Reliability and Cost-Benefit Analysis of a System Comprising One Big Unit and Two Small Identical Units with Priority for Operation/Repair to Big Unit

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Abstract

A three-unit system working in a sugar mill with one big unit and two small identical units is examined in the present paper. Upon failure of the big unit, both the small units are made operative and the failed unit is undertaken for repair immediately. Priority for operation as well as repair is given to the big unit. System is able to work with full capacity only if either the big unit or both the small units are in good condition. If only one small unit is operable, the system works at reduced capacity. The system under consideration goes to rest during the non-seasonal period. The information obtained from the mill revealed that the system is brought to work at reduced capacity when the system is about to go to the rest period due to shortage of sugarcane near the end of season, irrespective of the number of operable units. This fact has also been considered while developing the model. The expressions for the MTSF; availability; expected busy period for the repairman during both the periods, that is, working as well as rest period; PM/CM and the reliability have been obtained using semi-Markov processes and regenerative point technique.

Keywords: Reliability, Priority for operation and repair to big unit, Regenerative

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1 Introduction

The literature in reliability is becoming more and more rich day-by-day as a large number of researchers are making lot of contribution in the field by incorporating some new ideas/concepts/studies. Two/Three-unit standby systems with two stages, that is, working or failed, have been discussed under various assumptions/situations by numerous researchers including [1-12]. There may be one more stage i.e. stage of Rest period of the system which also exists in case of some seasonal systems like system working in a sugar mill. Maruthachalam [11] studied the MTSF and the availability analysis only for two-unit standby/parallel systems with alternating periods of Working and Rest. However, the situations considered by Maruthachalam cannot be fitted to many practical situations. Thus, such practical situations for systems with alternating periods of Working and Rest, which have not been studied (even hypothetically) so far in the literature of Reliability, need to be observed and studied. Also, the various measures of system effectiveness for such practical situations were left unstudied.

To have an extensive study on such a practical situation including the above-mentioned important aspects, the sugar mills situated at Yamunanagar and Karnal in Haryana were visited and the information on the Sulphated Juice Pump System Working therein was gathered. Then, on the basis of the situation observed in the mills, Goyal et al. [12] put a step towards this direction by analyzing the reliability and the profit of a 2-unit cold standby Sulphated Juice Pump System, evaluating various measures of system effectiveness. The system remains in the functional mode seasonally (i.e. November to April in the present study) and goes to Rest in the non-seasonal period (i.e., May to October). When the Rest period is about to complete, the PM/CM is carried out to make the system ready for operation. The aspect of the Rest period
has also been taken into account for evaluation of the profit for the system.

A three-unit system working in one of the visited sugar mills was also observed. Hence putting another step towards the direction of studying the untouched situations with alternating periods of working and rest, the present paper considers the analysis of a three-unit system with one big unit and two small identical units. Upon failure of the big unit, both the small units are made operative and the failed unit is undertaken for repair immediately. Priority for operation as well as repair is given to the big unit. System is able to work with full capacity only if either the big unit or both the small units are in good condition. If only one small unit is operable, the system works at reduced capacity. The system under consideration goes to rest during the non-seasonal period. The information obtained from the mill revealed that the system is brought to work at reduced capacity when the system is about to go to the rest period due to shortage of sugarcane near the end of season, irrespective of the number of operable units. This fact has also been considered while developing the model. The expressions for the MTSF; availability; expected busy period for the repairman during both the periods, that is, working as well as rest period; PM/CM and the reliability have been obtained using semi-Markov processes and regenerative point technique. Other assumptions of the model are:

1. System takes some random amount of time to reach from reduced capacity mode to full capacity mode.

2. Each unit has an exponential distribution of the time to failure and rest period while distribution of repair times is taken as arbitrary.

3. When the repairman is called on to do the job, it takes a negligible time to reach at the system.

4. Repair is kept in abeyance when change of mode from reduced capacity to full capacity is taking place and also when the rest period is about to start.

5. Repair rate during the rest period is comparatively slower than that during the working period and hence taken differently in the two periods. After any repair, the
unit works like a new one.

6. System goes to the state of rest only via the state of reduced capacity.

7. All random variables are mutually independent.

Notations

\( \lambda_1 \): Constant failure rate of the big unit when operative
\( \lambda_2 \): Constant failure rate of the small unit when operative
\( g_1(t), G_1(t) \): p.d.f. and c.d.f. of repair time for big unit during working period
\( g_2(t), G_2(t) \): p.d.f. and c.d.f. of repair time for big unit during rest period
\( h_1(t), H_1(t) \): p.d.f. and c.d.f. of repair time for small unit during working period
\( h_2(t), H_2(t) \): p.d.f. and c.d.f. of repair time for small unit during rest period
\( q_{i,j}(t), Q_{i,j}(t) \): p.d.f. and c.d.f. of first passage time from a regenerative state \( i \) to a regenerative state \( j \) or to a failed state \( j \) without visiting any other regenerative state in \((0,t]\)
\( \phi_i(t) \): c.d.f. of first passage time from a regenerative state \( i \) to a failed state \( j \)
\( \gamma \): rate of going to rest
\( \alpha_1 \): rate of change from full capacity to reduced capacity
\( \alpha_2 \): rate of change from reduced capacity to full capacity
\( \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5 \): rate when rest period is about to start
\( \beta_1 \): rate of going for PM/CM
\( \beta_2 \): rate of doing PM/CM
\( \beta_3 \): rate of starting of the working period after the completion of PM/CM

Symbols for the States of System

\( B_0 \): Big unit is operative
\( S_0 \): Small unit is operative
\( B_s \): Big unit as cold standby
\( S_s \): Small unit as cold standby
\( F_{Br} \): Repair of big unit under repairman when failed
\( S_r \): Repair of small unit under repairman when failed
$F_{Br}$ : Repair of big unit under repairman when failed in rest state
$S_{rr}$ : Repair of small unit under repairman when failed in rest state
$F_{Brus}$ : Repair of big unit under suspension when failed
$S_{rus}$ : Repair of small unit under suspension when failed
$F_{BR}$ : Big unit is under repair by repairman from previous state
$B_{ro}$ : Big unit ready to become operative as the working period is about to start.
$S_{rs}$ : Small unit ready to become standby as the working period is about to start
$S_{wr}$ : Small unit waiting for repair when failed
$r_{B}$ : Big unit under rest
$r_{S}$ : Small unit under rest

$PM/CM$ : Preventive maintenance/Corrective maintenance

The diagram showing the various states of transition of the system is shown in Fig.1

2 Transition Probabilities and Mean Sojourn Times

The epoch of entries into the states 0, 1, 2,3,4,5, 6,7,8,11,12,13,14,15,16,17,18,20,21,22 and 23 are regeneration points and thus these are the regenerative states. States 9 and 19 are failed states. States 10, 11,14,15,16,17,21,22 and 23 are the states where the system is at rest. States 2,4,18 and 20 are states where the rest period is about to start. States 5,6,7,8 and 21 are states where system is working at reduced capacity.

The non-zero elements $p_{ij} = \lim_{s \to 0} q_{ij}^*(s)$ are given by

\[ p_{01} = \frac{\lambda_1}{\lambda_1 + \gamma_1}; \quad p_{02} = \frac{\gamma_1}{\lambda_1 + \gamma_1}; \quad p_{10} = g_1^*(2\lambda_2 + \gamma_2); \quad p_{13} = \frac{2\lambda_2[1-g_1^*(2\lambda_2+\gamma_2)]}{2\lambda_2+\gamma_2}; \]
\[ p_{14} = \frac{\gamma_2(1-g_1^*(2\lambda_2+\gamma_2))}{2\lambda_2+\gamma_2}; \quad p_{25} = p_{36} = p_{47} = p_{5,15} = 1; \quad p_{68} = g_1^*(\lambda_2 + \gamma_3); \]
\[ p_{69} = \frac{\lambda_2(1-g_1^*(\lambda_2+\gamma_3))}{\lambda_2+\gamma_3} = p_{6,13}^{(9)}; \quad p_{6,14}^{(10)} = \frac{\gamma_3(1-g_1^*(\lambda_2+\gamma_3))}{\lambda_2+\gamma_3}; \]
\[ p_{7,11} = p_{8,12} = p_{11,15} = p_{14,15} = p_{15,16} = p_{16,17} = p_{17,0} = 1; \quad p_{12,0} = h_1^*(\lambda_1 + \gamma_4); \]
\[ p_{12,3} = \frac{\lambda_1(1-h_1^*(\lambda_1+\gamma_4))}{\lambda_1+\gamma_4}; \quad p_{12,18} = \frac{\gamma_4(1-h_1^*(\lambda_1+\gamma_4))}{\lambda_1+\gamma_4}; \quad p_{13,12} = h_1^*(\lambda_1 + \gamma_5); \]
\[ p_{13,19} = \frac{\lambda_1(1-h_1^*(\lambda_1+\gamma_5))}{\lambda_1+\gamma_5}; \quad p_{13,20} = \frac{\gamma_5(1-h_1^*(\lambda_1+\gamma_5))}{\lambda_1+\gamma_5}; \]
\[ p_{18,21} = p_{19,13} = p_{20,22} = p_{21,23} = p_{22,14} = p_{23,15} = 1; \]
Mean Sojourn times ($\mu_i$) in the regenerative state 'i' is defined as the time of stay in that state before transition to any other state. If $T$ denotes the sojourn time in the regenerative state i, then $\mu_i = E(T) = Pr(T > t)$. Then

$$\mu_0 = \frac{1}{\lambda_1 + \gamma_1}; \mu_1 = \frac{1-g_1^*(2\lambda_2+\gamma_2)}{2\lambda_2+\gamma_2}; \mu_2 = \mu_3 = \mu_4 = \mu_{18} = \frac{1}{\alpha_1}; \mu_5 = \mu_7 = \mu_{20} = \mu_{21} = \frac{1}{7};$$

$$\mu_6 = \frac{1-g_2^*(\lambda_2+\gamma_3)}{\lambda_2+\gamma_3}; \mu_8 = \frac{1}{\alpha_2}; \mu_{11} = K_2; \mu_{12} = \frac{1-h_1^*(\lambda_1+\gamma_4)}{\lambda_1+\gamma_4}; \mu_{13} = \frac{1-h_1^*(\lambda_1+\gamma_5)}{\lambda_1+\gamma_5};$$

$$\mu_{14} = \mu_{22} = \mu_{23} = K_3; \mu_{15} = \frac{1}{\beta_1}; \mu_{16} = \frac{1}{\beta_2}; \mu_{17} = \frac{1}{\beta_3}; \mu_{19} = K_1;$$

The unconditional mean time taken by the system to transit for any regenerative state j, when it is counted from the epoch of entrance in to the state i, is mathematically stated as: $m_{ij} = \int_0^\infty t dQ_{ij}(t) = -g_{ij}^*(0)$. 
\[ m_{01} + m_{02} = \mu_0; m_{10} + m_{13} + m_{14} = \mu_1; m_{25} = m_{36} = m_{47} = m_{18,21} = \mu_2; \]
\[ m_{5,15} = m_{7,11} = m_{20,22} = m_{21,23} = \mu_5; \]
\[ m_{68} + m_{69} + m_{6,14}^{(10)} = \frac{\lambda_2 \mu_6 + \gamma_3 K_1}{\gamma_3 + \lambda_2}; m_{68} + m_{6,13}^{(9)} + m_{6,14}^{(10)} = K_1; m_{8,12} = \mu_8; \]
\[ m_{14,15} = m_{22,14} = m_{23,15} = K_3; m_{15,16} = \mu_5; m_{16,17} = \mu_6; m_{17,0} = \mu_7; m_{19,13} = K_1; \]

where \( K_1 = \int_0^\infty t g_1(t)dt; \quad K_2 = \int_0^\infty t g_2(t)dt; \quad K_3 = \int_0^\infty t h_2(t)dt \)

3 Measures of the System Effectiveness

Various measures of the system effectiveness obtained using semi-Markov processes, regenerative point technique, recursive relations and Laplace/Stieltjes’ transforms are given as follows:

(i) Mean Time to System Failure (Including Rest Period)

To determine the mean time to system failure (MTSF) of the system we regarded the failed state of the system as absorbing state. The expression obtained for it

\[ T_0 = \text{MTSF} = \lim_{s \to 0} R^*(s) = \lim_{s \to 0} \frac{1 - e^{-s}}{s} = \frac{N}{D}, \]

where

\[ N = \mu_0 (1 - p_{68} p_{12,3}) + \mu_1 p_{01} (1 - p_{68} p_{12,3}) + \mu_2 [p_{02} (1 - p_{68} p_{12,3}) + p_{01} p_{13} + p_{01} p_{14} (1 - p_{68} p_{12,3}) + p_{01} p_{13} p_{68} p_{12,18}] + \mu_5 [p_{01} p_{14} (1 - p_{68} p_{12,3}) + p_{02} (1 - p_{68} p_{12,3}) + P_{01} p_{13} p_{68} p_{12,18} + (\lambda_2 \mu_6 + \gamma_3 K_1) p_{01} p_{13} p_{68} p_{12,18} + \mu_8 p_{01} p_{13} p_{68} + K_2 p_{01} p_{14} (1 - p_{68} p_{12,3}) + \mu_{12} p_{01} p_{13} p_{68} + K_3 p_{01} p_{13} p_{6,14} + p_{68} p_{12,18}] + (\mu_{15} + \mu_6 + \mu_7) [p_{01} p_{13} p_{6,14} + p_{11} (1 - p_{68} p_{12,3}) + p_{01} p_{13} p_{68} p_{12,18} + p_{02} (1 - p_{68} p_{12,3})] \]

\[ D = p_{01} p_{13} p_{68} \]

and \( R^*(s) \) is the Laplace transform of the reliability \( R(t) \). The reliability \( R(t) \) of the system at time \( t \) can be obtained taking inverse Laplace transform of \( R^*(s) \).

(ii) Steady State Availability at Full Capacity

Letting \( A_i(t) \) as the probability that the system is in upstate with full capacity at instant \( t \) given that it entered the state \( i \) at \( t=0 \), the obtained expression for the steady state availability at full capacity is

\[ A_0 = \lim_{s \to 0} s A_0^*(s) = \frac{N_1}{D_1} \]

where
$N_1 = [\mu_0 + \mu_1 p_0 + \mu_2 p_0^2][(1 - p_{13,19})(1 - p_{68,12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}] + \mu_2$

$[p_{01}p_{13}(1 - p_{13,19}) + p_{01}p_{14}(1 - p_{13,19})(1 - p_{68,12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}]$

$+ p_{01}p_{13}(\mu_2 + \mu_2 p_{12,18})p_{68}(1 - p_{13,19}) + p_{6,13}^{(9)}p_{13,12} + \mu_3 p_{01}p_{13}p_{6,13}^{(9)} +$

$\mu_5 p_{01}p_{13}p_{6,13}p_{13,20}.$

$D_1 = [\mu_0 + \mu_1 p_0 + (\mu_2 + \mu_5 + \mu_1 + \mu_6 + \mu_7)(p_{02} + p_{01}p_4) + p_{01}p_{14}K_2]$

$[(1 - p_{13,19})(1 - p_{68,12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}] + p_{01}p_{13}(1 - p_{13,19})(K_1 + \mu_8$

$p_{68} + \mu_2) + p_{01}p_{13}(\mu_2 + (\mu_2 + \mu_5 + K_4)p_{12,18})p_{6,13}^{(9)}p_{13,12} + p_{68}(1 - p_{13,19})]$

$[\mu_1 + (\mu_5 + K_4)p_{13,20} + K_1p_{13,19} + (\mu_5 + \mu_6 + \mu_7)p_{01}p_{13}p_{6,13}^{(9)}p_{13,20}$

$+ p_{14}^{(10)}(1 - p_{13,19})(1 - p_{13,19})p_{68,12,18} + p_{6,13}^{(9)}p_{13,12}p_{12,18} + p_{01}p_{14}$

$K_4[p_{6,13}^{(9)}p_{13,20} + p_{6,14}^{(10)}(1 - p_{13,19})].$

(iii) Availability Analysis at Reduced Capacity

Letting $AR_i(t)$ as the probability that the system is in upstate with reduced capacity at instant $t$ given that it entered the state $i$ at $t=0$, the obtained expression for the steady state availability at reduced capacity is

$N_2 = \mu_5(p_{02} + p_{01}p_4)[(1 - p_{13,19})(1 - p_{68,12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}] + \mu_5 p_{01}p_{13}$

$p_{12,18}[p_{68}(1 - p_{13,19}) + p_{6,13}^{(9)}p_{13,12}] + (\mu_6 + p_{68}\mu_8)p_{01}p_{13}(1 - p_{13,19}).$

(iv) Analysis of the Expected Rest Period of the System

Letting $R_i(t)$ as the probability that the system is in rest state at instant $t$ given that it entered the state $i$ at $t=0$, the expression obtained for the expected fraction of time the system remains in rest is

$R_0 = \lim_{s \to 0} s R_0^* = \frac{N_2}{D_1}.$

$N_3 = \frac{\gamma_3(K_3 - \mu_6) p_{01}p_{13}(1 - p_{13,19})}{\lambda_3 + \gamma_3} + K_2p_{01}p_{14}(1 - p_{13,19})(1 - p_{68,12,3}) - p_{6,13}^{(9)}$

$p_{13,12}p_{12,3}] + K_4 p_{01}p_{13}p_{6,14}(1 - p_{13,19}) + p_{6,13}^{(9)}p_{13,20} + (\mu_5 + \mu_6 + \mu_7)$

$[p_{01}p_{13}(p_{6,14} + p_{68,12,18})(1 - p_{13,19}) + p_{6,13}^{(9)}(p_{13,20} + p_{13,12}p_{12,18}) + (p_{01}$

$p_{14} + p_{02})(1 - p_{13,19}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}] + K_4 p_{01}p_{13}p_{6,13}^{(9)}p_{13,20} + p_{12,18}$

$(1 - p_{68,12,3})p_{68}(1 - p_{13,19}) + p_{6,13}^{(9)}p_{13,12}.$

(v) Busy Period Analysis for Repairing the Failed Units During Working Period for Big Unit

Letting $B_i(t)$ as the probability that the repairman is busy to repair the failed units during working period at instant $t$ given that it entered the state $i$ at $t=0$, the
expression obtained for the fraction of time the repairman is busy for repairing the failed units during working period is \( B_0 = \lim_{s \to 0} sB_0^*(s) = \frac{N_4}{D_1} \)

\[
N_4 = \mu_1p_{01}[1 - p_{13,19}(1 - p_{68}p_{12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}] + K_1p_{01}p_{13}(1 - p_{13,19})
\]

\[
(1 + p_{68}) + p_{6,13}^{(9)}p_{13,19}.
\]

(vi) Busy Period Analysis for Repairing the Failed Units during Working Period for Small Unit

Letting \( BS_i(t) \) as the probability that the repairman is busy to repair the failed units during working period at instant \( t \) given that it entered the state \( i \) at \( t=0 \), the expression obtained for the fraction of time the repairman is busy for repairing the failed units during working period is \( BS_0 = \lim_{s \to 0} sBS_0^*(s) = \frac{N_5}{D_1} \)

\[
N_5 = \mu_1p_{01}[1 - p_{13,19}(1 - p_{68}p_{12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3}] + K_1p_{01}p_{13}(1 - p_{13,19})
\]

(vii) Busy Period Analysis for Repairing the Failed Units during Rest Period for Big Unit

Letting \( BR_i(t) \) as the probability that the repairman is busy to repair the failed units during rest period at instant \( t \) given that it entered the state \( i \) at \( t=0 \), the expression obtained for the fraction of time the repairman is busy for repairing the failed units during rest period is \( BR_0 = \lim_{s \to 0} sBR_0^*(s) = \frac{N_6}{D_1} \)

\[
N_6 = K_2p_{01}p_{14}(1 - p_{13,19}(1 - p_{68}p_{12,3}) - p_{6,13}^{(9)}p_{13,12}p_{12,3})
\]

(viii) Busy Period Analysis for Repairing the Failed Units during Rest Period for Small Unit

Letting \( BRS_i(t) \) as the probability that the repairman is busy to repair the failed units during rest period at instant \( t \) given that it entered the state \( i \) at \( t=0 \), the expression obtained for the fraction of time the repairman is busy for repairing the failed units during rest period is \( BRS_0 = \lim_{s \to 0} sBRS_0^*(s) = \frac{N_7}{D_1} \)

\[
N_7 = K_4p_{01}p_{13}[(p_{6,14}^{(10)} + p_{68}p_{12,18})(1 - p_{13,19}) + 2p_{6,13}^{(9)}p_{13,20} + p_{6,13}^{(9)}p_{13,12}p_{12,18}]
\]

(ix) PM/CM Analysis of the system

Letting \( P_i(t) \) as the probability that the repairman is busy for doing PM/CM during rest period at instant \( t \) given that it entered the state \( i \) at \( t=0 \), the expres-
sion obtained for the fraction of time the repairman is busy for doing the PM/CM is

\[ P_0 = \lim_{s \to 0} s P_0^*(s) = \frac{N_8}{D_1} \]

\[ N_8 = \mu_{16}(p_{01}p_{14} + p_{02})[(1 - p_{13,19})(1 - p_{68}p_{12,3}) - p_{6,13}p_{13,12}p_{12,3}] + \mu_{16}p_{01}p_{13} \]

\[ [p_{6,13}p_{13,20} + (p_{6,14} + p_{12,18}p_{68})(1 - p_{13,19}) + p_{6,13}p_{12,18}p_{13,12}] \]

4 Cost-Benefit Analysis

In steady state, the expected profit per unit time incurred to the system is given by

\[ \text{Profit}(P_2) = C_0 A_0 + C_1 A R_0 - C_2 B_0 - C_3 B S_0 - C_4 P_0 - C_5 B R_0 - C_6 B R S_0 - C_7 R_0, \]

where

- \( C_0 \) = revenue per unit up time for which system is working at full capacity
- \( C_1 \) = revenue per unit up time for which system is working at reduced capacity
- \( C_2 \) = cost per unit time for which the repairman is busy to repair big unit
- \( C_3 \) = cost per unit time for which the repairman is busy to repair small unit
- \( C_4 \) = cost per unit time for PM/CM
- \( C_5 \) = cost per unit time for which the repairman is busy to repair big unit at rest period
- \( C_6 \) = cost per unit time for which the repairman is busy to repair small unit at rest period
- \( C_7 \) = cost per unit time for which the system remains at rest

5 Graphical Interpretation

For the graphical interpretation, the following particular case is considered

\[ g_1(t) = \alpha \exp(-\alpha t); g_2(t) = \beta \exp(-\beta t); h_1(t) = \lambda \exp(-\lambda t); h_2(t) = \mu \exp(-\mu t); \]

The behavior of the MTSF, the availability at full capacity and the Profit with respect to failure rate for different values of repair rate observed by plotting the graphs revealed that all these get decreased with increase in the values of failure rates. However, their values become higher for higher values of repair rate (\( \alpha \)). The trend for the
behavior of the availability at reduced capacity was just reversed with respect to failure rate i.e. it increases with the increase in the values of failure rate but has lower values for higher values of repair rate as shown in Fig. 2. The logic behind this is that as the failure rate increases, the availability at full capacity decreases which results into increase in the availability at reduced capacity. Figs 3 and 4 reveal the nature of the profit with respect to failure rate and revenue per unit up time, respectively. It can be noticed from these graphs that the profit gets decreased with the increases in the values of failure rate but gets increased with the increase in the values of revenue per unit up time. Following can also be interpreted from Figs 3 and 4:

1. For $\alpha = 2$, the value of the profit is $> \text{or} = \text{or} < 0$ according to whether $\lambda$ is $< \text{or} = \text{or} > .2974$. So, in this case the system is profitable only if the $\lambda < 0.2974$.

2. For $\alpha = 3$, the value of the profit is $> \text{or} = \text{or} < 0$ according to whether $\lambda$ is $< \text{or} = \text{or} > .4688$. So, in this case the system is profitable only if the $\lambda < 0.4688$.

3. For $\alpha = 4$, the value of the profit is $> \text{or} = \text{or} < 0$ according to whether $\lambda$ is $< \text{or} = \text{or} > .6424$. So, in this case the system is profitable only if the $\lambda < 0.6424$.

4. For $C_4 = 600$, the value of the profit is $> \text{or} = \text{or} < 0$ according to whether $C_0 >$ or $= \text{or} < 1074.99$. So, in this case the system is profitable only if $C_0 > 1074.99$.

5. For $C_4 = 1800$, the value of the profit is $> \text{or} = \text{or} < 0$ according to whether $C_0 >$ or $= \text{or} < 1074.78$. So, in this case the system is profitable only if $C_0 > 1074.78$.

6. For $C_4 = 3000$, the value of the profit is $> \text{or} = \text{or} < 0$ according to whether $C_0 >$ or $= \text{or} < 1094.58$. So, in this case the system is profitable only if $C_0 > 1094.58$.

6 Conclusion

From the interpretations as made above through various graphs, we can conclude that the cut off points for various rates and costs can be obtained which help decide the upper/lower acceptable values of rates/costs so that the system is profitable. That is,
the upper limit of the failure rate can be obtained, the lower value of the revenue per unit up time can be obtained on the basis of which the company can fix the price of the product manufactured by the company so that the system gives the positive profit, the upper limit of the cost per unit time paid for engaging the repairman can be obtained, the upper/lower limits of various other rates/ costs can be obtained. Obtaining such values, various suggestions can be given to the company using such systems.

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References


