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Impact of Abnormal Weather Conditions on Various Reliability Measures of a Repairable System with Inspection

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Abstract

The main concentration of the present paper is to analyze the impact of abnormal weather conditions on various reliability measures of a repairable system of single–unit. For this purpose, a reliability model is developed in which unit may fail totally either directly from normal mode or via partial failure. A single repair facility is available who plays the dual role of inspection and repair. The totally failed unit is first inspected by the server to examine the feasibility of its repair. If repair of the unit is not feasible, it is replaced by new one. The operation, inspection, replacement and repair of the unit are stopped in abnormal weather as a precautionary measure to avoid excessive damage to the system. Failure rates, repair rates, inspection rates, and rate of change of weather conditions follow general distribution like Weibull distribution. By using semi-Markov process and regenerative point technique some reliability and economic measures of system effectiveness are obtained. The graphical behavior of MTSF and profit with respect to abnormal weather rate has also been shown for a particular case.

Keywords: Reliability model, weather conditions, inspection, repairable system, semi-Markov process and cost-benefit analysis.

1. Introduction

It is very difficult to keep the environmental conditions under control which may fluctuate due to changing climate, voltage and other natural catastrophic. However, it becomes necessary to protect the operation of the system in abnormal weather for reducing the down time and maintaining the reliability of the system. Generally, the given controlled conditions reckon to normal weather; otherwise, weather is taken as abnormal. A number of reparable systems which operate under strict control of temperature, voltage, storm and moisture, etc. have been considered by the researchers including Osaki (1972), Goyal (1984), Naidu and Gopalan (1984) and Singh (1989) in the field of reliability theory. These conditions when satisfied correspond to normal weather; otherwise, it is supposed that the system is working under abnormal weather. Dhillon and Natesan (1983) and Goyal et al. (1985) have studied the stochastic behavior of systems operating under different weather conditions by assuming that repair of the unit is always possible and economical to the system. However, sometimes repair of the unit is not possible and beneficial due to excessive use and high cost of maintenance. In such a situation, the unit may be replaced by new one in order to increase the availability of the system and hence profit.

Many researchers such as Chander and Bansal (2005), Chander (2007) and Garg et al. (2010) in the field of reliability modeling of single-unit systems carried out reliability measures of these models under a common assumption that failure rate of these systems are constant distributed. But the failure rate of many systems such as shafts and valves are of linearly increased in nature due to wear out under mechanical stress and so their failure rates follows arbitrary distributions like Weibull distribution. Gupta et al. (2013) developed a reliability model for a two dissimilar cold standby system with Weibull failure and repair laws. Kumar and Saini (2014) carried out the cost-benefit analysis of a single-unit system with preventive maintenance and Weibull distribution for failure and repair activities.

While incorporating the idea of weather conditions and Weibull (arbitrary) distribution, a reliability model of a single–unit repairable system is analyzed considering two weather conditions–normal and abnormal. For this purpose, a reliability model is developed in which unit may fail totally either directly from normal mode or via partial failure. A single repair facility is available who plays the dual role of inspection and repair. The totally failed unit is first inspected by the server to examine the feasibility of its repair. If repair of the unit is not feasible, it is replaced by new one. The operation, inspection, replacement and repair of the unit are stopped in abnormal weather as a precautionary measure to avoid excessive damage to the system. It is assumed that the distribution of failure time and time to change in weather conditions, inspection and repair times are general distribution. The system is observed at suitable regenerative epochs by using regenerative point technique. Suppose random variable T denotes the failure time of the partial failure of an item/ device having Weibull distribution, its pdf will be:

$$f_1(t) = \lambda_1 \eta t^{\eta-1} \exp(-\lambda_1 t^{\eta}); \quad t \geq 0 \quad \text{and} \quad \lambda_1, \eta > 0. \tag{1}$$

The reliability/survival function and hazard (failure/repair/ maintenance) rate function for Weibull distribution are given by $R(t) = \exp(-\lambda_1 t^{\eta})$ and $h(t) = \lambda_1 \eta t^{\eta-1}$ $t \geq 0$ and $\lambda_1, \eta > 0$. It is important to note that λ_1 and η are the scale and shape parameters, respectively. If we put $\eta = 1$ in (1), Weibull distribution reduces to Exponential distribution and if $\eta = 2$, it reduces to Rayleigh distribution. The hazard function of this distribution will be constant for $\eta = 1$, linearly increasing for $\eta = 2$, non-linearly increasing for $\eta > 2$ and uniformly decreasing for $\eta < 1$. Some economic-related reliability characteristics such as mean sojourn times, mean time to system failure (MTSF), steady state availability, busy period and expected numbers of visits by the server are obtained. Finally, the profit is evaluated for the system to carry out the cost-benefit analysis. Numerical results are drawn to show the behavior of MTSF, availability and profit of the model for a particular case when all distributions are taken as Weibull distributed having different values of shape parameter.

2. Notation

O	:	Operative state
E	:	Set of regenerative states for each model
$f_1(t)/f_2(t)/f(t)$ $F_1(t)/F_2(t)/F(t)$	:	pdf/cdf of failure rate from normal mode to partial failure mode /partial failure mode to total failure mode/normal mode to total failure mode.
$z(t)/Z(t)$	:	p.d.f./c.d.f. of time to change of weather conditions form normal to abnormal,

$z_1(t)$ /$Z_1(t)$		abnormal to normal
p/q	:	Probability that repair is not feasible/feasible.
g(t)/G(t)	:	pdf/cdf of repair times of completely failed unit
h(t)/H(t)	:	pdf/cdf of inspection time.
O/PF	:	Unit is operative and in normal mode/unit is partially failed
$\overline{O}$ / $\overline{PF}$	:	Unit is good / partially failed but not working due to abnormal weather
FU_i/FU_r	:	Unit is totally failed and under inspection/under repair.
$\overline{FW_r}$ / $\overline{FW_i}$	:	Unit is completely failed and waiting for repair/ inspection due to abnormal weather.
$q_{ij}(t)$,$Q_{ij}(t)$	:	pdf and cdf of direct transition time from a regenerative state i to a regenerative state j or a failed state j without visiting any other regenerative state in $(0,t]$
$\phi_i(t)$	:	cdf of first passage time from regenerative state i to a failed state.
$A_i(t)$	:	Probability that the system is up at epoch $t / E_0 = S_i \in E$
$B_i(t)$	:	Probability that server is busy in the system at instant $t / E_0 = S_i \in E$.
$N_i(t)$	:	Expected number of visits by the server in $(0,t] / E_0 = S_i \in E$
$M_i(t)$	:	Probability that system initially in regenerative state S_i remains up till time 't' without making any transition to any other regenerative state or returning itself through one or more non-regenerative states.
$W_i(t)$	:	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 non-regenerative state.
m_{ij}	:	Contribution to mean sojourn time in state S_i when system transits directly to state $S_j (S_i, S_j \in E)$ so that $\mu_i = \sum_i m_{ij}$, where $m_{ij} = \int q_{ij}(t)dt$ $= \int dQ_{ij}(t)dt = -\left[\frac{d}{ds}(Q_{ij}^*(s))\right]_{s=0}$ and μ_i is the mean sojourn time in state $S_i \in E$.
Ⓢ\©	:	Symbols for Stieltjes convolution /Laplace convolution.
~/*	:	Symbols for Laplace Stieltjes transform(L.S.T.)/Laplace transform L.T .
L.S.T/L.T	:	Stand for Laplace Stieltjes transform(L.S.T.)/Laplace transform L.T .
$'$	:	Desh denote the derivative with respect to parameter.

The possible transitions states of system models are respectively shown in the following table:

Table 1 States Description

S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7
O	PF	FU_i	$\overline{O}$	$\overline{PF}$	$\overline{FW_i}$	FU_r	$\overline{FW_r}$

All the transition states of the model are regenerative.

3. Transition Probabilities and Mean Sojourn Times

It can be observed that the epochs of entry into any of the states $S_i \in E$ are regenerative point. Let $T_0(\equiv 0), T_1, T_2, \ldots$ denote the epochs at which the system enter any state $S_i \in E$. Let X_n denote the state visited at epoch T_{n+} i.e just after transition at T_n. Then $\{X_n, T_n\}$ is a Markov-renewal process with state space E and $Q_{ij}(t) = \Pr\{X_{n+1} = j, T_{n+1} - T_n \le t | X_n = i\}$ is the semi-Markov kernel over E.

The transition probability matrix of embedded Markov-chain is $p = (p_{ij}) = (Q_{ij}(\infty) = Q(\infty))$ with non-zero elements.

By probabilistic arguments, the non-zero elements p_{ij} are

$$p_{0,1} = \int_0^\infty \lambda_1 \eta t^{\eta-1} \exp(-\lambda_1 t^\eta) \quad \exp(-\lambda t^\eta) \quad \exp(-\beta t^\eta) dt = \frac{\lambda_1}{\lambda_1 + \beta + \lambda}, \quad p_{0,2} = \frac{\lambda}{\lambda_1 + \beta + \lambda},$$

$$p_{0,3} = \frac{\beta}{\lambda_1 + \beta + \lambda}, \quad p_{1,2} = \frac{\lambda_2}{\lambda_2 + \beta}, \quad p_{1,4} = \frac{\beta}{\lambda_2 + \beta}, \quad p_{2,5} = \frac{\beta}{\gamma + \beta}, \quad p_{2,0} = \frac{p\gamma}{\gamma + \beta}, \quad p_{2,6} = \frac{q\gamma}{\gamma + \beta},$$

$$p_{3,0} = 1, \quad p_{4,1} = 1, \quad p_{5,2} = 1, \quad p_{7,6} = 1, \quad p_{6,7} = \frac{\beta}{\alpha + \beta}, \quad p_{6,0} = \frac{\alpha}{\alpha + \beta}.$$

Here p_{ij} denotes the probability of the transition from S_i state to S_j state in state transition diagram. It can be easily verified that

$$p_{30} = p_{52} = p_{41} = p_{76} = p_{01} + p_{02} + p_{03} = p_{14} + p_{12} = p_{20} + p_{25} + p_{26} = p_{60} + p_{67} = 1. \qquad (2)$$

The mean sojourn times μ_i in the state S_i are given by

$$\mu_0 = \int_0^\infty \exp(-\lambda_1 t^\eta) \quad \exp(-\lambda t^\eta) \quad \exp(-\beta t^\eta) dt = \frac{\Gamma(1+\frac{1}{\eta})}{(\lambda_1 + \beta + \lambda)^{\frac{1}{\eta}}}, \quad \mu_1 = \frac{\Gamma(1+\frac{1}{\eta})}{(\lambda_2 + \beta)^{\frac{1}{\eta}}}, \quad \mu_2 = \frac{\Gamma(1+\frac{1}{\eta})}{(\beta + \gamma)^{\frac{1}{\eta}}},$$

$$\mu_3 = \mu_4 = \mu_5 = \mu_7 = \frac{\Gamma(1+\frac{1}{\eta})}{(\beta_1)^{\frac{1}{\eta}}}, \quad \mu_6 = \frac{\Gamma(1+\frac{1}{\eta})}{(\beta + \alpha)^{\frac{1}{\eta}}}. \qquad (3)$$

4. Reliability and Mean Time to System Failure

Let $\phi_i(t)$ be the c.d.f. of first passage time from the regenerative state i to a failed state. Regarding the failed state as absorbing state, we have the following recursive relation for $\phi_i(t)$:

$$\phi_i(t) = \sum_j Q_{i,j}(t) Ⓢ \varphi_j(t) + Z_k(t), \qquad (4)$$

where j is an un-failed regenerative state to which the given regenerative state i can transit and k is a failed state to which the state i can transit directly. Here $Z_k(t)$ denotes the direct first time transition from any operative state to failed state. Taking LST of above relations (4) and solving by Cramer's Rule for $\phi_0^{**}(s)$, we have

$$R^*(s) = \frac{1 - \varphi_0^{**}(s)}{s} = \frac{1 - \frac{N(s)}{D(s)}}{s} = \frac{D'(s) - N'(s)}{D(s)}. \qquad (5)$$

The reliability of the system model can be obtained by taking inverse LT of (5). MTSF is given by

$$MTSF = \lim_{s\to 0} R^*(s) = \lim_{s\to 0} \frac{1-\varphi_0^{**}(s)}{s} = \frac{N_1}{D_1}, \tag{6}$$

where

$$N_1 = m_{03} + m_{30}p_{03} + m_{14}p_{41} + m_{41} + p'_{03}p_{14} + p'_{30}p_{14}p_{03} + p_{03}p'_{14} + p'_{41}p_{14}p_{03} + m_{02} + m_{01}p_{12} + m_{12}p_{01} + p'_{02}p_{14} + p'_{14}p_{02} + p'_{41}p_{14}p_{02}$$

$$D_1 = -p_{14}p_{41} - p_{03}p_{30} + p_{03}p_{30}p_{41}p_{14} \ .$$

5. Steady State Availability

Let $A_i(t)$ be the probability that the system is in upstate at instant '*t*' given that the system entered regenerative state *i* at *t* = 0. The recursive relations for $A_i(t)$ are given as

$$A_i(t) = M_i(t) + \sum_j q_{i,j}(t) © A_j(t), \tag{7}$$

where *j* is any successive regenerative state to which the regenerative state *i* can transit and $M_i(t)$'s obtained as

$$M_0 = \exp(-\beta + \lambda + \lambda_1)t^{\eta}, \quad M_1 = \exp(-\beta + \lambda_2)t^{\eta} \ . \tag{8}$$

Taking LT of relations (7) and (8), solving by Cramer's Rule for $A_0^*(s)$. The steady state availability can be determined as

$$A_0(\infty) = \lim_{s\to 0} sA_0^*(s) = \frac{N_2}{D_2}, \tag{9}$$

where

$$N_2 = (1-p_{25}p_{52})(1-p_{67}p_{76})\left[\mu_0(1-p_{41}p_{14}) + p_{01}\mu_1\right]$$

$$D_2 = (\mu_0 + p_{03}\,\mu_3)\left[(1-p_{41}p_{14})(1-p_{25}p_{52})(1-p_{67}p_{76})\right] + (\mu_1 + p_{14}\,\mu_4)\left[p_{01}(1-p_{67}p_{76})\times(1-p_{25}p_{52}\right] + (\mu_2 + p_{25}\,\mu_5)(1-p_{67}p_{76})\left[(1-p_{41}p_{14})p_{02} + p_{01}p_{12}\right] + (\mu_6 + p_{67}\mu_7)\left[p_{26}((1-p_{41}p_{14})p_{02} + p_{01}p_{12})\right].$$

6. Busy Period Analysis

Let $B_i(t)$ be the probability that the server is busy in repairing the unit at an instant '*t*' given that the system entered regenerative state *i* at *t*=0. The recursive relations for $B_i(t)$ are given as

$$B_i(t) = W_i(t) + \sum_j q_{i,j}(t) © B_j(t), \tag{10}$$

where *j* is any successive regenerative state to which the regenerative state *i* can transit and $W_i(t)$'s obtained as

$$W_2(t) = \exp(-\beta + \gamma)t^{\eta}, \quad W_6(t) = \exp(-\beta + \alpha)t^{\eta} \ . \tag{11}$$

Taking LT of relations (10-11) and solving by Cramer's Rule for $B_0^*(s)$. The busy period of the server can be determined as

$$B_0 = \lim_{s\to 0} sB_0^*(s) = \frac{N_3}{D_2}, \tag{12}$$

where

$$N_3 = W_2(1-p_{67}p_{76})\left[p_{01}p_{12} + p_{02}(1-\mathrm{p}_{41}\mathrm{p}_{14})\right] + W_6 p_{26}\left[p_{01}p_{12} + p_{02}(1-\mathrm{p}_{14}\mathrm{p}_{41})\right],$$

and D_2 has already mentioned.

7. 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 *i* at *t* = 0, we have the following recurrence relations for $N_i(t)$:

$$N_i(t) = \sum_j Q_{i,j}(t) \circledS \left[\delta_j + N_j(t)\right], \tag{13}$$

where *j* is any regenerative state to which the given regenerative state *i* transits.

$$\delta_j = \begin{Bmatrix} 1 & j \text{ is regenerative state} \\ 0 & \text{otherwise} \end{Bmatrix}.$$

Taking LST of the relation (13) and solving by Cramer's Rule for $N_0^{**}(s)$. The expression for expected number of visits per unit time is given by

$$N_0 = \lim_{s\to 0} sN_0^{**}(s) = \frac{N_4}{D_2}, \tag{14}$$

where

$$N_4 = (1-\mathrm{p}_{25}\mathrm{p}_{52})(1-\mathrm{p}_{67}\mathrm{p}_{76})\left[p_{01}(1-\mathrm{p}_{14}\mathrm{p}_{41}) + \mathrm{p}_{01}\, p_{12}\right],$$

and D_2 has already mentioned.

8. Profit Analysis

Any manufacturing industry is basically a profit making organization and no organization can survive for long without minimum financial returns for its investment. There must be an optimal balance between the reliability aspect of a product and its cost. The major factors contributing to the total cost are availability, busy period of server and expected number of visits by the server. The cost of these individual items varies with reliability or mean time to system failure. In order to increase the reliability of the products, we would require a correspondingly high investment in the research and development activities. The production cost also would increase with the requirement of greater reliability.

The revenue and cost function leads to the profit function of a firm/organization, as the profit is excess of revenue over the cost of production. The profit function in time t is given by

$P(t)$ = Expected revenue in $(0,t]$ – Expected total cost in $(0,t]$.

In general, the optimal policies can more easily be derived for an infinite time span or compared to a finite time span. The profit per unit time, in infinite time span is expressed as

$$\lim_{t\to\infty} \frac{P(t)}{t},$$

i.e. profit per unit time = total revenue per unit time – total cost per unit time. Considering the various costs, the profit equation is given as

$$P = K_0 A_0 - K_1 B_0 - K_2 N_0,$$

where

P = Profit per unit time incurred to the system
K_0 = Revenue per unit up time of the system

A_0 = Total fraction of time for which the system is operative
K_1 = Cost per unit time for which server is busy
B_0 = Total fraction of time for which the server is busy
K_2 = Cost per visit by the server
N_0 = Expected number of visits per unit time for the server.

9. Results and Discussion

To show the importance of results and characterize the behavior of MTSF, availability and profit of the system, here we assume that failure times of unit, time of change of weather conditions, inspection time and repair times of the unit are Weibull distributed. Probability density function of Weibull distribution with two parameters is given by

$$z(t) = \beta\eta\, t^{\eta-1}\, e^{\left[-\beta t^{\eta}\right]}, t \geq 0,$$

where η and β are positive constants and are known as shape and scale parameters respectively. From the properties of Weibull distribution, If $\eta = 1$, it become the exponential distribution and for $\eta = 2$ Weibull is equivalent to Rayleigh distribution. The probability density function for time of change of weather conditions, repair time of the unit, failure times of the unit and inspection time are considered as:

$$z(t) = \beta\eta\, t^{\eta-1}\, e^{\left[-\beta t^{\eta}\right]},\ z_1(t) = \beta_1\eta\, t^{\eta-1}\, e^{\left[-\beta_1 t^{\eta}\right]},\ g(t) = \alpha\eta t^{\eta-1} e^{\left[-\alpha t^{\eta}\right]},\ f_1(t) = \lambda_1\eta t^{\eta-1} e^{\left[-\lambda_1 t^{\eta}\right]},$$

$$f_2(t) = \lambda_2\eta t^{\eta-1} e^{\left[-\lambda_2 t^{\eta}\right]},\ f(t) = \lambda\eta t^{\eta-1} e^{\left[-\lambda t^{\eta}\right]} \text{ and } h(t) = \gamma\eta t^{\eta-1} e^{\left[-\gamma t^{\eta}\right]}.$$

For particular values to various parameters and costs, the numerical results for MTSF, availability and profit function are obtained by considering the shape parameter $\eta =$ 0.5, 1, 2 for all random variables associated with failure, weather conditions and repair times as shown in Tables 1, 2 and 3.

10. Conclusions

The numerical results of mean time to system failure (MTSF) with respect to abnormal weather rate (β) and shape parameter (η) are shown in Table 1. It is observed that MTSF increase with the increase of β. It is also observed that MTSF decreases as direct failure rate (λ), shape parameter (η) and normal weather rate (β_1) increase. Thus, we can say that life time of the system keeps on increasing with the increase of abnormal weather rate (β) due to the increase of non working period of the system. Tables 2 and 3 highlights the behavior of availability and profit of the model with respect to abnormal weather rate (β) and shape parameter (η) respectively. It can be seen that availability and profit of the system decreases with the increase of abnormal weather rate (β) and shape parameter (η). Further, when failure rate (λ) and normal weather rate (β_1) increase, the availability and profit of the system increase. Thus finally, we conclude that with the passes of time the availability and profit of the system decreases.

Table 2 MTSF vs. Abnormal Weather Rate (β)

	$\eta=1$			$\eta=2$			$\eta=0.5$		
β ↓	α =1, λ =.02 λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7, γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2
0.01	35.2000	35.2000	33.6000	7.8434	7.8434	7.5807	0.0307	0.0307	0.0207
0.02	38.4000	38.4000	35.2000	9.2968	9.2968	8.7714	0.5423	0.4230	0.3230
0.03	41.6000	41.6000	36.8000	10.7116	10.7116	9.9236	0.9920	0.9920	0.9420
0.04	44.8000	44.8000	38.4000	12.0950	12.0950	11.0443	0.9671	0.9671	0.9671
0.05	48.0000	48.0000	40.0000	13.4520	13.4520	12.1386	0.9600	0.9600	0.9600
0.06	51.2000	51.2000	41.6000	14.7865	14.7865	13.2105	0.9658	0.9658	0.9658
0.07	54.4000	54.4000	43.2000	16.1015	16.1015	14.2629	0.9813	0.9813	0.9813
0.08	57.6000	57.6000	44.8000	17.3995	17.3995	15.2981	1.0043	1.0043	1.0043
0.09	60.8000	60.8000	46.4000	18.6823	18.6823	16.3183	1.0331	1.0331	1.0331
0.10	64.0000	64.0000	48.0000	19.9515	19.9515	17.3248	1.0667	1.0667	1.0667
0.11	67.2000	67.2000	49.6000	21.2085	21.2085	18.3192	1.1040	1.1040	1.1040
0.12	70.4000	70.4000	51.2000	22.4544	22.4544	19.3024	1.1445	1.1445	1.1445
0.13	73.6000	73.6000	52.8000	23.6902	23.6902	20.2755	1.1876	1.1876	1.1876
0.14	76.8000	76.8000	54.4000	24.9167	24.9167	21.2394	1.2328	1.2328	1.2228
0.15	80.0000	80.0000	56.0000	26.1346	26.1346	22.1946	1.2800	1.2800	1.2600

Table 3 Availability vs. Abnormal Weather Rate (β)

	$\eta=1$			$\eta=2$			$\eta=0.5$		
β ↓	α =1, λ =.02 λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7, γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2
0.01	0.8762	0.8637	0.9180	0.7610	0.7386	0.7844	0.9398	0.9278	0.9830
0.02	0.8032	0.7918	0.8762	0.7065	0.6904	0.7447	0.8716	0.8515	0.9631
0.03	0.7414	0.7309	0.8381	0.6644	0.6520	0.7126	0.7992	0.7738	0.9394
0.04	0.6885	0.6787	0.8032	0.6304	0.6205	0.6858	0.7267	0.6985	0.9124
0.05	0.6426	0.6334	0.7711	0.6023	0.5939	0.6629	0.6572	0.6282	0.8830
0.06	0.6024	0.5938	0.7414	0.5784	0.5711	0.6430	0.5925	0.5639	0.8516
0.07	0.5670	0.5589	0.7140	0.5577	0.5512	0.6254	0.5334	0.5061	0.8188
0.08	0.5355	0.5278	0.6885	0.5395	0.5337	0.6096	0.4802	0.4546	0.7853
0.09	0.5073	0.5001	0.6647	0.5234	0.5180	0.5954	0.4327	0.4091	0.7515
0.10	0.4819	0.4751	0.6426	0.5090	0.5039	0.5825	0.3906	0.3690	0.7178
0.11	0.4590	0.4524	0.6218	0.4959	0.4911	0.5707	0.3533	0.3336	0.6845
0.12	0.4381	0.4319	0.6024	0.4840	0.4794	0.5597	0.3204	0.3026	0.6520
0.13	0.4191	0.4131	0.5842	0.4731	0.4687	0.5496	0.2913	0.2752	0.6204
0.14	0.4016	0.3959	0.5670	0.4630	0.4588	0.5402	0.2656	0.2510	0.5900
0.15	0.3855	0.3800	0.5508	0.4537	0.4496	0.5314	0.2429	0.2296	0.5607

Table 4 Profit vs. Abnormal Weather Rate (β)

	$\eta=1$			$\eta=2$			$\eta=0.5$		
β ↓	α =1, λ =.02 λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7, γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ =2	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 =.1, p =0.3, q =0.7 γ **=4**	α =1, λ =.02, λ_1 =.03, λ_1 =.05, β_1 **=.2**, p =0.3, q =0.7 γ =2
0.01	3749.3	3624.6	3864.7	4369.4	4302.5	4577.4	4698.7	4638.4	4914.3
0.02	3484.8	3392.2	3673.3	4005.3	3944.1	4369.4	4357.5	4256.5	4814.7
0.03	3279.9	3207.0	3518.2	3697.3	3640.8	4179.5	3995.2	3867.9	4696.1
0.04	3114.7	3054.5	3388.4	3433.2	3380.9	4005.4	3632.9	3491.9	4561.5
0.05	2977.4	2926.0	3277.3	3204.4	3155.6	3845.2	3285.5	3140.1	4414.1
0.06	2860.7	2815.5	3180.5	3004.1	2958.4	3697.4	2961.8	2818.7	4257.1
0.07	2759.7	2719.1	3094.8	2827.4	2784.4	3560.5	2666.3	2529.7	4093.4
0.08	2671.0	2633.8	3018.1	2670.4	2629.8	3433.4	2400.3	2272.4	3925.8
0.09	2592.1	2557.7	2948.9	2529.9	2491.4	3315.0	2163.0	2044.8	3756.7
0.10	2521.4	2489.1	2885.8	2403.4	2366.9	3204.5	1952.4	1844.2	3588.1
0.11	2457.4	2426.8	2828.0	2289.0	2254.2	3101.2	1766.1	1667.6	3421.8
0.12	2399.0	2369.9	2774.6	2185.0	2151.8	3004.3	1601.6	1512.2	3259.2
0.13	2345.5	2317.6	2725.1	2090.0	2058.3	2913.3	1456.2	1375.3	3101.4
0.14	2296.2	2269.2	2679.0	2002.9	1972.5	2827.6	1327.7	1254.4	2949.1
0.15	2250.5	2224.3	2635.9	1922.8	1893.7	2746.9	1213.9	1147.5	2802.8

References

Chander S. Reliability models with priority for operation and repair with arrival time of server. Pure Appl Math Sci. 2007; LXI: 9-22.

Chander S, Bansal RK. Profit analysis of single-unit reliability models with repair at different failures modes. In: Proc. INCRESE IIT Kharagpur. 2005: 577-587.

Dhillon BS, Natesan J. Stochastic analysis of outdoor power system in fluctuating environment. Microelectron Reliab. 1983; 23: 867-881.

Garg S, Singh J, Singh DV. Availability analysis of crank-case manufacturing in a two-wheeler automobile industry. Appl Math Model. 2010; 34: 1672-1683.

Goyal LR, Gupta R, Rastogi AK. Cost analysis of a system with partial failure mode and abnormal weather condition. Microelectron Reliab. 1985; 25: 461-466.

Goyal V. Cost analysis in a two-unit standby system with a regular repairman and patience time. Microelectron Reliab. 1984; 24: 453-459.

Gupta R, Kumar P, Gupta A. Cost-benefit analysis of a two dissimilar unit cold standby system with Weibull failure and repair laws. Int J Syst Assur Eng Manag. 2013; 4: 327-334.

Kumar A, Saini M. Cost-Benefit analysis of a single-unit system with preventive maintenance and weibull distribution for failure and repair activities. J Appl Math Stat Inform. 2014; 10: 5-19.

Naidu RS, Gopalan MN. Cost benefit analysis of a one server two-unit system to arbitrary failure, Inspection and repair. Reliability Engg. 1984; 8: 11-22.

Osaki S. Reliability analysis of a two-unit standby redundant system with preventive maintenance. IEEE Trans Reliab. 1972; R-21.

Singh SK. Profit evaluation of a two unit cold standby system with random appearance and disappearance time of the service facility. Microelectron Reliab. 1989; 29: 705-709.