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COST-BENEFIT ANALYSIS OF A REPAIRABLE SYSTEM IN ABNORMAL ENVIRONMENTAL CONDITIONS

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Abstract The main concentration of present study is carried out the cost-benefit analysis of a cold standby repairable system under varying environmental conditions-normal and abnormal. For this purpose, a stochastic model of two-identical units is developed in which initially- one unit is operative and other unit is kept as cold standby under normal environmental conditions. A single repair facility is made available to the system to do repair and preventive maintenance of the unit as and when required. The operation and repair of the system is not allowed in abnormal environmental. The operative unit undergoes for preventive maintenance only if other unit is available for use due to priority to operation over preventive maintenance. All random variables are statistically independent. The repairs and switch devices are perfect. All time distribution except failures follows arbitrary distribution while failures are exponentially distributed. The expressions for several reliability measures are derived by making use of semi-Markov processes and regenerative point of technique. Numerical results are drawn for a particular case to highlight the importance of the study.

1 Introduction

Cost-benefit analysis of repairable systems is a widely discussed topic in the field of reliability theory. Reliability of a system is the probability that the system performs its intended function adequately for a given period of time under the stated environmental conditions. The violation of these stated environmental conditions gives the result in form of system failure. A lot of research work is done by many researchers such as Mokkadis et al. (1989) and Chander et al. (2007) in this field under different set of assumptions with static environmental conditions. But, the assumption of static environment seems to be far from reality. The environmental conditions may change with the passes of time and effect on the working capacity of system. Goel at el. (1985) discussed the cost-analysis of a cold standby system under different weather conditions. Malik and Deswal (2012) also stochastically investigated a system of non-identical units with no repair and operation activities in abnormal weather. Recently, Barak et al. (2014) obtained reliability measures of a single-unit system by using the concept of inspection operating under different weather conditions.

Further, the continuous operation of the systems also reduces their reliability, performance and safety. And, a breakdown of such systems is not useful for society. So, it becomes more important to operate such systems with great importance. It is well-known fact that by conducting preventive maintenance we can control the deterioration process of the system. Priority is another important concept of reliability improvement. But, sometimes operation of system becomes necessary in any circumstances. So, it becomes necessary to operate system by giving priority to operation over preventive maintenance. But no such type of work is visualized related to the cost-benefit analysis of repairable system by using concept of priority to operation over preventive maintenance in abnormal weather conditions. So, to fill the gap in literature in the present paper, an effort has been made to carry out the cost-benefit analysis of a cold standby repairable system in abnormal environmental conditions. For this purpose, a stochastic model is developed by using the arguments of semi-Markov process and regenerative point technique. The following measures of system effectiveness are obtained:

- Transition Probabilities and Mean Sojourn Times
- Reliability and Mean Time to System Failure
- Steady State Availability

- Busy Period of the Server due to Repair
- Busy Period of the Server due to Preventive Maintenance
- Expected Number of repairs
- Expected Number of Preventive Maintenances
- Expected Number of Visits by Server
- Cost-Benefit Analysis

1.1 Assumptions

The system consists of two identical units- Initially one unit is operative and other is kept as spare in cold standby.

A single repair facility is provided to the system for repair and preventive maintenance purpose of the components.

If standby unit is not available then preventive maintenance of the unit is not carried out.

After failure of initial operative unit the cold standby becomes operative.

There are two environmental conditions-normal and abnormal. Operation and repair is not allowed in abnormal environmental conditions.

The failure time and maximum operation time of the unit follows negative exponential distribution while the distributions of repair policies are taken as arbitrary with different probability density functions.

2 System Model Description

In this section, a two-unit cold standby system under abnormal environmental conditionsis described through semi-Markov process and regenerative point technique. The states of the system according semi-Markov process and regenerative point technique are as follows:

State 1. Initial state, one unit works, one unit in standby, normal environmental conditions and the system is working

State 2. Operative unit undergoes for preventive maintenance after maximum operation time,cold standby unit becomes operative, normal environmental conditions and the system is working

State 3. Operative unit fails and under repair, cold standby unit becomes operative,normal environmental conditions and the system is working

State 4. Due to abnormal environmental conditions operation and preventive maintenance activity of the system stop and the system is failed

State 5. Due to abnormal environmental conditions operation of the system stop and the system is failed

State 6. Due to abnormal environmental conditions operation and repair activity of the system stop and the system is failed

State 7. First failed unit is continuously under repair, second failed unit is waiting for repair and the system failed

State 8. First unit is continously under preventiv maintenance, second failed unit is waiting for repair and the system failed

State 9. Due to abnormal environmental conditions repair activity of the system stop and the system is failed

State 10. First failed unit is under repair, second failed unit is waiting for repair and the system failed. There is n-times transition between state 8 and state 9.

State 11. Due to abnormal environmental conditions repair and maintenance activities of the system stop and the system is failed

State 12. First failed unit is under preventive maintenance, second failed unit is waiting for repair and the system failed. There is n-times transition between state 10 and state 11.

The system may be any one of the possible states:

$$S_0 = (o, Cs),\quad S_1 = (o, Pm),\quad S_2 = (o, Fur),\quad S_3 = (\bar{o}, \overline{WPm}),$$
$$S_4 = (\bar{o}, \overline{Cs}),\quad S_5 = (\bar{o}, \overline{Fwr}),\quad S_6 = (FUR, Fwr),\quad S_7 = (PM, Fwr),$$
$$S_8 = (\overline{Fwr}, \overline{FWR}),\quad S_9 = (Fur, \overline{FWR}),\quad S_{10} = (\overline{WPm}, \overline{FWR}),\quad S_{11} = (Pm, FWR)$$

where $E = \{S_0, S_1, S_2, S_3, S_4, S_5\}$ is the set of regenerative states.

3 Notations

O	:	The unit is operative and in normal mode
Cs	:	The unit is in cold standby
λ_1	:	Constant failure rate
β/β_1	:	Constant rate of change of environment from normal to abnormal/abnormal to normal
α_0	:	Constant rate of Maximum Operation Time
$\overline{O}$	:	Unit is good but waiting for operation due to abnormal environment
Pm/PM	:	The unit is under preventive maintenance/under preventive maintenance continuously from previous state
WPm/WPM	:	The unit is waiting for preventive maintenance/waiting for preventive maintenance continuously from previous state
FUr/FUR	:	The unit is failed and is under repair/under repair continuously from previous state
FWr/FWR	:	The unit is failed and is waiting for repair/waiting for repair continuously from previous state
$\overline{WPm}/\overline{WPM}$	:	The unit is waiting for preventive maintenance due to abnormal environmental conditions/unit is waiting for preventive maintenance from previous state due to abnormal environmental conditions
$\overline{FWr}/\overline{FWR}$	:	The unit is failed and waiting for repair due to abnormal environmental conditions/unit is waiting for repair from previous state due to abnormal environmental conditions
$g(t)/G(t)$	:	pdf/cdf of repair time of the unit
$f(t)/F(t)$	:	pdf/cdf of preventive maintenance time of the unit
$q_{ij}(t)/Q_{ij}(t)$	:	pdf/cdf of passage time from regenerative state S_i to a regenerative state S_j or to a failed state S_j without visiting any other regenerative state in $(0, t]$
pdf/cdf	:	Probability density function/ Cumulative density function
$q_{ij} \cdot k(t)/Q_{ij} \cdot k(t)$	:	pdf and cdf of first passage time from a regenerative state S_i to a regenerative state S_j or to a failed state S_j visiting state S_k once in $(0, t]$
m_{ij}	:	The conditional mean sojourn time in regenerative state S_i when system is to make transition in to regenerative state S_j. Mathematically, it can be written as $m_{ij} = E(T_{ij}) = \int_0^\infty td[Q_{ij}(t)] = -q_{ij}^{*'}(0)$, where T_{ij} is the transition time from state S_i to S_j; $S_i, S_j \in E$
μ_i	:	The mean sojourn time in state S_i is given by $\mu_i = E(T_i) = \int P(T_i > t)dt = \sum_j m_{ij}$, where S_i is the sojourn time in state S_i
$W_i(t)$	:	Probability that the server is busy in the state S_i up to time$'t'$ without making any transition to any other regenerative state or returning to the same state via one or more regenerative states
$\sim /*$	:	Symbol for Laplace-Steiltjes Transform (LST)/ Laplace Transform (LT)

Transition Probabilities and Mean Sojourn Times

Simple probabilistic considerations yield the following expressions for the non-zero elements

$$p_{ij} = Q_{ij}(\infty) = \int_0^\infty q_{ij}(t)dt \tag{3.1}$$

as

$$p_{01} = \frac{\alpha_0}{\alpha_0+\beta+\lambda_1}, \qquad p_{02} = \frac{\lambda_1}{\alpha_0+\beta+\lambda_1},$$

$$p_{03} = \frac{\beta}{\alpha_0+\beta+\lambda_1}, \qquad p_{10} = f^*(\beta+\lambda_1),$$

$$p_{13} = \frac{\beta}{\beta+\lambda_1}[1-f^*(\beta+\lambda_1)], \qquad p_{17} = \frac{\lambda_1}{\beta+\lambda_1}[1-f^*(\beta+\lambda_1)] = p_{12.7},$$

$$p_{20} = g^*(\beta+\lambda_1), \qquad p_{25} = \frac{\beta}{\beta+\lambda_1}[1-g^*(\beta+\lambda_1)],$$

$$p_{26} = \frac{\lambda_1}{\beta+\lambda_1}[1-g^*(\beta+\lambda_1)], \qquad p_{22.6} = \frac{\lambda_1}{\beta+\lambda_1}[1-g^*(\beta+\lambda_1)],$$

$$p_{31} = p_{52} = p_{40} = p_{89} = p_{10.11} = 1, \qquad p_{62} = g^*(\beta),$$

$$p_{68} = 1-g^*(\beta), p_{11.2} = f^*(\beta), p_{11.10} = 1-f^*(\beta), \quad p_{72} = f^*(\beta), p_{7.10} = 1-f^*(\beta),$$

$$p_{92} = g^*(\beta), p_{98} = 1-g^*(\beta), \qquad p_{12.7.(10.11)^n} = \frac{p_{17}p_{7.10}p_{10.11}p_{11.2}}{1-p_{11.10}p_{10.11}},$$

$$p_{22.6.(8.9)^n} = \frac{p_{26}p_{68}p_{89}p_{92}}{1-p_{89}p_{98}}$$

It can be easily verified that

$$\begin{aligned} p_{01}+p_{02}+p_{03} &= p_{10}+p_{13}+p_{12.7}+p_{12.7,(8.9)^n} \\ &= p_{20}+p_{26}+p_{25} \\ &= p_{10}+p_{17}+p_{13} \\ &= p_{20}+p_{25}+p_{22.6}+p_{22.6,(8,9)^n} \\ &= p_{31}=p_{52}=p_{40}=p_{89}=p_{10.11} \\ &= p_{92}+p_{98}=p_{62}+p_{68} \\ &= p_{72}+p_{7.10}=p_{11.2}+p_{11.10}=1 \end{aligned} \tag{3.2}$$

By taking $g(t) = \theta e^{-\theta t}$ and $f(t) = \alpha e^{-\alpha t}$, we have the following mean sojourn times (μ_i) is the respective states S_i

$$\begin{aligned} &\mu_0 = \frac{1}{\alpha_0+\beta+\lambda_1}, \quad \mu_1 = \frac{1}{\alpha+\beta+\lambda_1}, \quad \mu_2 = \frac{1}{\theta+\beta+\lambda_1}, \\ &\mu_3 = \mu_4 = \mu_5 = \frac{1}{\beta}, \quad \mu_1' = \frac{1}{\alpha}\mu_2' = \frac{1}{\theta} \end{aligned} \tag{3.3}$$

Steady State Availability

By probabilistic arguments

$$M_0(t) = e^{-(\alpha_0+\lambda_1+\beta)t}, M_1(t) = e^{-(\lambda_1+\beta)t}\overline{F(t)}, M_2(t) = e^{-(\lambda_1+\beta)t}\overline{G(t)}$$

From the arguments used in the theory of regenerative processes, the point wise availabilities $A_i(t)$ are seen to satisfy the following recursive relations

$$A_i(t) = M_i(t) + \sum_j q_{i,j}^{(n)}(t) © A_j(t) \tag{3.4}$$

where j is any successive regenerative state to which the regenerative state i can transit through n transitions. Taking LT of above relations (3.4) and solving for $A_0^*(s)$, the steady state availability is given by

$$A_0(\infty) = \lim_{s\to 0} sA_0^*(s) = \frac{N_1(0)}{D_1'(0)} \tag{3.5}$$

where

$$D_1(s) = \begin{vmatrix} 1 & -q_{01}^*(s) & -q_{02}^*(s) & -q_{03}^*(s) & 0 & 0 \\ -q_{10}^*(s) & 1 & -q_{12.7}^*(s) - q_{12.7,(10.11)^n}^*(s) & -q_{13}^*(s) & 0 & 0 \\ -q_{20}^*(s) & 0 & 1 - q_{22.6}^*(s) - q_{22.6,(8.9)^n}^*(s) & 0 & 0 & -q_{25}^*(s) \\ 0 & -q_{31}^*(s) & 0 & 1 & 0 & 0 \\ -q_{40}^*(s) & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -q_{52}^*(s) & 0 & 0 & 1 \end{vmatrix}$$

and

$$N_1(s) = \begin{vmatrix} M_0^*(s) & -q_{01}^*(s) & -q_{02}^*(s) & -q_{03}^*(s) & 0 & 0 \\ M_1^*(s) & 1 & -q_{12.7}^*(s) - q_{12.7,(10.11)^n}^*(s) & -q_{13}^*(s) & 0 & 0 \\ M_2^*(s) & 0 & 1 - q_{22.6}^*(s) - q_{22.6,(8.9)^n}^*(s) & 0 & 0 & -q_{25}^*(s) \\ 0 & -q_{31}^*(s) & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -q_{52}^*(s) & 0 & 0 & 1 \end{vmatrix}$$

4 Busy Period Analysis for Server

By probabilistic arguments, we have following recursive relations for $B_i^p(t)$ and $B_i^R(t)$:

$$\begin{aligned} B_i^p(t) &= W_i(t) + \sum_j q_{i,j}^{(n)}(t) © B_j^p(t), \\ B_i^r(t) &= W_i(t) + \sum_j q_{i,j}^{(n)}(t) © B_j^r(t) \end{aligned} \tag{4.1}$$

where S_j is any successive regenerative state to which the regenerative state S_i can transit through n transitions. $W_i(t)$ be the probability that the server is busy in state S_i due to preventive maintenance and repair of the unit up to time t without making any transition to any other regenerative state or returning to the same via one or more non-regenerative states and so

$$W_1 = e^{-(\lambda_1+\beta)t}\overline{F}(t), \qquad W_2 = e^{-(\lambda_1+\beta)t}\overline{G}(t)$$

Taking LT of above relations (4.1) and solving for $B_i^{*p}(t)$ and $B_i^{*r}(t)$ the time for which server is busy due to preventive maintenance and repair respectively is given by

$$B_0^p = \lim_{s\to 0} sB_0^{*p}(s) = \frac{N_2(0)}{D_1'(0)}, \qquad B_0^r = \lim_{s\to 0} sB_0^{*r}(s) = \frac{N_3(0)}{D_1'(0)}$$

where

$$N_2(s) = \begin{vmatrix} 0 & -q_{01}^*(s) & -q_{02}^*(s) & -q_{03}^*(s) & 0 & 0 \\ W_1^*(s) & 1 & -q_{12.7}^*(s) - q_{12.7,(10.11)^n}^*(s) & -q_{13}^*(s) & 0 & 0 \\ 0 & 0 & 1 - q_{22.6}^*(s) - q_{22.6,(8.9)^n}^*(s) & 0 & 0 & -q_{25}^*(s) \\ 0 & -q_{31}^*(s) & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -q_{52}^*(s) & 0 & 0 & 1 \end{vmatrix}$$

and

$$N_3(s) = \begin{vmatrix} 0 & -q^*_{01}(s) & -q^*_{02}(s) & -q^*_{03}(s) & 0 & 0 \\ 0 & 1 & -q^*_{12.7}(s) - q^*_{12.7,(10.11)^n}(s) & -q^*_{13}(s) & 0 & 0 \\ W^*_2(s) & 0 & 1 - q^*_{22.6}(s) - q^*_{22.6,(8.9)^n}(s) & 0 & 0 & -q^*_{25}(s) \\ 0 & -q^*_{31}(s) & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -q^*_{52}(s) & 0 & 0 & 1 \end{vmatrix}$$

and $D_1(s)$ is already defined.

5 Expected Number of Preventive Maintenances

Let $R^p_i(t)$ be the expected number of preventive maintenances conducted by the server in $(0, t]$ given that the system entered the regenerative state at $t = 0$. The recursive relations for $R^p_i(t)$ are given as

$$R^p_i(t) = \sum_j Q^{(n)}_{i,j}(t)\circledR[\delta_j + R^p_j(t)] \tag{5.1}$$

where S_j is any regenerative state to which the given regenerative state S_i transits and $\delta_j = 1$, if S_j is the regenerative state where the server does job afresh, otherwise $\delta_j = 0$.

Taking LT of relation (5.1) and solving for $\widetilde{R}^p_0(s)$. The expected numbers of preventive maintenances per unit time of the system is given by

$$R^p_0(\infty) = \lim_{s\to 0} s\widetilde{R}^p_0(s) = \frac{N_4(s)}{D'_1(s)} \tag{5.2}$$

where

$$N_4(s) = \begin{vmatrix} 0 & -Q^*_{01}(s) & -Q^*_{02}(s) & -Q^*_{03}(s) & 0 & 0 \\ \begin{matrix} Q^*_{12.7}(s)+ \\ Q^*_{12.7,(10.11)^n}(s) \end{matrix} & 1 & \begin{matrix} -Q^*_{12.7}(s)- \\ Q^*_{12.7,(10.11)^n}(s) \end{matrix} & -Q^*_{13}(s) & 0 & 0 \\ 0 & 0 & \begin{matrix} 1 - Q^*_{22.6}(s)- \\ Q^*_{22.6,(8.9)^n}(s) \end{matrix} & 0 & 0 & -Q^*_{25}(s) \\ 0 & -Q^*_{31}(s) & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -Q^*_{52}(s) & 0 & 0 & 1 \end{vmatrix}$$

and $D_1(s)$ is already mentioned.

Expected Number of Repairs by Server

Let $R^r_i(t)$ be the expected number of repairs conducted by the server in $(0, t]$ given that the system entered the regenerative state at $t = 0$. The recursive relations for $R^r_i(t)$ are given as

$$R^r_i(t) = \sum_j Q^{(n)}_{i,j}(t)\circledR[\delta_j + R^r_j(t)] \tag{5.3}$$

where S_j is any regenerative state to which the given regenerative state S_i transits and $\delta_j = 1$, if S_j is the regenerative state where the server does job afresh, otherwise $\delta_j = 0$.

Taking LT of relation (5.3) and solving for $\widetilde{R}^r_0(s)$. The expected numbers of repairs per unit time of the system conducted by server is given by

$$R^r_0(\infty) = \lim_{s\to 0} s\widetilde{R}^r_0(s) = \frac{N_5(s)}{D'_1(s)} \tag{5.4}$$

where

$$N_5(s) = \begin{vmatrix} 0 & -Q^*_{01}(s) & -Q^*_{02}(s) & -Q^*_{03}(s) & 0 & 0 \\ 0 & 1 & \begin{matrix} -Q^*_{12.7}(s)- \\ Q^*_{12.7,(10.11)^n}(s) \end{matrix} & -Q^*_{13}(s) & 0 & 0 \\ \begin{matrix} Q^*_{22.6}(s)+ \\ Q^*_{22.6,(8.9)^n}(s) \end{matrix} & 0 & \begin{matrix} 1-Q^*_{22.6}(s)- \\ Q^*_{22.6,(8.9)^n}(s) \end{matrix} & 0 & 0 & -Q^*_{25}(s) \\ 0 & -Q^*_{31}(s) & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -Q^*_{52}(s) & 0 & 0 & 1 \end{vmatrix}$$

and $D_1(s)$ is already mentioned.

6 Expected Number of Visits by the Server

Let $N_i(t)$ be the expected number of visits by the server in $(0, t]$ given that the system entered the regenerative state Si at $t = 0$. The recursive relations for $N_i(t)$ are given as

$$N_i(t) = \sum_j Q^{(n)}_{i,j}(t) Ⓡ [\delta_j + N_j(t)] \tag{6.1}$$

where j is any regenerative state to which the given regenerative state i transits and $\delta = 1$, if j is the regenerative state where the server does job afresh, otherwise $\delta j = 0$.

Taking LT of relation (6.1) and solving for $\widetilde{N}_0(s)$. The expected number of visit per unit time by the server are given by

$$N_0(\infty) = \lim_{s \to 0} s\widetilde{N}_0(s) = \frac{N_6}{D_2},$$

where

$$N_6(s) = \begin{vmatrix} Q^*_{01}(s) + Q^*_{02}(s) & -Q^*_{01}(s) & -Q^*_{02}(s) & -Q^*_{03}(s) & 0 & 0 \\ 0 & 1 & \begin{matrix} -Q^*_{12.7}(s)- \\ Q^*_{12.7,(10.11)^n}(s) \end{matrix} & -Q^*_{13}(s) & 0 & 0 \\ 0 & 0 & \begin{matrix} 1-Q^*_{22.6}(s)- \\ Q^*_{22.6,(8.9)^n}(s) \end{matrix} & 0 & 0 & -Q^*_{25}(s) \\ 0 & -Q^*_{31}(s) & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -Q^*_{52}(s) & 0 & 0 & 1 \end{vmatrix}$$

and $D_1(s)$ is already mentioned.

7 Cost-Benefit Analysis

The profit incurred to the system model in steady state can be obtained as

$$P = K_0 A_0 - K_1 B^p_0 - K_2 B^r_0 - K_3 R^p_0 - K_4 R^r_0 - K_5 N_0 \tag{7.1}$$

$K_0 =$ Revenue per unit up-time of the system

$K_1 =$ Cost per unit time for which server is busy due preventive maintenance

$K_2 =$ Cost per unit time for which server is busy due to repair

$K_3 =$ Cost per unit time for preventive maintenance of system

$K_4 =$ Cost per unit time for repair

$K_5 =$ Cost per unit time visit by the server

8 Numerical Study

The numerical results considering a particular case $g(t) = \theta e^{-e}$ and $f(t) = \alpha e^{-\alpha t}$ are obtained for various measures of system effectiveness with abnormal environmental conditions rate (β) with fixed values of other parameters.

Case: β

Method 1: $\alpha_0 = .003$, $\alpha = 0.5$, $\beta_1 = 0.1$, $\lambda_1 = 0.05$ and $\theta = 0.9$

Method 2: $\alpha_0 = .003$, $\alpha = 0.5$, $\beta_1 = 0.1$, $\lambda_1 = 0.05$ and $\theta = 1.4$

Method 3: $\alpha_0 = .003$, $\alpha = 1.0$, $\beta_1 = 0.1$, $\lambda_1 = 0.05$ and $\theta = 0.9$

Method 4: $\alpha_0 = .003$, $\alpha = 0.5$, $\beta_1 = 0.1$, $\lambda_1 = 0.2$ and $\theta = 0.9$

Table 1 shown the effect of environmental conditions on steady state availability with respect to abnormal environmental conditions (β) with different method of values.

Table 1. Availability vs. abnormal environmental conditions

Case	Method #1	Method #2	Method #3	Method #4
0.01	0.9040	0.9056	0.9056	0.8700
0.02	0.8267	0.8284	0.8295	0.7955
0.03	0.7613	0.7629	0.7650	0.7325
0.04	0.7053	0.7067	0.7098	0.6787
0.05	0.6566	0.6581	0.6620	0.6321
0.06	0.6141	0.6155	0.6201	0.5914
0.07	0.5766	0.5779	0.5832	0.5556
0.08	0.5433	0.5446	0.5503	0.5238
0.09	0.5135	0.5147	0.5210	0.4954
0.10	0.4868	0.4879	0.4945	0.4698

Table 2 shown the effect of environmental conditions on profit function with respect to abnormal environmental conditions (β) with fixed values of the other parameters having costs $K_0 = 2000$, $K_1 = 100$, $K_2 = 200$, $K_3 = 75$, $K_4 = 120$, $K_5 = 150$.

Table 2. Profit function vs. abnormal environmental conditions

Case	Method #1	Method #2	Method #3	Method #4
0.01	1769.2	1775.3	1772.3	1667.7
0.02	1608.5	1614.1	1613.8	1521.0
0.03	1474.5	1479.7	1481.7	1397.3
0.04	1360.8	1365.6	1369.6	1291.8
0.05	1263.1	1267.6	1273.2	1200.8
0.06	1178.2	1182.4	1189.5	1121.4
0.07	1103.8	1107.7	1116.1	1051.6
0.08	1037.9	1041.6	1051.1	989.7
0.09	979.3	982.8	993.2	934.6
0.10	926.8	930.1	941.2	885.1

9 Conclusion

The numerical results obtained for availability and profit indices of a cold standby system with abnormal environmental conditions shows that the availability and profit of the system decreases with the increase of the failure rate (λ_1) and abnormal environmental conditions (β). From these results, it is revealed that Availability and profit increase with the increase of preventive maintenance rate (α) and repair rate (θ) of the system. Thus, on the basis of the results obtained for a particular case, it is suggested that the availability and profit of a system under different environmental conditions can be improved by

(i) By operating the system in suitable environmental conditions.

(ii) Conducting preventive maintenance of the units after a pre-specific period of time.

(iii) Controlling the failure rate of the unit.

(iv) By increasing the repair rate of the system.

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