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Research Article

COST- BENEFIT ANALYSIS OF TWO DISSIMILAR WARM STANDBY SPACE SHUTTLE SYSTEM SUBJECT FAILURE DUE TO DAMAGE OF THE THERMAL PROTECTION SYSTEM, ATMOSPHERIC HOT GAS AND DEPLETION OF OZONE LAYER

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ABSTRACT

Ozone depletion describes two distinct but related phenomena observed since the late 1970s: a steady decline of about 4% per decade in the total volume of ozone in Earth's stratosphere (the ozone layer), and a much larger springtime decrease in stratospheric ozone over Earth's polar regions. The latter phenomenon is referred to as the ozone hole. In addition to these well-known stratospheric phenomena, there are also springtime polar troposphere ozone depletion events.

The details of polar ozone hole formation differ from that of mid-latitude thinning, but the most important process in both is catalytic destruction of ozone by atomic halogens. The main source of these halogen atoms in the stratosphere is photo dissociation of man-made halocarbon refrigerants, solvents, propellants, and foam-blowing agents (CFCs, HCFCs, freons, halons). These compounds are transported into the stratosphere after being emitted at the surface. Both types of ozone depletion have been observed to increase as emissions of halo-carbons increased.

CFCs and other contributory substances are referred to as ozone-depleting substances (ODS). Since the ozone layer prevents most harmful UVB wavelengths (280–315 nm) of ultraviolet light (UV light) from passing through the Earth's atmosphere, observed and projected decreases in ozone have generated worldwide concern leading to adoption of the Montreal Protocol that bans the production of CFCs, halons, and other ozone-depleting chemicals such as carbon tetrachloride and trichloroethane. It is suspected that a variety of biological consequences such as increases in skin cancer, cataracts, damage to plants, and reduction of plankton populations in the ocean's photic zone may result from the increased UV exposure due to ozone depletion.

The Space Shuttle *Columbia* disaster occurred on February 1, 2003, when *Columbia* disintegrated over Texas and Louisiana as it reentered Earth's atmosphere, killing all seven crew members.

During the launch of STS-107, *Columbia*'s 28th mission, a piece of foam insulation broke off from the Space Shuttle external tank and struck the left wing. Most previous shuttle launches had seen minor damage from foam shedding, but some engineers suspected that the damage to *Columbia* was more serious. NASA managers limited the investigation, reasoning that the crew could not have fixed the problem if it had been confirmed.

When the Shuttle reentered the atmosphere of Earth, the damage allowed hot atmospheric gases to penetrate and destroy the internal wing structure, which caused the spacecraft to become unstable and slowly break apart.

After the disaster, Space Shuttle flight operations were suspended for more than two years, similar to the aftermath of the *Challenger* disaster. Construction of the International Space Station (ISS) was put on hold; the station relied entirely on the Russian Federal Space Agency for resupply for 29 months until Shuttle flights resumed with STS-114 and 41 months for crew rotation until STS-121.

Several technical and organizational changes were made, including adding a thorough on-orbit inspection to determine how well the shuttle's thermal protection system had endured the ascent, and keeping a designated rescue mission ready in case irreparable damage was found. Except for one final mission to repair the Hubble Space Telescope, subsequent missions were flown only to the ISS so that the crew could use it as a "safe haven".

Two-unit standby system subject to environmental conditions such as shocks, change of weather conditions etc. have been discussed in reliability literature by several authors Dhillon, B.S. and Natesen[3] , Goel, L.R., Sharma,G.C. and Gupta, Rakesh[4] and Cao, Jinhua[5] due to significant importance in defenses , industry etc. In the present paper we have taken two-non-identical warm standby system with failure time distribution as exponential and repair time distribution as general. We are considering system subject to failure due to (i) damaged thermal protection and (ii) atmospheric hot gas (iii) failure due to the effect of depletion of ozone layer requiring different types of repair facilities. Using semi Markov regenerative point technique we have calculated different reliability characteristics[1][2] such as MTSF, reliability of the system, availability analysis in steady state, busy period analysis of the system under repair, expected number of visits by the repairman in the long run and gain-function and graphs are drawn.
Keyword: warm standby, failure due to damaged thermal protection, failure due to atmospheric hot gas, failure due to effect of depletion of Ozone layer.

INTRODUCTION

On the morning of Feb. 1, 2003, the space shuttle returned to Earth, intending to land at Kennedy Space Center. At launch, a briefcase-sized piece of insulation had broken off and damaged the thermal protection system of the shuttle's wing, the shield that protects it from heat during re-entry. As the shuttle passed through the atmosphere, hot gas streaming into the wing caused it to break up. The unstable craft rolled and bucked, pitching the astronauts about less than a minute passed before the ship depressurized, killing the crew. The shuttle broke up over Texas and Louisiana before plunging into the ground. The accident was the second major disaster for the space shuttle program, following the 1986 explosion of the shuttle Challenger.

Biological effects

The main public concern regarding the ozone hole has been the effects of increased surface UV radiation on human health. So far, ozone depletion in most locations has been typically a few percent and, as noted above, no direct evidence of health damage is available in most latitudes. Were the high levels of depletion seen in the ozone hole ever to be common across the globe, the effects could be substantially more dramatic. As the ozone hole over Antarctica has in some instances grown so large as to reach southern parts of Australia, New Zealand, Chile, Argentina, & South Africa, environmentalists have been concerned that the increase in surface UV could be significant. Ozone depletion would change all of the effects of UV on human health, both positive and negative.

UVB (the higher energy UV radiation absorbed by ozone) is generally accepted to be a contributory factor to skin cancer and to produce Vitamin D. In addition, increased surface UV leads to increased troposphere ozone, which is a health risk to humans.

Assumptions

1. The failure time distribution is exponential whereas the repair time distribution is arbitrary of two non-identical units.
2. The repair facility is of four types :
   Type I, II repair facility
   - when failure due to damage thermal protection and failure due to atmospheric hot gas of first unit occurs respectively and Type III, IV repair facility
   - when failure due to damage thermal protection and failure due to atmospheric hot gas of the second unit occurs respectively.
3. The repair starts immediately upon failure of units and the repair discipline is FCFS.
4. The repairs are perfect and start immediately after failure due to damage thermal protection and failure due to atmospheric hot gas as soon as the of the system become normal. The failure due to damage thermal protection and failure due to atmospheric hot gas in both the units do not occur simultaneously.
5. The failure of a unit is detected immediately and perfectly.
6. The switches are perfect and instantaneous.
7. All random variables are mutually independent.

Symbols for states of the System

Superscripts O, WS, SO, FDTPS, FAHG, FDOL

Operative, Warm Standby, Stops the operation, failure due to damage thermal protection, failure due to atmospheric hot gas, failure due to effect of depletion of Ozone layer respectively

Subscripts nahg, ahg, dtp, dol, ur, wr, uR

No atmospheric hot gas, atmospheric hot gas, damage thermal protection, depletion of ozone layer, under repair, waiting for repair, under repair continued respectively

Up states – 0,1,2,9 ; Down states – 3,4,5,6,7,8,10,11

Regeneration point – 0,1,2,4,7,10

States of the System

0(O_{nahg}, WS_{nahg})

One unit is operative and there are no atmospheric hot gas and the other unit is warm standby with no atmospheric hot gas in both the units.

1(SO_{ahg}, O_{nahg})

The operation of the first unit stops automatically due to atmospheric hot gas and warm standby unit's starts operating with no atmospheric hot gas .

2($FDTDS_{ur}$, O_{nahg})

The first unit fails and undergoes repair after damage thermal detection system is over and the other unit continues to be operative with no atmospheric hot gas.

3($FDTD_{uR}$, SO_{ahg})

The repair of the first unit is continued from state 2 and the operation of second unit stops automatically due to atmospheric hot gas.

4($FDTD_{ur}$, SO_{ahg}) The first unit fails and undergoes repair after the damage thermal detection system is over and the other unit also stops automatically due to atmospheric hot gas.

5($FDTD_{uR}$, $FAHG_{ahg,wr}$) The repair of the first unit is continued from state 4 and the other unit is failed due to atmospheric hot gas & is waiting for repair.

6(O_{nahg}, $FAHG_{ur}$) The first unit becomes operative with no atmospheric hot gas.
and the second unit is failed due to atmospheric hot gas is under repair.

7(SO_{nahg}, $FDOL_{nahg, ur}$)
The operation of the first unit stops automatically due to no atmospheric hot gas and during switchover to the second unit fails due to effect of depletion of Ozone layer and undergoes repair and there is no atmospheric hot gas

8($FAHG_{ga, wr}$, $FDOL_{nahg, uR}$)
The repair of failed unit due to effect of depletion of Ozone layer is continued from state 7 and the first unit is failed after atmospheric hot gas is waiting for repair.

9(O_{nahg}, SO_{ahg})
The first unit is operative with no atmospheric hot gas and the operation of warm standby second unit is stopped automatically due to atmospheric hot gas.

10(SO_{ahg}, $FDOL_{ur}$)
The operation of the first unit stops automatically due to atmospheric hot gas and the second unit fails due to effect of depletion of Ozone layer and undergoes repair after the atmospheric hot gas is over.

11($FAHG_{ga, wr}$, $FAHG_{uR}$)
The repair of the second unit is continued from state 10 and the first unit is failed due to atmospheric hot gas is waiting for repair.

Transition Probabilities

Simple probabilistic considerations yield the following expressions :

$$p_{01} = \frac{\lambda 1}{\lambda 1+\lambda 2+\lambda 3}, \quad P_{07} = \frac{\lambda 2}{\lambda 1+\lambda 2+\lambda 3}, \quad p_{09} = \frac{\lambda 2}{\lambda 1+\lambda 2+\lambda 3},$$

$$p_{12} = \frac{\lambda 1}{\lambda 1+\lambda 3}, \quad p_{14} = \frac{\lambda 3}{\lambda 1+\lambda 3},$$

$$P_{20} = \overline{G_1}^*(\lambda_1), \quad P_{22}^{(3)} = G_1^*(\lambda_1) = p_{23},$$

$$P_{72} = \overline{G_2}^*(\lambda_4), \quad P_{72}^{(8)} = G_2^*(\lambda_4) = P_{78}$$

We can easily verify that

$$p_{01}+p_{07}+p_{09} = 1, \quad p_{12} + p_{14} = 1, \quad p_{20} + p_{23} (=p_{22}^{(3)}) = 1,$$
$$p_{46}^{(6)} = 1 \quad p_{60} = 1,$$
$$p_{72} + P_{72}^{(5)} + p_{74} = 1, \quad p_{9,10} = 1, \quad p_{10,2} + p_{10,2}^{(11)} = 1 \qquad (1)$$

And mean sojourn times are

$$\mu_0 = E(T) = \int_0^\infty P[T > t]dt \qquad (2)$$

Mean Time To System Failure

We can regard the failed state as absorbing

$$\theta_0(t) = Q_{01}(t)[s]\theta_1(t) + Q_{09}(t)[s]\theta_9(t) + Q_{07}(t)$$
$$\theta_1(t) = Q_{12}(t)[s]\theta_2(t) + Q_{14}(t),$$
$$\theta_2(t) = Q_{20}(t)[s]\theta_0(t) + Q_{22}^{(3)}(t)$$
$$\theta_4(t) = Q_{9,10}(t) \qquad (3\text{-}5)$$

Taking Laplace-Stiltjes transform of eq. (3-5) and solving for

$$Q_0^*(s) = N_1(s) / D_1(s) \qquad (6)$$

where

$$N_1(s) = Q_{01}^*(s) \{ Q_{12}^*(s) Q_{22}^{(3)*}(s) + Q_{14}^*(s) \} + Q_{09}^*(s) Q_{9,10}^*(s) + Q_{07}^*(s)$$
$$D_1(s) = 1 - Q_{01}^*(s) \quad Q_{12}^*(s) Q_{20}^*(s)$$

Making use of relations (1) & (2) it can be shown that $\theta_0^*(0) = 1$, which implies that $\theta_0(t)$ is a proper distribution.

$$MTSF = E[T] = d/ds \ \theta_0^*(s) \Big|_{s=0} = (D_1'(0) - N_1'(0)) / D_1(0)$$

$$= (\mu_0 + p_{01} \ \mu_1 + p_{01} \ p_{12} \ \mu_2 + p_{09} \ \mu_9) / (1 - p_{01} \ p_{12} \ p_{20})$$

where

$$\mu_0 = \mu_{01} + \mu_{07} + \mu_{09}, \quad \mu_1 = \mu_{12} + \mu_{14}, \mu_2 = \mu_{20} + \mu_{22}^{(3)}, \quad \mu_9 = \mu_{9,10}$$

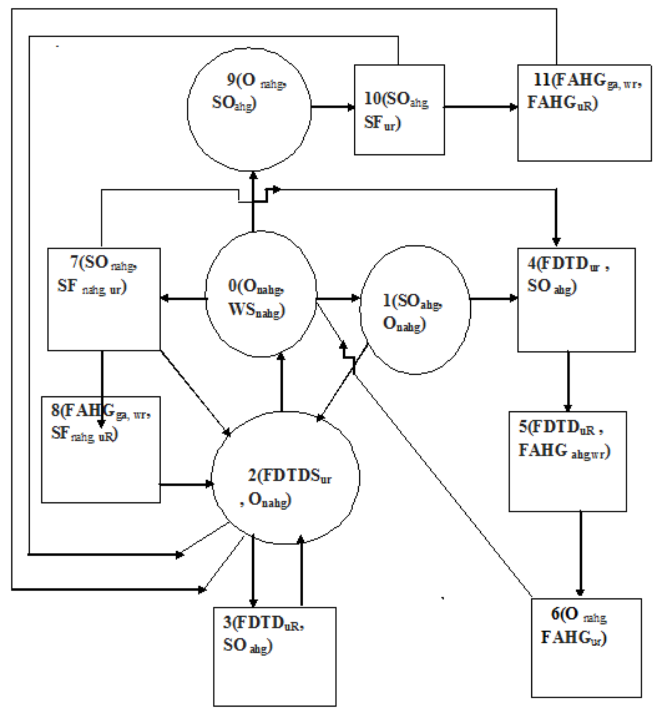

Figure 1: The State Transition Diagram

○ Up State
□ Down State

Availability analysis

Let $M_i(t)$ be the probability of the system having started from state I is up at time t without making any other regenerative state . By probabilistic arguments, we have
The value of $M_0(t)$, $M_1(t)$, $M_2(t)$, $M_4(t)$ can be found easily.
The point wise availability $A_i(t)$ have the following recursive relations

$$A_0(t) = M_0(t) + q_{01}(t)[c]A_1(t) + q_{07}(t)[c]A_7(t) + q_{09}(t)[c]A_9(t)$$
$$A_1(t) = M_1(t) + q_{12}(t)[c]A_2(t) + q_{14}(t)[c]A_4(t), \quad A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) + q_{22}^{(3)}(t)[c]A_2(t)$$
$$A_4(t) = q_{46}^{(3)}(t)[c]A_6(t), \quad A_6(t) = q_{60}(t)[c]A_0(t)$$
$$A_7(t) = (q_{72}(t) + q_{72}^{(8)}(t)) [c]A_2(t) + q_{74}(t)[c]A_4(t)$$
$$A_9(t) = M_9(t) + q_{9,10}(t)[c]A_{10}(t), \quad A_{10}(t) = q_{10,2}(t)[c]A_2(t) + q_{10,2}^{(11)}(t)[c]A_2(t) \qquad (7\text{-}14)$$

Taking Laplace Transform of eq. (7-14) and solving for $\hat{A}_0(s)$

$$\hat{A}_0(s) = N_2(s) / D_2(s) \qquad (15)$$

where

$$N_2(s) = (1 - \hat{q}_{22}^{(3)}(s)) \{ \hat{M}_0(s) + \hat{q}_{01}(s) \hat{M}_1(s) + \hat{q}_{09}(s) \hat{M}_9(s)\} + \hat{M}_2(s)\{ \hat{q}_{01}(s) \hat{q}_{42}(s) + \hat{q}_{07}(s)(\hat{q}_{72}(s) + \hat{q}_{73}^{(8)}(s)) + \hat{q}_{09}(s) \hat{q}_{9,10}(s)(\hat{q}_{10,2}(s) + \hat{q}_{10,2}^{(11)}(s))\}$$

$D_2(s) = (1 - \hat{q}_{22}^{(3)}(s))\ \{ 1 - \hat{q}_{46}^{(5)}(s)\ \hat{q}_{60}(s)\ (\hat{q}_{01}(s)\ \hat{q}_{44}(s) + \hat{q}_{07}(s)\ \hat{q}_{74}(s)) - \hat{q}_{20}(s)\{ \hat{q}_{01}(s)\ \hat{q}_{12}(s) + \hat{q}_{07}(s)(\hat{q}_{72}(s)) + \hat{q}_{72}^{(8)}(s) + \hat{q}_{09}(s)\ \hat{q}_{9,10}(s)\ (\hat{q}_{10,2}(s) + \hat{q}_{10,2}^{(11)}(s))\}$

The steady state availability

$$A_0 = \lim_{t\to\infty}[A_0(t)] = \lim_{s\to 0}[s\,\hat{A}_0(s)] = \lim_{s\to 0}\frac{s\,N_2(s)}{D_2(s)}$$

Using L' Hospitals rule, we get

$$A_0 = \lim_{s\to 0}\frac{N_2(s)+s\ N_2'(s)}{D_2'(s)} = \frac{N_2(0)}{D_2'(0)} \qquad (16)$$

Where

$N_2(0) = p_{20}(\hat{M}_0(0) + p_{01}\hat{M}_1(0) + p_{09}\,\hat{M}_9(0)) + \hat{M}_2(0)\ (p_{01}p_{12} + p_{07}\,(p_{72} + p_{72}^{(8)} + p_{09}))$

$D_2'(0) = p_{20}\{ \mu_0 + p_{01}\,\mu_1 + (p_{01}\,p_{14} + p_{07}\,p_{74})\,\mu_4 + p_{07}\,\mu_7 + p_{07}\,\mu_7 + p_{09}(\mu_9 + \mu_{10}) + \mu_2\ \{1 - ((p_{01}p_{14} + p_{07}\,p_{74})\}$

$$\mu_4 = \mu_{46}^{(5)}\ ,\ \mu_7 = \mu_{72} + \mu_{72}^{(8)} + \mu_{74}\ ,\ \mu_{10} = \mu_{10,2} + \mu_{10,2}^{(11)}$$

The expected up time of the system in (0,t] is

$$\lambda_u(t) = \int_0^{\infty} A_0(z)dz \ \text{ So that } \ \widehat{\lambda_u}(s) = \frac{\hat{A}_0(s)}{s} = \frac{N_2(S)}{S D_2(S)} \quad (17)$$

The expected down time of the system in (0,t] is

$$\lambda_d(t) = t - \lambda_u(t) \ \text{ So that } \ \widehat{\lambda_d}(s) = \frac{1}{s^2} - \widehat{\lambda_u}(s) \qquad (18)$$

The expected busy period of the server for repairing the failed unit under atmospheric hot gas in (0,t]

$R_0(t) = S_0(t) + q_{01}(t)[c]R_1(t) + q_{07}(t)[c]R_7(t) + q_{09}(t)[c]R_9(t)$

$R_1(t) = S_1(t) + q_{12}(t)[c]R_2(t) + q_{14}(t)[c]R_4(t)$,

$R_2(t) = q_{20}(t)[c]R_0(t) + q_{22}^{(3)}(t)[c]R_2(t)$

$R_4(t) = q_{46}^{(3)}(t)[c]R_6(t)$,

$R_6(t) = q_{60}(t)[c]R_0(t)$

$R_7(t) = (q_{72}(t) + q_{72}^{(8)}(t))\ [c]R_2(t) + q_{74}(t)[c]R_4(t)$

$R_9(t) = S_9(t) + q_{9,10}(t)[c]R_{10}(t)$,

$R_{10}(t) = q_{10,2}(t) + q_{10,2}^{(11)}(t)[c]R_2(t)$ (19-26)

Taking Laplace Transform of eq. (19-26) and solving for $\widehat{R_0}(s)$

$$\widehat{R_0}(s) = N_3(s)\ /\ D_2(s) \qquad (27)$$

Where

$N_2(s) = (1 - \hat{q}_{22}^{(3)}(s))\ \{ \hat{S}_0(s) + \hat{q}_{01}(s)\ \hat{S}_1(s) + \hat{q}_{09}(s)\ \hat{S}_9(s)\}$

and $D_2(s)$ is already defined.

In the long run, $R_0 = \frac{N_3(0)}{D_2'(0)}$ (28)

where $N_3(0) = p_{20}(\hat{S}_0(0) + p_{01}\hat{S}_1(0) + p_{09}\,\hat{S}_9(0))$ and $D_2'(0)$ is already defined.

The expected period of the system under atmospheric hot gas in (0,t] is

$$\lambda_{rv}(t) = \int_0^{\infty} R_0(z)dz \ \text{ So that } \ \widehat{\lambda_{rv}}(s) = \frac{\hat{R}_0(s)}{s}$$

The expected Busy period of the server for repairing the failed units under the damage thermal detection system by the repairman in (0,t]

$B_0(t) = q_{01}(t)[c]B_1(t) + q_{07}(t)[c]B_7(t) + q_{09}(t)[c]B_9(t)$

$B_1(t) = q_{12}(t)[c]B_2(t) + q_{14}(t)[c]B_4(t)$,

$B_2(t) = q_{20}(t)[c]\ B_0(t) + q_{22}^{(3)}(t)[c]B_2(t)$

$B_4(t) = T_4(t) + q_{46}^{(3)}(t)[c]B_6(t)$,

$B_6(t) = T_6(t) + q_{60}(t)[c]B_0(t)$

$B_7(t) = (q_{72}(t) + q_{72}^{(8)}(t))\ [c]B_2(t) + q_{74}(t)[c]B_4(t)$

$B_9(t) = q_{9,10}(t)[c]B_{10}(t)$,

$B_{10}(t) = T_{10}(t) + (q_{10,2}(t) + q_{10,2}^{(11)}(t)[c]B_2(t)$

(29- 36)

Taking Laplace Transform of eq. (29-36) and solving for $\widehat{B_0}(s)$

$$\widehat{B_0}(s) = N_4(s)\ /\ D_2(s) \qquad (37)$$

where

$N_4(s) = (1 - \hat{q}_{22}^{(3)}(s))\ \{ \hat{q}_{01}(s)\ \hat{q}_{14}(s)(\hat{T}_4(s) + \hat{q}_{46}^{(5)}(s)\ \hat{T}_6(s)) + \hat{q}_{07}^{(3)}(s)\ \hat{q}_{74}(s)\ (\hat{T}_4(s) + \hat{q}_{46}^{(5)}(s)\ \hat{T}_6(s)) + \hat{q}_{09}(s)\ \hat{q}_{09,10}(s)\ \hat{T}_{10}(s)\ )$

And $D_2(s)$ is already defined.

In steady state,

$$B_0 = \frac{N_4(0)}{D_2'(0)} \qquad (38)$$

where $N_4(0) = p_{20}\ \{(p_{01}\,p_{14} + p_{07}\,p_{74})\ (\hat{T}_4(0) + \hat{T}_6(0)) + p_{09}\,\hat{T}_{10}(0)\}$ and $D_2'(0)$ is already defined.

The expected busy period of the server for repair in (0,t] is

$$\lambda_{ru}(t) = \int_0^{\infty} B_0(z)dz \qquad \text{So that } \widehat{\lambda_{ru}}(s) = \frac{\hat{B}_0(s)}{s} \qquad (39)$$

The expected Busy period of the server for repair of the unit when failure is due to effect of depletion of Ozone layer in (0,t]

$P_0(t) = q_{01}(t)[c]P_1(t) + q_{07}(t)[c]P_7(t) + q_{09}(t)[c]P_9(t)$

$P_1(t) = q_{12}(t)[c]P_2(t) + q_{14}(t)[c]P_4(t)$, $P_2(t) = q_{20}(t)[c]P_0(t) + q_{22}^{(3)}(t)[c]P_2(t)$

$P_4(t) = q_{46}^{(3)}(t)[c]P_6(t)$, $P_6(t) = q_{60}(t)[c]P_0(t)$

$P_7(t) = L_7(t) + (q_{72}(t) + q_{72}^{(8)}(t))\ [c]P_2(t) + q_{74}(t)[c]P_4(t)$

$P_9(t) = q_{9,10}(t)[c]P_{10}(t)$, $P_{10}(t) = (q_{10,2}(t) + q_{10,2}^{(11)}(t))[c]P_2(t)$

(40-47)

Taking Laplace Transform of eq. (40-47) and solving for

$$\widehat{P_0}(s) = N_5(s)\ /\ D_2(s) \qquad (48)$$

where $N_2(s) = \hat{q}_{07}(s)\ \hat{L}_7(s)\ (1 - \hat{q}_{22}^{(3)}(s))$ and $D_2(s)$ is defined earlier.

In the long run , $P_0 = \frac{N_5(0)}{D_2'(0)}$ (49)

where $N_5(0) = p_{20}\,p_{07}\,\hat{L}_4(0)$ and $D_2'(0)$ is already defined.

The expected busy period of the server for repair of the unit when failure is due to effect of depletion of Ozone layer in (0,t] is

$$\lambda_{rs}(t) = \int_0^{\infty} P_0(z)dz \quad \text{So that } \widehat{\lambda_{rs}}(s) = \frac{\hat{P}_0(s)}{s} \qquad (50)$$

The expected number of visits by the repairman for repairing the non-identical units in (0,t]

$H_0(t) = Q_{01}(t)[c]H_1(t) + Q_{07}(t)[c]H_7(t) + Q_{09}(t)[c]H_9(t)$

$H_1(t) = Q_{12}(t)[c][1+H_2(t)] + Q_{14}(t)[c][1+H_4(t)]$,

$H_2(t) = Q_{20}(t)[c]H_0(t) + Q_{22}^{(3)}(t)[c]H_2(t)$

$H_4(t) = Q_{46}^{(3)}(t)[c]H_6(t)$, $H_6(t) = Q_{60}(t)[c]H_0(t)$

$H_7(t) = (Q_{72}(t) + Q_{72}^{(8)}(t))\ [c]H_2(t) + Q_{74}(t)[c]H_4(t)$

$H_9(t) = Q_{9,10}(t)[c][1+H_{10}(t)]$,

$H_{10}(t) = (Q_{10,2}(t)[c] + Q_{10,2}^{(11)}(t))[c]H_2(t)$ (51-58)

Taking Laplace Transform of eq. (51-58) and solving for $H_0^*(s)$

$$H_0^*(s) = N_6(s)\ /\ D_3(s) \qquad (59)$$

Where

$N_6(s) = (1 - Q_{22}^{(3)*}(s))\ \{ Q^*_{01}(s)(Q^*_{12}(s) + Q^*_{14}(s)) + Q^*_{09}(s)\ Q^*_{9,10}(s)\}$

$D_3(s) = (1 - Q_{22}^{(3)*}(s))\ \{1 - (Q^*_{01}(s)\ Q^*_{14}(s) + Q^*_{07}(s)Q^*_{74}(s))\ Q_{46}^{(5)*}(s)\ Q^*_{60}(s)\} - Q^*_{20}(s)\{ Q^*_{01}(s)\ Q^*_{12}(s) + Q^*_{07}(s)(Q^*_{72}(s)) + Q^*_{72}^{(8)}(s) + Q^*_{09}(s)\ Q^*_{9,10}(s)\ (Q^*_{10,2}(s) + Q_{10,2}^{(11)*}(s))\}$

In the long run, $H_0 = \frac{N_6(0)}{D_3'(0)}$ (60)

where $N_6(0) = p_{20}\,(p_{01} + p_{09})$ and $D'_3(0)$ is already defined.

The expected number of visits by the repairman for repairing the unit when failure is due to the effect of depletion of Ozone layer in (0,t]

$V_0(t) = Q_{01}(t)[c]V_1(t) + Q_{07}(t)[c]V_7(t) + Q_{09}(t)[c]V_9(t)$

$V_1(t) = Q_{12}(t)[c]V_2(t) + Q_{14}(t)[c]V_4(t)$,

$V_2(t) = Q_{20}(t)[c]V_0(t) + Q_{22}^{(3)}(t)[c]V_2(t)$

$V_4(t) = Q_{46}^{(3)}(t)[c]V_6(t)$, $V_6(t) = Q_{60}(t)[c]V_0(t)$

$V_7(t) = (Q_{72}(t)[1+V_2(t)]+ Q_{72}^{(8)}(t))\ [c]V_2(t) + Q_{74}(t)[c]V_4(t)$

$V_9(t) = Q_{9,10}(t)[c]V_{10}(t)$, $V_{10}(t) = (Q_{10,2}(t) + Q_{10,2}^{(11)}(t))[c]V_2(t)$ (61-68)

Taking Laplace-Stieltjes transform of eq. (61-68) and solving for $V_0^*(s)$

$$V_0^*(s) = N_7(s) / D_4(s) \quad (69)$$

where $N_7(s) = Q^*_{07}(s)\, Q^*_{72}(s)\, (1 - Q_{22}^{(3)*}(s))$ and $D_4(s)$ is the same as $D_3(s)$

In the long run , $V_0 = \frac{N_7(0)}{D_4'(0)}$ (70)

where $N_7(0)= p_{20}\, p_{07}\, p_{72}$ and $D'_3(0)$ is already defined.

Cost-Benefit Analysis

The gain- function of the system considering mean up-time, expected busy period of the system under the damage thermal detection system when the units stops automatically, expected busy period of the server for repair of unit due to atmospheric hot gas & failure due to effect of depletion of Ozone layer, expected number of visits by the repairman for unit failure, expected number of visits by the repairman for failure due to effect of depletion of Ozone layer.

The expected total cost-benefit incurred in (0,t] is

C(t) = Expected total revenue in (0,t]

- Expected total repair cost for failure due to the effect of depletion of Ozone layer in (0,t]
- Expected total repair cost for repairing the units due to damage thermal detection system in (0, t] when the units automatically stop in (0,t]
- Expected busy period of the system under atmospheric hot gas
- Expected number of visits by the repairman for repairing the unit fails under the effect of depletion of Ozone layer in (0,t]
- Expected number of visits by the repairman for repairing of the non-identical units in (0,t]

The expected total cost per unit time in steady state is

$$C = \lim_{t\to\infty}(C(t)/t) = \lim_{s\to 0}(s^2 C(s))$$
$$= K_1A_0 - K_2P_0 - K_3B_0 - K_4R_0 - K_5V_0 - K_6H_0$$

Where

K_1 → Revenue per unit up-time,

K_2 → Cost per unit time repair of the system when failure due to the effect of depletion of Ozone layer .

K_3 → Cost per unit time for which the system is under repair due to damage thermal detection system when units automatically stop,

K_4 → Cost per unit time for which the system is under repair due to atmospheric hot gas,

K_5 → Cost per visit by the repairman for repair when the failure is due to the effect of depletion of Ozone layer,

K_6 → Cost per visit by the repairman for units repair.

CONCLUSION

After studying the system, we have analyzed graphically that when the failure rate due to damage thermal detection system, failure rate due to atmospheric hot gas and failure due to the effect of depletion of Ozone layer increases, the MTSF and steady state availability decreases and the cost function decreased as the failure increases.

REFERENCES

1. Barlow RE. and Proschan F. Mathematical theory of Reliability, John Wiley, New York, 1965.
2. Gnedanke BV, Belyayar YK and Soloyer AD, Mathematical Methods of Relability Theory, Academic Press, New York, 1969.
3. Dhillon BS and Natesen J, Stochastic Anaysis of outdoor Power Systems in fluctuating environment, Microelectron. Reliab. 1983; 23: 867-881.
4. Goel LR, Sharma GC and Gupta Rakesh. Cost Analysis of a Two-Unit standby system with different weather conditions, Microelectron. Reliab., 1985; 25: 665-659.
5. Cao Jinhua, Stochatic Behaviour of a Man Machine System operating under changing environment subject to a Markov Process with two states, Microelectron. Reliab., 1989; 28: 373-378.

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