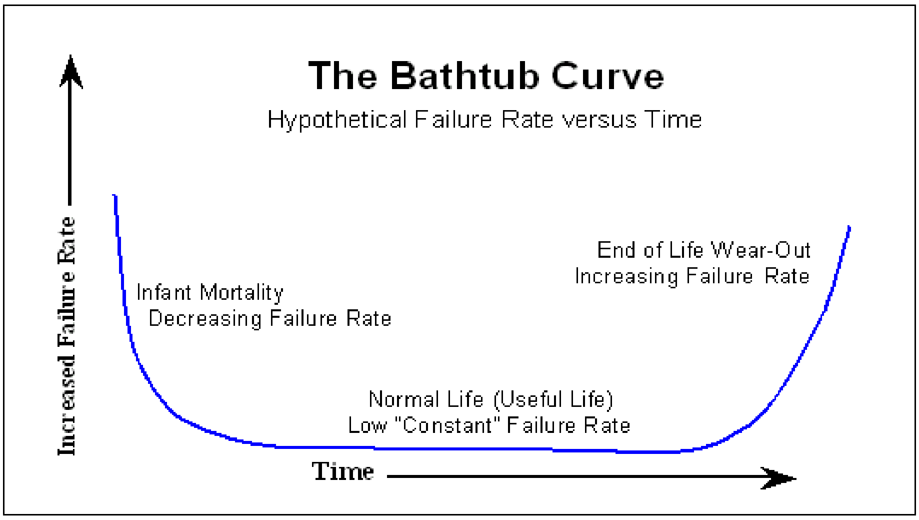
Abstract

This paper deals with a single unit sophisticated system wherein unit has bath-tub curved failure pattern. Some components of the system are assumed to be under warranty up to the useful life period. It is considered that there are two type service facilities-one service engineer during warranty period and another available repairman on payment basis during non-warranty period. On failure of the system during warranty/ non warranty period, the service engineer /available repairman first inspects whether the components having fault requires repairs/replacements and accordingly, carries out repairs/replacements. Further, during warranty period, the service engineer inspects the components periodically for the online/offline repairs/replacements, if required. Various measures of the system effectiveness are obtained at different stages of operation using Markov process and regenerative point techniques. Profit analyses of the system, both in system user's and system provider's point of view, are carried out and various conclusions have been drawn on the basis of graphical study.

Keywords: Bath-tub curved shape, burn-in period, useful life period, wear out period, warranty, profit, Markov process and Regenerative point techniques.

INTRODUCTION

A typical bath-tub curve and its "standard" shape have been widely accepted as an engineering tool in reliability management and training. Therefore, a critical discussion is developed to research the bath-tub curve along three significant periods of bath-tub; i.e. early life period, useful life and wear-out



Several researchers in the reliability theory including Pulcini (2001), Stancliff et al. (2006), Sarkar and Behera (2012) and Vijay et al. (2013) has considered bath-tub curve for estimation of various systems parameter and equipments such as water mains system, mobile robot, electric power system and equipment, turbine, compressor, generator and combustion chamber, power plant, automobiles etc. and Murari and Goyal (1983),Tuteja and Taneja (1991), Kumar et al (2001), Tuteja et al. (2006) and Kumar and Batra (2013) analyzed a large number of systems considering various concepts such as different failure modes,faults, repairs, replacements, inspections,degradation etc. In most of the system it is observed that during the installation of the system the failure rate is high then it decreases. This failure may be due to poor manufacturing defect, poor design, poor materials, errors in assembly or even poor knowledge of operation etc. This period is called Burn-in Period. In the useful life period the failure rate is approximately constant throughout the period. Here, the failure is random and unpredictable. Finally, the failure rate increases and it is due to aging of the system, and it is called wear-out period.The system under warranty with three operational stages of the system viz. proper installation, after proper installation during warranty period and after the expiry of the warranty period has been discussed by Kumar et al.(2009). Kumar et al. (2010) carried out profit analysis of a three stage operational single unit system under warranty and two types of service facility.

In practical situtaions when an unit is under warranty for some specified period as per the warranty contract the service enginer periodically visits the system for perventive/ corrective maintenaces of the system and after inspection of the system carries out online repairs or repalcements, if required. This aspect has not been considered in the litarature of reliabilty modeling.

Keeping above practical situation in view, this paper investigates a single unit sophisticated system having bath-tub curve shaped failure pattern and some of its components are under warranty. That is, during early life /burn-in period failure rate is high. Then it decreases and goes to a constant level during useful life period and again it increases during wear-out period. Two types of service facilities-one service engineer during warranty period and another available repairman on payment basis during non-warranty period are considered. On failure of the system the available repairman/service engineer first inspects whether the components having fault requires repair /replacement and then carry out repair /replacement. It is assumed that during warranty period the service enginer periodically visits the system for perventive/ corrective maintenaces of the system and after inspection of the system carries out online/offline repairs or repalcements, if required. Various measures of the system effectiveness are obtained using the concept of Markov Process and regenerative point technique. Profit analyses of the system, both in system user's and system provider's point of view, are carried out and various conclusions have been drawn on the basis of graphical study.

Assumptions

1. The system may have minor or major failure(s) during any of its operational stage and the failures can be detected immediately and properly.
2. The minor failure can be repaired on-line whereas major failure requires off-line replacement by a new unit that needs re-installation.
3. The service engineer carries out proper installation or burn-in process, i.e during burn-in period of the system. The srrvice engineer is available with the system.
4. The available repairman takes negligible time to reach the system.
5. The service engineer takes some arrival time to visit the system for periodic perventive/corrective maintances.
6. The unit works as good as new after each repair/replacement in that particular operational stage.
7. The unit has exponential distributions for times to failure, improvement and deterioration while the other distributions are arbitrary.
8. All the random variables are mutually independent.

Notations

$\lambda_1/\lambda_2/\lambda_3$	rate of occurance of faults during burn-in / useful life /wear-out period
η_1/η_2	improvement rate/deterioration rate of the system
$p_1/p_2/p_4$	probability that the unit requires repair during burn-in / useful life / wear-out period
p_3	probability that the unit requires online repair during useful life period
$q_1/q_2/q_4$	probability that the unit requires replacement during burn-in / useful life / wear-out period
q_3	probability that the unit requires online replacement during useful

	life period
r_3	probability that the unit after online inspection is found O.K. during useful life.
$g_1(t)/g_2(t)/ g_4(t)$	p.d.f of off-line repair time during burn-in / useful life / wear-out period
$g_3(t)$	p.d.f of online repair time during useful life
$G_1(t)/G_2(t)/G_4(t)$	c.d.f. of repair time during burn-in / useful life / wear-out period
$G_3(t)$	c.d.f of online repair time during useful life
$h_1(t)/h_2(t) /h_4(t)$	p.d.f of replacement time by similar unit during burn-in / useful life / wear-out period
$h_3(t)$	p.d.f of online replacement time during useful life
$H_1(t)/ H_2(t)/ H_4(t)$	c.d.f of replacement time during burn-in / useful life / wear-out period
$H_3(t)$	c.d.f of online replacement time during useful life
$i_1(t)/i_2(t)/ i_4(t)$	p.d.f of inspection time of the system during burn-in / useful life / wear-out period
$i_3(t)$	p.d.f of online inspection time during useful life period
$I_1(t)/I_2(t)/ I_4(t)$	c.d.f of inspection time of the system during burn-in / useful life / wear-out period
$I_3(t)$	c.d.f of online inspection time during useful life period
$k(t)/K(t)$	p.d.f /c.d.f. of arrival time of service engineer

State of the System

Si	state numbers i, i = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
$O_I/O_w/O_{Nw}$	system is operating during burn-in / useful life /wear-out period
F_{I_i}	system is in failed state and is under inspection during burn-in period
$F_{I_r}/F_{I_{rp}}$	system is in failed state and is under repair/replacement during burn-in period
O_{wi_3}	system is under inspection during useful life period
O_{wr}/O_{wrp}	system is under on-line repair/replacement on inspection during useful life period
F_{wi_2}	system is in failed state and is under inspection during useful life period
F_{wr}/F_{wrp}	system is in failed state and is under repair/replacement during useful life period
F_{i_4}	system is in failed state and is under inspection during wear-out period
F_r/F_{rp}	system is in failed state and is under repair/replacement during wear-out period

A state transition diagram in fig. 1 shows various states of transitions of the system. The epochs of entry into states 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12,13 and 14 are regeneration points and thus these are regenerative states. The states 1,2, 3,5, 6, 7, 12 ,13 and 14 are failed states.

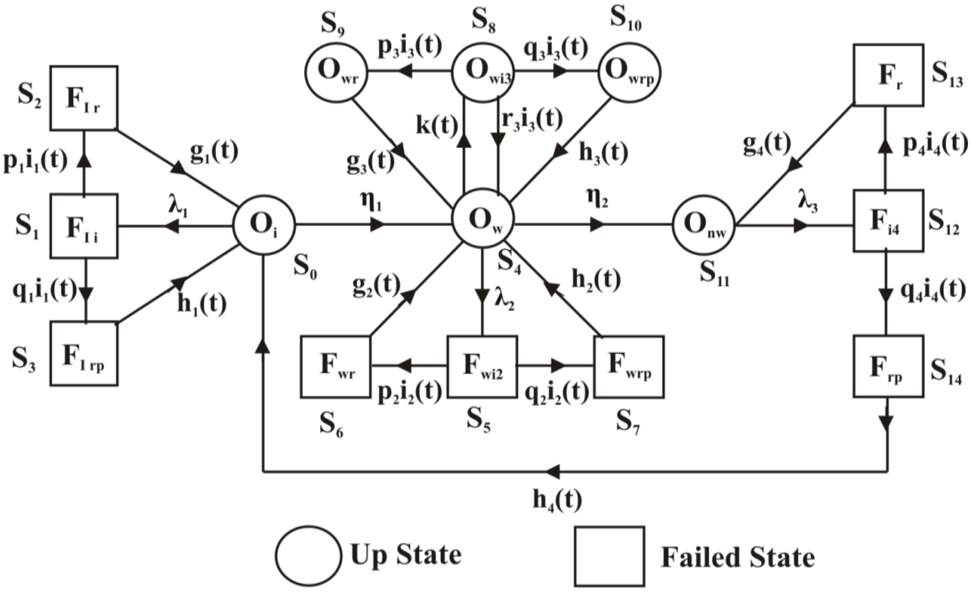


Figure 1. State Transition Diagram

Transition Probabilities and Mean Sojourn Times

The transition probabilities are given by

$q_{01}(t) = \lambda_1 e^{-(\lambda_1+\eta_1)t}$ $\qquad q_{04}(t) = \eta_1 e^{-(\lambda_1+\eta_1)t}$

$q_{12}(t) = p_1 i_1(t)$ $\qquad q_{12}(t) = q_1 i_1(t)$

$q_{20}(t) = g_1(t)$ $\qquad q_{30}(t) = h_1(t)$

$q_{45}(t) = \lambda_2 e^{-(\lambda_2+\eta_2)t}\overline{K}(t)$ $\qquad q_{48}(t) = k(t)e^{-(\lambda_2+\eta_2)t}$

$q_{4,11}(t) = \eta_2 e^{-(\lambda_2+\eta_2)t}\overline{K}(t)$ $\qquad q_{56}(t) = p_2 i_2(t)$

$q_{57}(t) = q_2 i_2(t)$ $\qquad q_{64}(t) = g_2(t)$

$q_{74}(t) = h_2(t)$ $\qquad q_{84}(t) = p_3 i_3(t)$

$q_{89}(t) = q_3 i_3(t)$ $\qquad q_{8,10}(t) = r_3 i_3(t)$

$q_{94}(t) = g_3(t)$ $\qquad q_{10,4}(t) = h_3(t)$

$q_{11,12}(t) = \lambda_3 e^{-\lambda_3 t}$ $\qquad q_{12,13}(t) = p_4 i_4(t)$

$q_{12,14}(t) = q_4 i_4(t)$ $\qquad q_{13,11}(t) = g_4(t)$

$q_{14,0}(t) = h_4(t)$

The non-zero elements p_{ij} obtained as $p_{ij} = \lim_{s\to 0} q^*_{ij}(s)$ and are given by

$p_{01} = \lambda_1/D$; $p_{04} = \eta_1/D$; $p_{45} = (1- k^*(\lambda_2+\eta_2))\lambda_2/D_0$;

$p_{48} = k^*(\lambda_2+\eta_2)$; $p_{411} = (1- k^*(\lambda_2+\eta_2))\eta_2/D_0$; $p_{12} = p_1$;

$p_{13} = q_1$; $p_{56} = p_2$; $p_{57} = q_2$;

$p_{89} = q_3$; $p_{810} = r_3$; $p_{84} = p_3$;

$p_{12,13} = p_4$; $p_{12,14} = q_4$;

where

$D=\lambda_1+\eta_1$ and $D_0= \lambda_2+\eta_2$

By these transitions probabilities it can be verified that

$p_{20} = p_{30} = p_{64} = p_{74} = p_{94} = p_{10,4} = p_{13,11} = p_{11,12} = p_{14,0} = 1$

$p_{01}+p_{04} = p_{12}+p_{13} = p_{45}+p_{48}+p_{411} = p_{56}+p_{57} = p_{84}+p_{89}+p_{810} = p_{1213}+p_{1214} = 1$

Also the mean sojourn times in regenerative states i (μ_i) are:

$\mu_0 = 1/(\lambda_1 + \eta_1)$ $\mu_1 = -i_1^{*'}(0)$ $\mu_2 = -g_1^{*'}(0)$

$\mu_3 = -h_1^{*'}(0)$ $\mu_4 = (1/(\lambda_2 + \eta_2))(1+ k^*(\lambda_2+\eta_2))$ $\mu_5 = -i_2^{*'}(0)$

$\mu_6 = -g_2^{*'}(0)$ $\mu_7 = -h_2^{*'}(0)$ $\mu_8 = -i_3^{*'}(0)$

$\mu_9 = -g_3^{*'}(0)$ $\mu_{10} = -h_3^{*'}(0)$ $\mu_{11} = 1/\lambda_3$

$\mu_{12} = -i_4^{*'}(0)$ $\mu_{13} = -g_4^{*'}(0)$ $\mu_{14} = -h_4^{*'}(0)$

The unconditional mean time taken by the system to transit for any state j when it is counted from the epoch of entrance into the state i, is mathematically stated as:

$$m_{ij} = \int_0^\infty t q_{ij}(t)dt = -q^{*'}_{ij}(s)$$

Thus

$m_{01} + m_{04} = \mu_0$; $m_{12} + m_{13} = \mu_1$; $m_{20} = \mu_2$;

$m_{30} = \mu_3$; $m_{45} + m_{48} + m_{411} = \mu_4$; $m_{56}+m_{57}=\mu_5$;

$m_{64} = \mu_6$; $m_{74} = \mu_7$; $m_{84} + m_{89}+m_{810} = \mu_8$;

$m_{94} = \mu_9$ $m_{104} = \mu_{10}$ $m_{1112} = \mu_{11}$;

$m_{1213}+m_{1214} = \mu_{12}$; $m_{1311} = \mu_{13}$ $m_{140} = \mu_{14}$

Other Measures of System Effectiveness

Using the probabilistic arguments for regenerative process, recursive relations for various other measures of the system effectiveness for different stages of operation are obtained and on solving them using Laplace/Laplace-Shieltjes transforms, we get

Mean Time to System Failure

In the steady-state, mean time to system failure is given by

$$T_0 = \frac{N_1}{D_1}$$

where $N_1 = \mu_0(1-p_{48}) + p_{0,4}(\mu_4 + \mu_8 p_{4,8} + \mu_9 p_{4,8}\, p_{8,9} + \mu_{10} p_{4,8}\, p_{8,10} + \mu_{11} p_{4,11})$

and $D_1 = 1-p_{48}$

Availability Analysis

In the steady-state, availability of the system is given by

$$A_0 = \frac{N_2}{D_2},$$

where

$$N_2 = \mu_0\, p_{4,11}\, p_{12,14} + \mu_4\, p_{0,4} p_{12,14} + \mu_{11}\, p_{0,4} p_{4,11}$$

and

$$D_2 = [\mu_0 + p_{01}[\mu_1 + \mu_2 p_{12} + p_{13}\mu_3] p_{4,11} p_{12,14}] + [\mu_{11} + \mu_{12} + \mu_{13} p_{12,13} + p_{12,14}\mu_{14}] p_{04} p_{4,11} + [\mu_4 + p_{45}[\mu_5 + p_{56}\mu_6 + p_{57}\mu_7] + p_{48}[1 + \mu_8 + \mu_9 p_{89} + p_{8,10}\mu_{10}]] p_{04} p_{12,14}$$

Busy Period of the Service Engineer/ Available Repairman

At Burn in Period

Eepected Busy period of the service engineer inspection time only (BI_0) $= \frac{N_3}{D_2}$

Eepected Busy period of the service engineer Repair time only(BR_0) $= \frac{N_4}{D_2}$

Eepected number of replacement by service engineer(RP_0) $= \frac{N_5}{D_2}$

Expected number of visit by Service Engineer (V_0) $= \frac{N_6}{D_2}$

At Useful life Period:

Eepected Busy period of the service engineer inspection time only (BI_4) $= \frac{N_7}{D_2}$

Eepected Busy period of the service engineer Repair time only (BR_4) $= \frac{N_8}{D_2}$

Eepected number of replacement by service engineer

(i) for off-line(RP_4) $= \frac{N_9}{D_2}$

(ii) for online (RPO_4) $= \frac{N_{10}}{D_2}$

Expected number of visit by Service Engineer (V_4) $= \frac{N_{11}}{D_2}$

At Wear out Period

Eepected Busy period of the available repairman inspection time only (BI_{11}) $= \frac{N_{12}}{D_2}$

Eepected Busy period of the available repairman Repair time only (BR_{11}) $= \frac{N_{13}}{D_2}$

Eepected number of replacement by the available repairman (RP_{11}) $= \frac{N_{14}}{D_2}$

Expected number of visit by the available repairman (V_{11}) $= \frac{N_{15}}{D_2}$

where

$N_3 = \mu_1 p_{0,1} p_{12,14} p_{4,11}$

$N_4 = \mu_2 p_{0,1} p_{1,2} p_{12,14} p_{4,11} p_{11,12}$

$N_5 = p_{12,14} (1 - p_{0,1} p_{1,2})(p_{4,11} - p_{0,4})$

$N_6 = p_{0,1} p_{12,14} p_{4,11}$

$N_7 = p_{12,13} p_{0,4} [\mu_5 p_{4,5} + \mu_8 p_{4,8}]$

$N_8 = p_{0,4} p_{12,14} [\mu_6 p_{4,5} p_{5,6} + \mu_9 p_{4,8} p_{8,9}]$

$N_9 = p_{0,4} p_{12,14} [1 - p_{0,4} p_{4,11} - p_{4,5} p_{5,6} - p_{4,8}]$

$N_{10} = p_{0,4} p_{4,8} p_{8,10} p_{12,14}$

$N_{11} = p_{12,14} p_{0,4} [p_{4,5} + p_{4,8}]$

$N_{12} = \mu_{12} p_{0,4} p_{4,11}$

$N_{13} = \mu_{13} p_{0,4} p_{4,11} p_{12,13}$

$N_{14} = p_{0,4} p_{4,11} p_{12,14}$

$N_{15} = p_{0,4} p_{4,11}$

and

D_2 is already specified.

Profit Analysis of the System

(A) Profit analysis for the system user:

$$P_1 = C_0[A_0] - C_1 BI_{11} - C_2 BR_{11} - C_3 RP_{11} - C_4 V_{11}$$

where

C_0 = revenue per unit up time of the system

C_1 = cost per unit time of inspection by the available repairman

C_2 = cost per unit time of repair by the available repairman

C_3 = cost per unit replacement by the available repairman

C_4 = cost per visit of the available repairman

(B) Profit analysis for the system provider:

$$P_2 = (SP - CP) - C_5(BI_0 + BI_4) - C_6(BR_0 + BR_4) - C_7(RP_0 + RP_4 + RPO_4) - C_8(V_0 + V_4)$$

where

SP/CP = sale price/ cost price of the system
C_5= cost per unit time of inspection by the service engineer
C_6 = cost per unit time of repair by the service engineer
C_7 = cost per unit replacement by the service engineer
C_8 = cost per visit of the service engineer

Graphical Interpretations and Conclusions

For the graphical analysis of the system at various stages of its operation following particular cases are considered:

$g_1(t)=\beta_1 e^{-\beta_1 t}$, $g_2(t)=\beta_2 e^{-\beta_2 t}$, $g_3(t)=\beta_3 e^{-\beta_3 t}$,

$g_4(t)=\beta_4 e^{-\beta_4 t}$ $h_1(t)=\gamma_1 e^{-\gamma_1 t}$, $h_2(t)=\gamma_2 e^{-\gamma_2 t}$,

$h_3(t)=\gamma_3 e^{-\gamma_3 t}$, $h_4(t)=\gamma_4 e^{-\gamma_4 t}$, $i_1(t)= \alpha_1 e^{-\alpha_1 t}$,

$i_2(t)= \alpha_2 e^{-\alpha_2 t}$, $i_3(t)= \alpha_3 e^{-\alpha_3 t}$, $i_4(t)= \alpha_4 e^{-\alpha_4 t}$

and $k(t)= \delta e^{-\delta t}$,

Various graphs are plotted for the mean time to system failure, availability and profit of the system user and system provider for the different operational stages of the syetm for various values of failure rates (λ_1, λ_2 ,λ_3) , repair rates (β_1, β_2, β_3, β_4) replacement rates (γ_1, γ_2, γ_3, γ_4) , inspection rates (α_1, α_2, α_3, α_4) and arrival rate δ . The following conclusions have been drawn from the graphs.

Fig. 2 shows the behavior of mean time to system failure (MTSF) with respect to failure rate (λ_1) of the system during burn in perod for different values of improvement rate (η_1). It can be concluded from the graph that MTSF decreases with the increase in the values of λ_1 and has higher values for higher values of η_1 when other parameters are fixed.

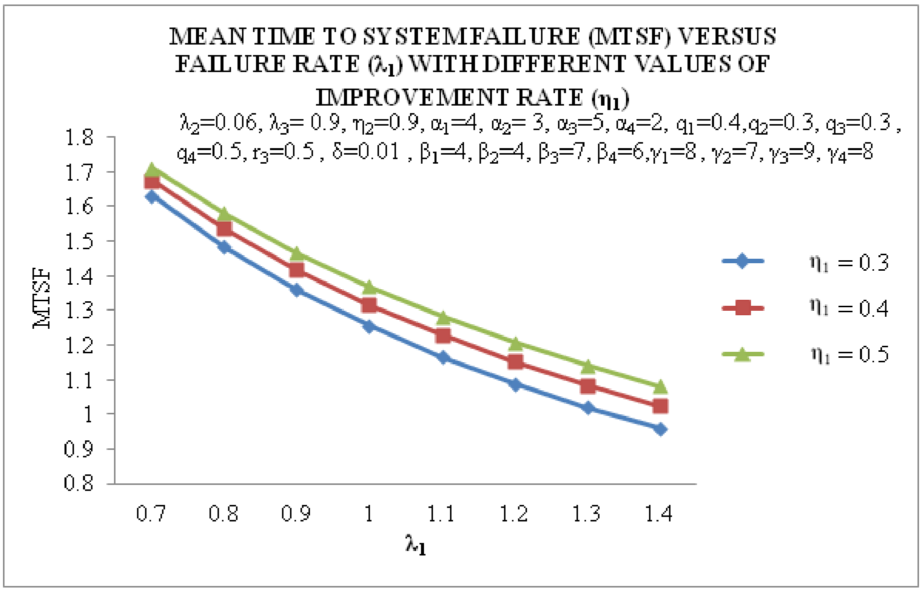


Figure 2.

The curves in fig. 3 reveal the pattern of mean time to system failure (MTSF) with respect to failure rate (λ_2) of the system during useful life perod for different values of deterioration rate (η_2). It is concluded from the graph that MTSF decreases with the increase in the values of λ_2 and has lower values for higher values of η_2 when other parameters are fixed.

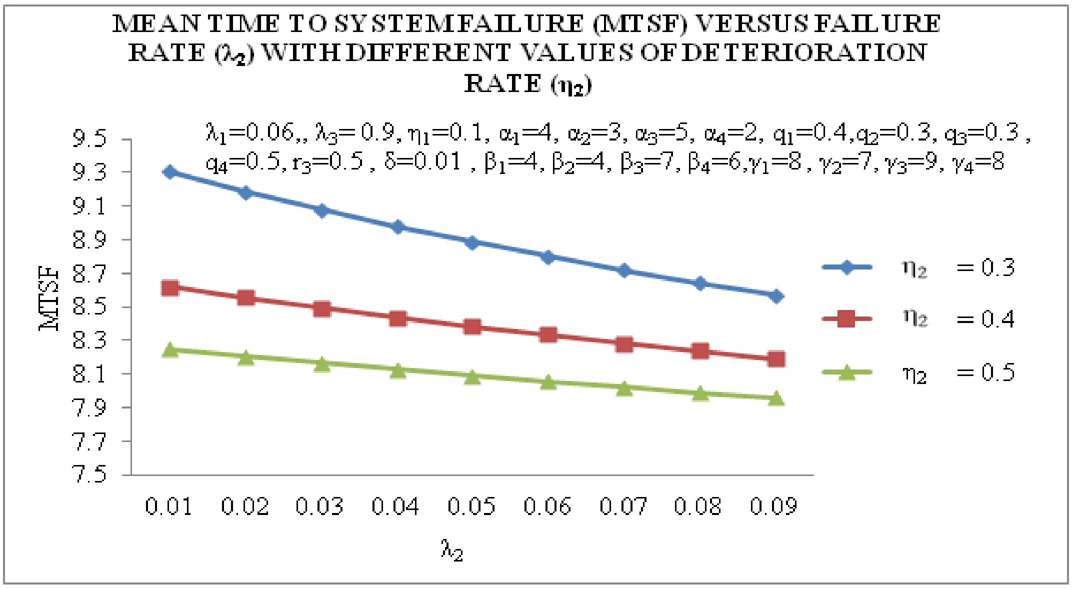


Figure 3.

Fig. 4 depicts the behavior of mean time to system failure (MTSF) with respect to failure rate (λ_3) of the system during wear-out perod for different values of deterioration rate (η_2). It can be interpreted from the graph that MTSF decreases with the increase in the values of λ_3 when other parameters are fixed and has lower values for higher values of η_2 .

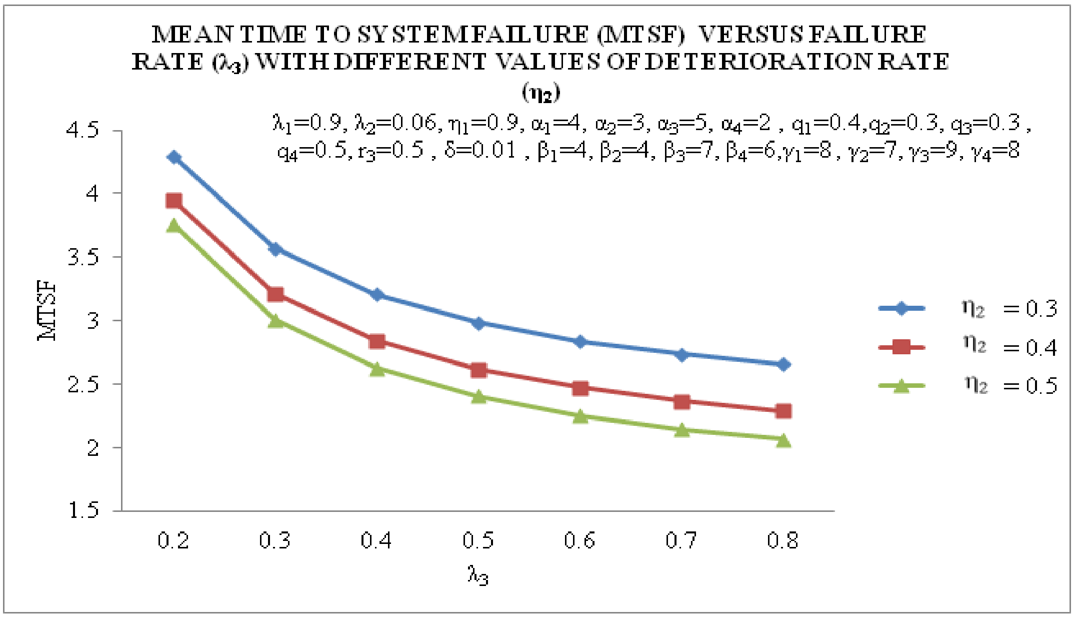


Figure 4.

The graph in fig. 5 shows the behavior of availability (A_0) with respect to failure rate (λ_1) of the system during burn-in perod for different values of improvement rate (η_1). It is concluded from the graph that A_0 decreases with the increase in the values of λ_1 and has higher values for higher values of η_1 when other parameters are fixed .

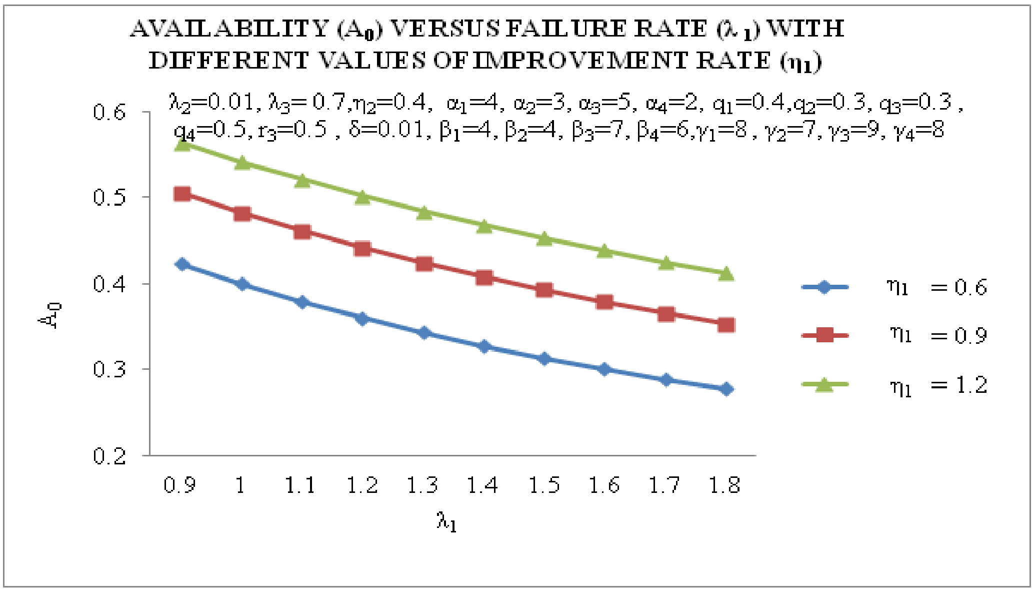


Figure 5.

Fig. 6 presents the behavior of availability(A_0) with respect to failure rate (λ_2) of the system during useful life perod for different values of deterioration rate (η_2). It can be concluded from the graph that A_0 decreases with the increase in the values of λ_2 when other parameters are fixed and has lower values for higher values of η_2 .

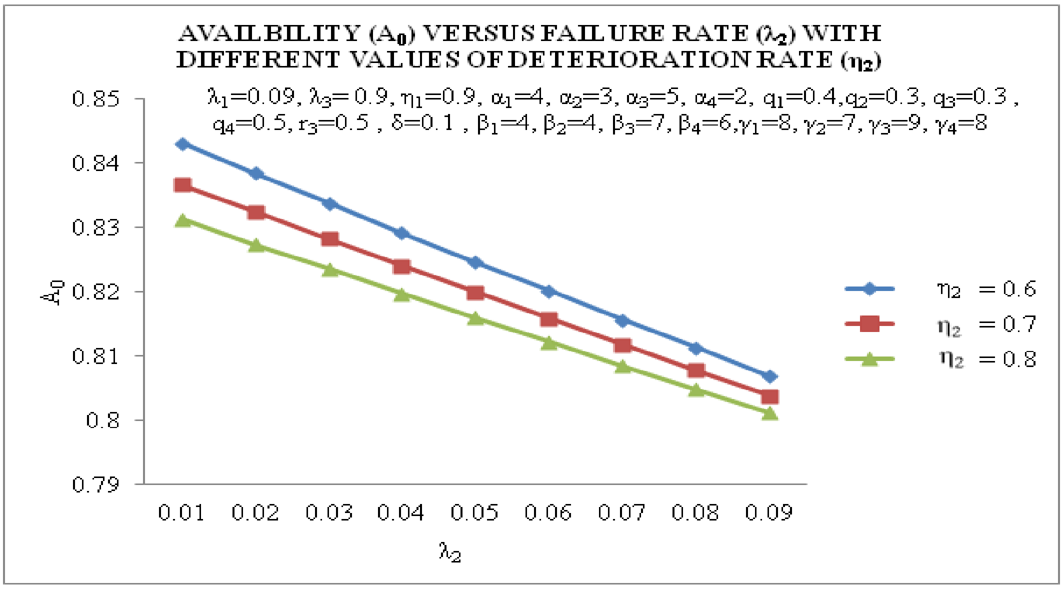


Figure 6.

The curves in fig. 7 shows the pattern of availability(A_0) with respect to failure rate (λ_3) of the system during wear-out perod for different values of deterioration rate (η_2). It is concluded from the graph that A_0 decreases with the increase in the values of λ_3 and has lower values for higher values of η_2 when other parameters are fixed.

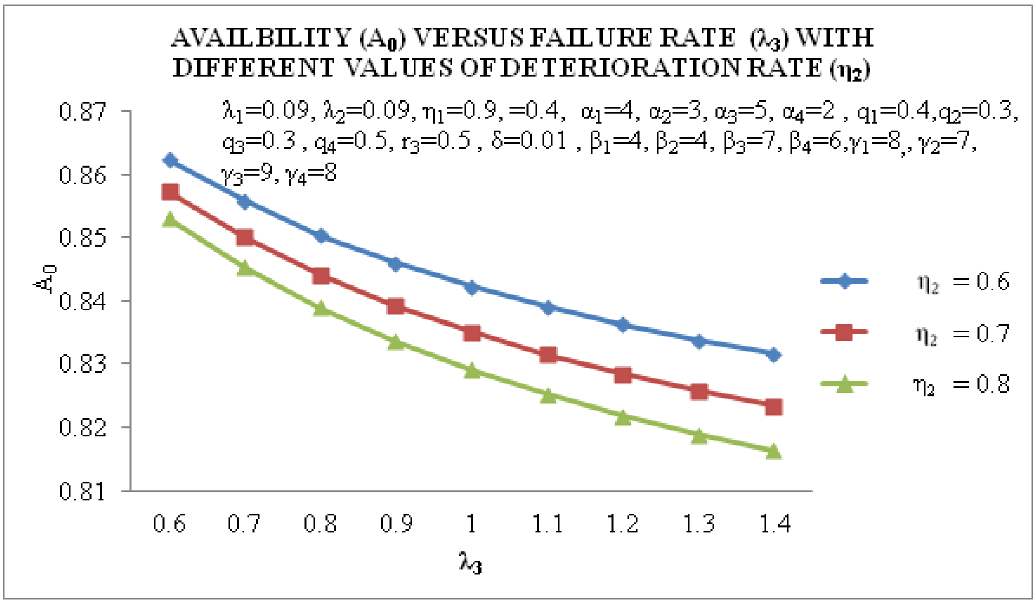


Figure 7.

Fig. 8 represents the behaviour of profit of system user (P_1) with respect to revenue per unit up time (C_0) for different values of cost per visit (C_4) of the available repairman. It can be concluded that profit of system user increases with the increase in the values of revevue per unit uptime and has lower values for higher values of cost per visit of the available repairman. From the fig. 8, it can also be observed that for C_4 = Rs.200, P_1 is positive or zero or negative as C_0 > or = or < Rs.174.57 and thus in this case, the system is profitable whenever revenue per unit up time is greater than Rs. 174.57. Similarly for C_4 = Rs.350 and C_4 = Rs.500, the system user is profitable whenever C_0 > Rs.209.48 and Rs.244.39 respectively.

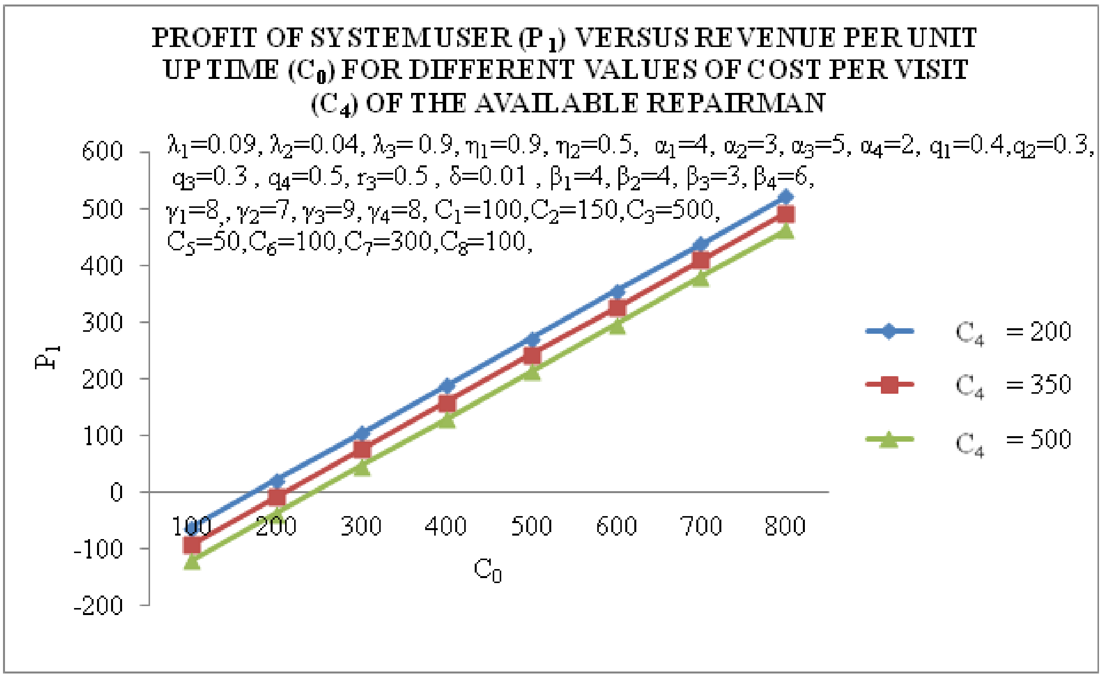


Figure 8.

Fig. 9 depicts the behaviour of profit of system provider (P_2) with respect to cost per visit (C_8) of the service engineer for different values of failure rate (λ_2). It is concluded from the graph that P_2 decreases with the increase in the values of C_8 and has lower values for higher values of λ_2. From the fig. 10, it can also be observed that for λ_2 = 0.5, P_2 is positive or zero or negative as C_8 < or = or > Rs.1872.96 and thus in this case, the system is profitable whenever C_8 should be fixed less than Rs.

1872.96. Similarly for λ_2 = 1 and λ_2 = 1.5, the system provider is profitable whenever C_8 < Rs.1340.94 and Rs.1158.74 respectively.

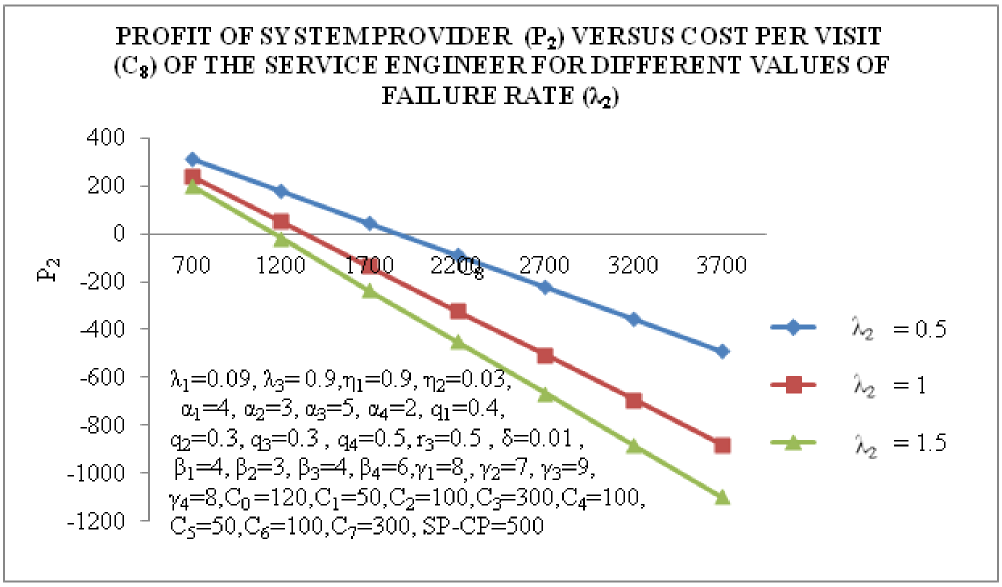


Figure 9.

Fig. 10 depicts the behaviour of profit of system provider (P_2) with respect to profit (SP-CP) for different values of failure rate (λ_2). It is concluded from the graph that P_2 increase with the increase in the values of SP-CP and has lower values for higher values of λ_2. From the fig. 10, it can also be observed that for λ_2 = 0.5, P_2 is positive or zero or negative as SP-CP > or = or < Rs. 26.17 and thus in this case, the system is profitable whenever SP-CP should be fixed greater than Rs. 26.17. Similarly for λ_2 = 1 and λ_2 = 1.5, the system provider is profitable whenever SP-CP > Rs.37.39 and Rs.43.35 respectively.

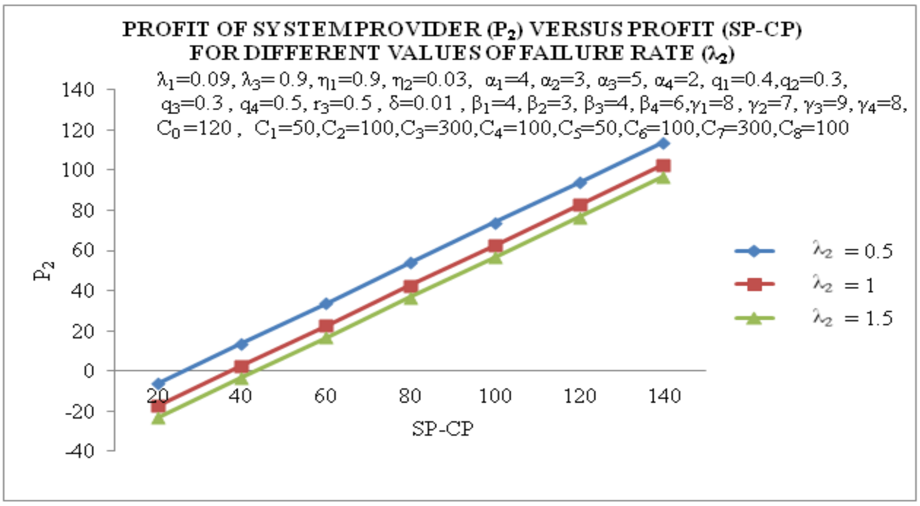


Figure 10.

REFERENCES

[1] Kumar, R. and Batra, S. (2013): Cost Benefit Analysis of a Reliability Model on Printed Circuit Boards Manufacturing System, International Journal of Advances in Science and Technology,Vol.6, No.3,1-.9

[2] Kumar, R., Vashishtha, U. and Tuteja, R.K. (2001): A two unit redundant system with degradation and replacement, Pure and Applied Mathematics Sciences, Vol.LIV, 27-38.

[3] Kumar, R., Sharma, M.K. and Mor, S.S. (2010): Profit analysis of a three stage operational single unit system under warranty and two types of service facility, Pure and Applied Mathematika Sciences, Vol. LXXI, No. 1-2, 49-56.

[4] Kumar, R., Sharma and Mor, S.S. (2009): Profit evaluation of a warranted system with three operational stages, J. Indian Soc. Stat. Opers. Res., Vol. XXX, 53-61

[5] Murari, K. and Goyal, V. (1983): Reliability system with two types of repair facilities, Microelectron Reliab., Vol.23, 1015-1025.

[6] Pulcini G. (2001): Modeling the failure data of repairable equipment with bathtub type failure intensity, Reliability Engineering and System Safety, Vol.71, 209-218.

[7] Sarkar A. and Behera D.K. (2012): Gas Turbine Power Plant System: A Case Study of Rukhia Gas Thermal Power Plant, International Journal of Emerging Technology and Advanced Engineering, Vol. 2, 555-572.

[8] Stancliff S.B., Dolan J.M. and Trebi-Ollennu A. (2006) :Mission Reliability Estimation for Repairable Robot Teams, International Journal of Advanced Robotic Systems, Vol. 3, 2, 155-164.

[9] Tuteja, R.K., Minocha, A. and Singh D.V. (2006): Reliability and Profit Analysis of a 2-out of-3 unit system for an Ash Handling Plant, Pure and Applied Mathematics Sciences, Vol. LXIII, 1-2, 13-21.

[10] Tuteja, R.K. and Taneja, G. (1991): Proper utilization of a system with two identical repairmen. International Journal of Management and Systems, Vol.7, 273-281.

[11] Vijay P., Rao T.G. and Kumar M.M. (2013): Application of Preventive Maintenance for Effectual Freight Operations, International Journal of Engineering Research and Application, Vol. 3, 1659-1662.