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Cost Benefit Analysis of a Two Unit System Model with the Concept with Service Facility-FCFS

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Abstract – The present study seeks to explore cost benefit analysis of a cold standby system with conditional failure of a server. The model consists of two identical units; one unit is in operative mode and other in cold standby. The cold standby unit becomes active when operative unit breaks down. The failure of the server may happen during any service activity which produces unpleasant results in terms of safety as well as economic losses. In this system model we assume that there is a single server for repair activity, who may go for refreshment/treatment to increase his efficiency whenever required. But in case of repair of cold standby unit, server is not allowed to take refreshment/treatment. The server works afresh after taking refreshment with full efficiency. The time to take refreshment and repair activity follows negative exponential distribution whereas the distributions of unit and server failure are taken as arbitrary with different probability density functions. The expressions for various reliability measures such as transition probabilities, mean sojourn times, mean time to system failure, steady state availability etc. are deduced by using semi-Markov process and regenerative point technique. The numerical behaviour of some important performance measures to check the efficacy of the system model under such situations is delineated for arbitrary values of the parameters in the tables respectively.

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INTRODUCTION

In literature, the stochastic behavior of cold standby system has been widely discussed by many researchers including, Osaki and Nakagawa [1971] discussed a two-unit standby redundant system with standby failure. Nakagawa and Osaki [1975] analyzed stochastic behavior of a two-unit priority standby redundant system with repair. Subramanian et al. [1976] explored reliability of a repairable system with standby failure. Gopalan and Nagarwalla [1985] evaluated cost benefit analysis of one server two unit cold standby system with repair and age replacement. Gupta and Goel [1989] studied profit analysis of two-unit priority standby system with administrative delay in repair.

Reliability and availability analysis of a system with standby and common cause failures have been explained by Dhillon [1992]. Lam [1997] studied a maintenance model for two–unit redundant system. Malik [2009] discussed reliability modelling and cost-benefit analysis of a system – A case study. Dhankhar and Malik [2011] studied cost- benefit analysis of system reliability models with server failure during inspection and repair. Bhardwaj and Kaur [2014] analyzed reliability and profit of a redundant system with possible renewal of standby subject to inspection.

Recently, Grewal *et al.* [2017] obtained economic analysis of a system having duplicate cold standby unit with priority to repair of original unit. Rohila and Kumar [2018] analyzed cost benefit of industry having duplicate cold standby unit with different failure rate. It is assumed that the operative unit may fail directly from normal mode and on the contrary, the cold standby unit may be out of order owing to remain unused for a longer period of time or due to any other reason. So far, the cold standby systems with the possibility of server failure have been debated much by many scholars, but the standby unit failure is also of high significance during endeavour. The failure of standby unit highly affects the reliability and availability of the system. Although, a two unit redundant system with standby failure has been much discussed, the concept of standby failure needs more emphasis due to its significant benefaction during study.

SYSTEM DESCRIPTION OF MODEL

Table: 1

S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7
O, Cs	O, Fur	O, Fwr, Sut	Fwr, Csur	FUR, Fwr	FWR, Fwr, Sut	FUR, FWR	FWR, Fwr, SUT

S_0: This state is a regenerative state in which the system is in operative mode with one unit working and another unit is kept as cold standby. There are two possible ways of transition to another state as follows:

(i) $S_0 \rightarrow S_1$: the operative unit may get failed with rate 'λ' and this failed unit goes for under repair. The standby unit takes its place with probability 'a' which is the probability that cold standby unit is ready for use.

(ii) $S_0 \rightarrow S_3$: the operative unit may get failed with rate 'λ' and the standby unit takes its place but standby unit also found out of order with probability 'b' that standby unit in inoperable situation.

S_1: This is also a regenerative state in which the system is in operative mode with one unit and another failed unit is under repair. There are three possible ways of transition to another state as follows:

(i) $S_1 \rightarrow S_4$: the operative unit may get failed with rate 'λ'

(ii) $S_1 \rightarrow S_0$: the failed unit gets repaired with distribution g(t).

(iii) $S_1 \rightarrow S_2$: It may be possible that server gets failed /tired with rate 'μ' while repairing the unit.

S_2: S_2 is a regenerative state in which the system is in operative mode with one unit operating and another failed unit is waiting for repair due to server is for taking refreshment/treatment. There are two possible ways of transition to another state are as follows:

(i) $S_2 \rightarrow S_1$: the server repaired the unit after taking refreshment/treatment.

(ii) $S_2 \rightarrow S_7$: the operating unit may gets failed with rate 'λ' during the server is busy in taking refreshment/treatment.

S_3: This is also a regenerative and failed state in which the operative unit failed and waiting for repair, same time standby unit is also out of order due to unused for a long period of time. Server is busy for repairing cold standby unit with condition that server is not allowed to take refreshment when busy with repairing of cold standby unit. At last server repaired the cold standby unit. So only one possible way of transition is as follows:

(i) $S_3 \rightarrow S_1$: the unit gets repaired by the distribution g(t).

S_4: This is a non-regenerative failed state in which the failed unit under repair continuously from previous state while recent failed unit is waiting for repair due to server can repair one unit at a time. The server may feel the need of refreshment to improve his efficiency with rate 'μ' or server repaired the failed unit. So there are two possible ways of transition state as follows:

(i) $S_4 \rightarrow S_1$: the unit is repaired that was under continuous repair from the previous state with pdf 'g(t)'.

(ii) $S_4 \rightarrow S_5$: During repairing of the failed unit, server may go for refreshment before completion of his job with rate 'μ'.

S_5: It is non-regenerative failed state in which one failed unit is waiting for repair; another failed unit is also waiting for repair continuously from previous state because server is busy to getting refreshment for increase his efficiency. There is only one possible transition that after taking refreshment, server resumes his work i.e.

(i) $S_5 \rightarrow S_6$: server got the refreshment with pdf 'f(t)'.

S_6: It is a non-regenerative failed state, in which one failed unit is under repair continuously from previous state while another failed unit is waiting for repair continuously from previous state. There are two possible ways of transition to another state as follows:

(i) $S_6 \rightarrow S_5$: Again the server may get tired during his repair work of the unit and goes for refreshment to increase his efficiency.

(ii) $S_6 \rightarrow S_1$: the unit is repaired by the server and the unit assumed a new.

S_7: This is a non-regenerative failed state in which one failed unit is waiting for repair and another failed unit is waiting for repair continuously from previous state. The server is busy with having refreshment/treatment continuously from previous state. There is only one possible way to transit as follows:

i) $S_7 \rightarrow S_6$: The server gets his refreshment or treatment with pdf 'f(t)'.

NOTATIONS

E : Set of regenerative states $\{S_0, S_1, S_2, S_3\}$.

O/Cs : The unit is operative /cold standby

Fur / FUR: The failed unit is under repair/ under repair continuously from previous state.

Sut / SUT: The server is busy with taking refreshment/continuously busy with taking refreshment from previous state.

Fwr / FWR : The failed unit is waiting for repair / waiting for repair continuously from previous state because server is busy with taking refreshment.

λ/ μ: Constant failure rate of unit / rate by which server feels tiredness.

a / b: Probability that cold standby unit is operable / not operable.

Csur : The cold standby unit is under repair.

f(t) / F(t): pdf / cdf of refreshment rate by which the server recovers his freshness.

g(t)/G(t): pdf / cdf of repair rate of the failed unit.

$q_{ij}(t)/Q_{ij}(t)$: pdf / cdf of direct transition time from a state S_i to a state S_j without visiting any other state.

$q_{i,jk}(t)/Q_{i,jk}(t)$: pdf / cdf of first passage time from a state S_i to a state S_j visiting state S_k once in (0,t].

$q_{i,jkrs}(t)/ Q_{i,jkrs}(t)$: pdf / cdf of first passage time from a state S_i to a state S_j visiting state S_k , S_r and S_s once in (0,t].

$q_{i,j;k(r,s)}(t)/ Q_{i,j;k(r,s)}(t)$: pdf / 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 , S_r and S_s once or more than one time in (0,t].

$M_i(t)$: Probability that the system is up initially in state $S_i \in E$ is up at time 't' without visiting to any other state.

$W_i(t)$: Probability that the server is busy in state S_i up to time 't' without making any transition to any other regenerative state or before returning to the same state via one or more states.

m_{ij} : Contribution to mean sojourn time μ_i in state S_i when system transits directly to state S_j so that

$$\mu_i = \sum_j m_{ij} = \int t dQ_{ij}(t) = -q_{ij}^{*\prime}(0)$$

ⓢ/©: Symbol for Laplace Stieltjes convolution / Laplace convolution

*/**: Symbol for Laplace transformation/ Laplace Stieltjes transformation.

′(desh) : Symbol for derivative of the function.

TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

Simple probabilities considerations produce the following expressions for the non-zero elements

$$p_{ij} = Q_{ij}(\infty) = \int_0^\infty q_{ij}(t)dt \qquad (1)$$

In particular case:

$$\text{let } g(t) = \theta e^{-\theta t}, f(t) = \phi e^{-\phi t},$$

then transition probabilities evaluated are as follows:

$$p_{01} = a, p_{03} = b, p_{10} = \frac{\theta}{\theta+\lambda+\mu}, p_{12} = \frac{\mu}{\theta+\lambda+\mu} \quad p_{14} = \frac{\lambda}{\theta+\lambda+\mu}, p_{21} = \frac{\phi}{\lambda+\phi}$$
$$p_{27} = \frac{\lambda}{\lambda+\phi}, p_{41} = p_{61} = \frac{\theta}{\theta+\mu}, p_{45} = p_{65} = \frac{\mu}{\theta+\mu}, p_{31} = p_{56} = p_{76} = 1,$$
$$p_{1,1;4(56)} = \frac{\lambda\mu}{(\theta+\lambda+\mu)(\theta+\mu)}, \quad p_{2,1;7(65)} = \frac{\lambda}{\phi+\lambda} \qquad (2)$$

for the above transition probabilities, it can be verified that

$$p_{01} + p_{03} = p_{10} + p_{12} + p_{14} = p_{21} + p_{27} = p_{41} + p_{45} = p_{61} + p_{65} = 1$$
$$p_{10} + p_{12} + p_{1,1;4} + p_{1,1;4(5,6)} = p_{21} + p_{2,1;7(6,5)} = 1 \qquad (3)$$

Let T denotes the time to system failure then the mean sojourn times (μ_i and μ_i') with particular values $g(t) = \theta e^{-\theta t}$ and $f(t) = \phi e^{-\phi t}$ in the state S_i are given by

$$\mu_i = E(t) = \int_0^\infty P(T > t)dt;$$

$$\mu_0 = \frac{1}{\lambda}, \mu_1 = \frac{1}{\theta+\lambda+\mu}, \mu_2 = \frac{1}{\phi+\lambda}, \mu_1' = \frac{\theta\phi + \lambda(\phi+\mu)}{\theta\phi(\phi+\lambda+\mu)}$$
$$\mu_2' = \frac{\theta(\mu-\lambda) + \lambda(\phi+\mu)(\mu+\theta)}{\mu(\phi+\lambda)} \qquad (4)$$

MEAN TIME TO SYSTEM FAILURE (MTSF)

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

$$\phi_0(t) = Q_{01}(t) Ⓢ \phi_1(t) + Q_{03}(t)$$

$$\phi_1(t) = Q_{10}(t) Ⓢ \phi_0(t) + Q_{12}(t) Ⓢ \phi_2(t) + Q_{14}(t)$$

$$\phi_2(t) = Q_{21}(t) Ⓢ \phi_1(t) + Q_{27}(t) \qquad (5)$$

Taking Laplace Stieltjes transformation of relation (5) and solving for MTSF we get

$$\text{MTSF} = \frac{\theta\phi + \lambda\{(\theta+\phi+\lambda+\mu) + a(\phi+\lambda+\mu)\}}{\lambda[\theta\phi + \lambda(\theta+\phi+\lambda+\mu-a\theta) - a\theta\phi]} \qquad (6)$$

STEADY STATE AVAILABILITY

Let $A_i(t)$ be the probability that the system is in up-state at instant 't' given that the system entered regenerative state S_i at t = 0. The recursive relations for $A_i(t)$ are given as follows:

$$A_0(t) = M_0(t) + q_{01}(t) © A_1(t) + q_{03}(t) © A_3(t)$$

$$A_1(t) = M_1(t) + q_{10}(t) © A_0(t) + q_{12}(t) © A_2(t) + q_{1,1;4}(t) © A_1(t) + q_{1,1;4(56)}(t) © A_1(t)$$

$$A_2(t) = M_2(t) + q_{21}(t) © A_1(t) + q_{2,1;7(65)}(t) © A_1(t)$$

$$A_3(t) = q_{31}(t) © A_1(t) \qquad (7)$$

$M_i(t)$ is the probability that the system is up initially in state $S_i \in E$ is up at time t without visiting to any other regenerative state where

$$M_0(t) = e^{-\lambda t}, \quad M_1(t) = e^{-(\lambda+\mu)t}\,\overline{G(t)} \quad \text{and} \quad M_2(t) = e^{-\lambda t}\,\overline{F}(t) \qquad (8)$$

Now solving for availability A_0, the steady state availability is given by

$$A_0 = \frac{\theta\phi(\phi+\lambda+\mu)\{\theta(\phi+\lambda) + \lambda(\phi+\lambda+\mu)\}}{[\lambda(\phi+\lambda)(\theta+\lambda+\mu)\{\theta\phi+\lambda(\phi+\mu)\} + \theta\phi(\phi+\lambda+\mu)\{(\theta+\lambda b)(\phi+\lambda) + \lambda\theta(\mu-\lambda) + \lambda^2(\phi+\mu)(\mu+\theta)\}]} \qquad (9)$$

Evaluation of busy period of the server owing to repair of the failed unit

Let $B_i(t)$ be the probability that the server is busy due to repair of the failed unit at instant t, given that the system entered the regenerative state S_i at t = 0. The recursive relations for $B_i(t)$ are as follows:

$$B_0^R(t) = q_{01}(t) © B_1^R(t) + q_{03}(t) © B_3^R(t)$$

$$B_1^R(t) = W_1(t) + q_{10}(t) © B_0^R(t) + q_{12}(t) © B_2^R(t) + q_{1,1;4}(t) © B_1^R(t) + q_{1,1;4(56)}(t) © B_1^R(t)$$

$$B_2^R(t) = W_2(t) + q_{21}(t) © B_1^R(t) + q_{2,1;7(65)}(t) © B_1^R(t)$$

$$B_3^R(t) = W_3(t) + q_{31}(t) © B_1^R(t) \qquad (10)$$

where $W_i(t)$ is the probability that the server is busy in state S_i due to repairing of unit up to time t without making any transition to any other regenerative state or before returning to the same state via one or more non-regenerative states. The time period for which server is busy due to repair respectively is obtained by solving for $B_0^{*R}(\infty)$ we get

$$B_0^R(\infty) = \frac{\lambda\theta(\phi+\lambda+\mu)(\phi+\mu)\{\lambda(\lambda+\phi+\mu) + \phi(\lambda+\phi)(1+b)\}}{[\lambda(\phi+\lambda)(\theta+\lambda+\mu)\{\theta\phi+\lambda(\phi+\mu)\} + \theta\phi(\phi+\lambda+\mu)\{(\theta+\lambda b)(\phi+\lambda) + \lambda\theta(\mu-\lambda) + \lambda^2(\phi+\mu)(\mu+\theta)\}]} \qquad (11)$$

Evaluation of expected number of visits by the server owing to repair of the unit

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

$$R_0(t) = Q_{01}(t) Ⓢ (R_1(t)+1) + Q_{03}(t) Ⓢ (R_3(t)+1)$$

$$R_1(t) = Q_{10}(t) Ⓢ R_0(t) + Q_{12}(t) Ⓢ R_2(t) + Q_{1,1;4}(t) Ⓢ R_1(t) + Q_{1,1;4(56)}(t) Ⓢ R_1(t)$$

$$R_2(t) = Q_{21}(t) Ⓢ R_1(t) + Q_{2,1;7(65)}(t) Ⓢ R_1(t)$$

$$R_3(t) = Q_{31}(t) Ⓢ R_1(t) \qquad (12)$$

$$R_0(\infty) = \frac{\lambda\phi\theta^2(\phi+\lambda)(\phi+\lambda+\mu)}{[\lambda(\phi+\lambda)(\theta+\lambda+\mu)\{\theta\phi+\lambda(\phi+\mu)\} + \theta\phi(\phi+\lambda+\mu)\{(\theta+\lambda b)(\phi+\lambda) + \lambda\theta(\mu-\lambda) + \lambda^2(\phi+\mu)(\mu+\theta)\}]} \qquad (13)$$

Evaluation of expected number of refreshments provided to server

Let $T_i(t)$ be the expected number of treatments given to server in (0,t] such that the system entered the regenerative state at t = 0. The recursive relations for $T_i(t)$ are as follows:

$$T_0(t) = Q_{01}(t) Ⓢ T_1(t) + Q_{03}(t) Ⓢ T_3(t)$$

$$T_1(t) = Q_{10}(t) Ⓢ T_0(t) + Q_{12}(t) Ⓢ [1+T_2(t)] + Q_{1,1;4}(t) Ⓢ T_1(t) + Q_{1,1;4(56)}(t) Ⓢ [1+T_1(t)]$$

$$T_2(t) = Q_{21}(t) Ⓢ T_1(t) + Q_{2,1;7(65)}(t) Ⓢ T_1(t)$$

$$T_3(t) = Q_{31}(t) Ⓢ T_1(t) \qquad (14)$$

Taking Laplace Stieltjes transform of the relation (14), and solve for T_0 we have

$$T_0 = \frac{\lambda\phi\theta\mu(\phi+\lambda)(\phi+\lambda+\mu)(\theta+\lambda+\mu)}{(\theta+\mu)[\lambda(\phi+\lambda)(\theta+\lambda+\mu)\{\theta\phi+\lambda(\phi+\mu)\} + \theta\phi(\phi+\lambda+\mu)\{(\theta+\lambda b)(\phi+\lambda) + \lambda\theta(\mu-\lambda) + \lambda^2(\phi+\mu)(\mu+\theta)\}]} \qquad (15)$$

Cost -Benefit evaluation of the system

The profit appeared in the system model in steady state can be evaluated as

$$P_0 = K_0 A_0 - K_1 B_0^R - K_2 R_0 - K_3 T_0 \qquad (16)$$

Where

K_0 = 10000: Revenue per unit up- time of the system

K_1 = 600: Cost per unit time for which server is busy

K_2 = 500: Cost per unit visits by the server

K_3 = 300: Cost per unit time refreshment provided to server

DISCUSSION:

The system model illustrates such a system having two identical units in which one unit is absolutely needed to operate the system and other unit is kept as cold standby mode. The utility of the model can be seen in water supply boosting station. The entire system is examined by taking particular values of the various parameters like (θ, ϕ, λ and μ). The numerical behaviours of some reliability measures like mean time to system failure, availability and profit function have been examined with respect to repair rate (θ) and treatment rate (ϕ) as shown in the tables 2 to 4 respectively.

A) Reliability measures Vs Repair rate θ

In this exploration, the effect of various parameters on performance measures of system model is envisaged. Table-2 reflects the facts and figures that MTSF having increasing trend with respect to increasing repair rate (θ). The second column of this table represents as the server failure rate (μ) decreases, values of MTSF in the table increase. In the third column reveals that whenever treatment rate (ϕ) decreases, values of MTSF in the table decrease still having increasing pattern. But in the fourth column of the table, whenever the unit failure rate (λ) decreases, values of MTSF in sharply increase having increasing trend as compare with the first column of the table. Hence the effect of the parameters can be analysis form this table very easily or the numerical behaviour is very helpful to analysis the MSTF of such important system.

Table- 2 MTSF(Mean Time to System Failure) Vs Repair Rate(θ)

θ↓	λ=.55,μ=.45,ϕ=.65	λ=.55,μ=.35,ϕ=.65	λ=.55,μ=.45,ϕ=.35	λ=.40,μ=.45,ϕ=.65
.1	2.991294	2.996315	2.984761	4.147196
.2	3.065634	3.074711	3.053742	4.276316
.3	3.133186	3.145555	3.116883	4.390496
.4	3.194841	3.209887	3.174896	4.492188
.5	3.251337	3.268567	3.228381	4.583333
.6	3.303296	3.322307	3.277849	4.665493
.7	3.351245	3.371706	3.323735	4.739933
.8	3.395629	3.41727	3.366415	4.807692
.9	3.436832	3.459429	3.406214	4.869632
1.0	3.475184	3.49855	3.443414	4.926471

The table-3 clearly exhibits that availability keeps on increasing with respect to repair rate (θ). It also indicates that as server failure (μ) decrease, values in the table increase for fixed values of other parameters. So availability can be increased by keeping check on server failure. It is fascinating that as treatment rate (ϕ) decreases, values in the table also decrease. It is also known from illustration that whenever rate of unit failure (λ) decreases from .55 to .45 then the values availability in the fourth column of the table sharply increase for fixed values of other parameters.

Table-3 Availability Vs Repair Rate(θ)

θ↓	λ=.55,μ=.45,ϕ=.65	λ=.55,μ=.35,ϕ=.65	λ=.55,μ=.45,ϕ=.35	λ=.40,μ=.45,ϕ=.65
.1	0.201593	0.214306	0.141355	0.289122
.2	0.335219	0.352601	0.247318	0.45366
.3	0.423857	0.442553	0.325864	0.548047
.4	0.483801	0.502566	0.384365	0.604298
.5	0.525346	0.543786	0.428455	0.639221
.6	0.554853	0.572895	0.462167	0.661699
.7	0.576288	0.593974	0.488332	0.676603
.8	0.592175	0.609576	0.508936	0.68672
.9	0.604159	0.621348	0.525383	0.693713
1.0	0.61334	0.63038	0.538677	0.698606

Table-4 exhibits that profit is also increasing with increasing repair rate (θ) from 0.1 to 1.0. It is also observed from first and second columns that decrease in value of server failure rate (μ) causes increase in values of profit function. Third column of the table reveals that decrease in treatment rate (ϕ) causes decrease in the values of profit but still having increasing trend and fourth column shows sharp increase in the values of profit whenever unit failure rate (λ) is reduced from .55 to .40.

Table 3.4 Profit Vs Repair Rate(θ)

θ↓	λ=.55,μ=.45,ϕ=.65	λ=.55,μ=.35,ϕ=.65	λ=.55,μ=.45,ϕ=.35	λ=.40,μ=.45,ϕ=.65
.1	574.9705	573.232	877.0761	1196.246
.2	2246.837	2348.215	2036.977	3356.883
.3	3348.597	3498.605	2892.319	4610.441
.4	4081.82	4258.603	3525.54	5363.586
.5	4573.995	4770.205	3999.178	5832.189
.6	4903.705	5118.472	4357.786	6131.201
.7	5119.647	5355.127	4632.493	6323.966
.8	5252.474	5512.351	4845.037	6446.809
.9	5321.807	5610.638	5010.706	6521.346
1.0	5340.394	5663.312	5140.383	6560.855

CONCLUSION:

The idea to make refreshment available to the server (whenever required) enhances the efficiency of the server and having check on sever failure is more beneficial and economical for the productiveness of the system. It is also noteworthy during study that when MTSF, availability and profit are observed with respect to repair rate and with respect to treatment rate for fixed values of other parameters in the tables 2, 3 and 4. It means provision of refreshment is also significant to make the system profitable. Hence the sum and substance of this problem is that the system can be made more efficient and lucrative by increasing repair, having check on server failure, failure of unit and providing refreshment to the server at appropriate time.

The study has its utility in water supply boosting station, power generation station with standby reservoirs etc. Keeping the above study in mind, there is possibility to make progress in the availablity and profit of the system by removing condition on server failure in case of standby unit.

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