Research Article

Cost-benefit analysis of two identical cold standby IRNSS system subject to glitch in the telemetry system and failure due to owing to thunderstorm

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Abstract

A computer glitch is the failure of a system, usually containing a computing device, to complete its functions or to perform them properly. In public declarations, glitch is used to suggest a minor fault which will soon be rectified and is therefore used as a euphemism for a bug, which is a factual statement that a programming fault is to blame for a system failure. It frequently refers to an error which is not detected at the time it occurs but shows up later in data errors or incorrect human decisions. While the fault is usually attributed to the computer hardware, this is often not the case since hardware failures rarely go undetected. India successfully launches IRNSS-1C navigation satellite on board PLSV C-26 Indian rocket Polar Satellite Launch Vehicle (PSLV-C26) successfully injected the third navigation satellite (IRNSS-1C) into the intended orbit early Thursday (October 16, 2014).With this, the country has moved a step closer to setting up its own satellite navigation system. At 1:32 am Thursday, the rocket (PSLV-C26) carrying the 1,425-kg Indian Regional Navigation Satellite System-1C (IRNSS-1C) lifted off from Satish Dhawan Space Centre, Sriharikota in Andhra Pradesh. Twenty minutes after liftoff, the launch vehicle successfully placed the IRNSS-1C satellite on the intended orbit. “India's third navigation satellite is up in the orbit”, said ISRO chairman K Radhakrishnan after the launch. Initially, the satellite was scheduled for launch October 10, but was put off by a week due to a glitch in the telemetry system.IRNSS-1C is the third out of seven in the Indian Regional Navigational Satellite System (IRNSS) series of satellites after IRNSS-1A and IRNSS-1B. IRNSS-1C is the first geostationary satellite in the IRNSS system. IRNSS-1C is part of the Indian Regional Navigation Satellite System (IRNSS) and will provide navigation, tracking and mapping services to India and other surrounding region. The satellite is powered by two solar arrays, which generate up to 1,660 watts, and has a life-time of ten years. The first satellite, IRNSS-1A, was launched onboard PSLV-C22 on 1 July 2013 with the seven-satellite constellation scheduled for completion by the end of 2015. The second navigation satellite (IRNSS-1B) was successfully placed in the orbit through PSLV-C24 rocket on 4 April 2014.The IRNSS is an autonomous regional satellite navigation system being developed by the Indian Space Research Organization (ISRO).India recently created space history by becoming the first country in the world to enter the Martian orbit in first attempt. On 24 September, 2014, India's Mars Orbiter Mission (MOM), affectionately called 'Mangalyaan' was successfully placed in the orbit of the Red Planet, catapulting the country into the elite club of Mars explorers- the US, Europe and Russia. India's successful Mars mission has also made the country as the first Asian nation to reach the Red Planet Reliability is a measure of how well a system performs or meets its design requirements. It is hence the prime concern of all scientists and engineers engaged in developing such a system.. In this paper we have taken two types of failures (1) GTS- glitch in the telemetry system (2) FTS-failure owing to thunderstorm. Applying the regenerative point technique with renewal process theory the various reliability parameters MTSF, Availability, Busy period, Benefit-Function analysis have been evaluated.

Keywords: Cold Standby, GTS- glitch in the telemetry system, FTS-failure owing to thunderstorm, first come first serve, MTSF, Availability, Busy period, Cost-Benefit analysis

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INTRODUCTION

India prepares to launch its third navigation satellite

The 67-hour countdown for the Thursday launch of India's third navigation satellite is progressing smoothly though a thunder storm Wednesday delayed some operations. "Today (Wednesday) morning we moved the mobile service tower (MST) backwards. The operation was delayed by around two hours owing to thunderstorm in the morning. There is sufficient time cushion built in for such unforeseen delays in the countdown period," M.Y.S. Prasad, director, Satish Dhawan Space Centre at Sriharikota. "At 10 p.m., based on the climatic conditions like thunderstorm, we will decide on the launch. Currently everything is normal," he added. Prasad said the filling of propellants in the second stage/engine would be completed by 2 p.m. Following that the gases in the various stages would be pressurized. At 1.32 a.m. Thursday, Indian rocket Polar Satellite Launch Vehicle (PSLV-C26) carrying the 1,425-kg third Indian navigational satellite badge as Indian Regional Navigation Satellite System-1C (IRNSS-1C) will kiss final goodbye to Mother Earth.

The 44.4 meters tall rocket, weighing around 320 tones is expected to spit out the satellite into the space around 20 minutes after the blast-off. Once the satellite is successfully placed in its orbit, India will be just one more satellite away from having its own satellite based navigation system. Indian Space Research Organisation (ISRO) chairman K. Radhakrishnan had earlier said, though IRNSS is a seven-satellite system, it could be made operational with four satellites. On Oct 12, ISRO's Launch Authorization Board (LAB) gave its nod for the launch. The countdown began Monday morning. Originally the satellite was scheduled for launch Oct 10, but was put off by a week due to a **glitch in the telemetry system**. During the countdown, propellant filling activities would be carried out along with checking of the various systems. The satellite is part of the Indian Regional Navigation Satellite System (IRNSS) that will have a constellation of seven satellites to provide accurate positioning service for terrestrial, aerial and maritime navigation in 1,500-km area in the Indian peninsula. The second navigation satellite (IRNSS-1B) was launched April 4 this year from the spaceport. The first one – IRNSS-1A – was launched July 2013. The Indian system will be similar to the US Global Positioning System (GPS), Russia's Glonass and Europe's Galileo constellation of navigation satellites. India began its space journey in 1975 with the launch of "Aryabhatta" using a Russian rocket and till date, it has completed over 100 space missions including missions to the Moon and Mars. Stochastic behaviour of systems operating under changing environments has widely been studied. Dhillon, B.S. and Natesan, J. (1983) studied an outdoor power systems in fluctuating environment. Kan Cheng 1985) has studied reliability analysis of a system in a randomly changing environment. Jinhua Cao (1989) has studied a man machine system operating under changing environment subject to a Markov process with two states. The change in operating conditions viz. fluctuations of voltage, corrosive atmosphere, very low gravity etc. may make a system completely inoperative. Severe environmental conditions can make the actual mission duration longer than the ideal mission duration. In this paper we have taken two types of failures (1) **GTS- glitch in the telemetry system** (2) **FTS-failure owing to thunderstorm.** When the main operative unit fails then cold standby system becomes operative. After failure the unit undergoes repair facility of very high cost in case of **glitch in the telemetry system** immediately. The repair is done on the basis of first fail first repaired.

Assumptions

1. $F_1(t)$ and $F_2(t)$ are general failure time distributions due to (1) **GTS- glitch in the telemetry system** (2) **FTS-failure owing to thunderstorm.** The repair is of two types -Type -I, Type-II with repair time distributions as $G_1(t)$ and $G_2(t)$ respectively.
2. The **thunderstorm** is non-instantaneous and it cannot be available simultaneously in both the units.
3. Whenever there is **no thunderstorm,** it works as normal as before. But as soon as there is **thunderstorm** the operation of the unit stops automatically.

4. The repair starts immediately after detecting the failure due to **thunderstorm** and works on the principle first fail first repaired basis.
5. The repair facility does no damage to the units and after repair units are as good as new.
6. The switches are perfect and instantaneous.
7. All random variables are mutually independent.
8. When both the units fail, we give priority to operative unit for repair.
9. Repairs are perfect and failure of a unit is detected immediately and perfectly.
10. The system is down when both the units are non-operative.

SYMBOLS FOR STATES OF THE SYSTEM

$F_1(t)$ and $F_2(t)$ – **glitch in the telemetry system** and **failure owing to thunderstorm** respectively $G_1(t)$, $G_2(t)$ – repair time distribution Type -I, Type-II due to **GTS- glitch in the telemetry system** and **FTS-failure owing to thunderstorm** respectively

Superscripts: O, CS, FGTS, FTS

Operative, Cold Standby, **glitch in the telemetry system, failure owing to thunderstorm** respectively

Subscripts: ngts, tsf, ntsf, ur, wr, uR

No glitch in the telemetry system, failure owing to thunderstorm, no failure owing to thunderstorm, under repair, waiting for repair, under repair continued from previous state respectively

Up states: 0, 1, 2;

Down states: 3, 4

Regeneration point: 0, 1, 2

Notations

M_i (t) System having started from state i is up at time t without visiting any other regenerative state

A_i (t) state is up state as instant t

R_i (t) System having started from state i is busy for repair at time t without visiting any other regenerative state.

B_i (t) the server is busy for repair at time t.

H_i (t) Expected number of visits by the server for repairing given that the system initially starts from regenerative state i

STATES OF THE SYSTEM

0(O_{ngts}, CS_{ngts})

One unit is operative and the other unit is cold standby and there is no glitch in the telemetry system in both the units.

1($SOGTS_{gts,\ ur}$, O_{ngts})

The operating unit fails due to glitch in the telemetry system and is under repair immediately of very costly Type- I and standby unit starts operating with no glitch in the telemetry system.

2($GTS_{ngts,\ tsf,\ ur}$, O_{ngts})

The operative unit failure owing to thunderstorm and undergoes repair of type II and the standby unit becomes operative with no glitch in the telemetry system.

3($GTS_{ngts,uR}$, $FTS_{tsf,\ ngts,\ wr}$)

The first unit fails due to glitch in the telemetry system and undergo very costly Type-I repair is continued from state 1 and the other unit fails owing to thunderstorm and is waiting for repair of Type -II.

4($GTS_{gts,uR}$, $GTS_{gts,wr}$)

The glitch in the telemetry system is continues and undergo very costly repair of Type - I from state 1 and there is glitch in the telemetry system in another unit is waiting for very costly Type -I repair.

5($FTS_{ngts,\ tsf,\ uR}$, $GTS_{gts,\ wr}$)

The operating unit fails owing to thunderstorm and undergo repair of Type - II continues from the state 2 and in the other unit glitch in the telemetry system is waiting for repair of very costly Type- I.

6($FTS_{tsf,ngts,uR}$, $FTS_{ngts,ntsf,wr}$)

The operative unit fails owing to thunder storm and under repair continues from state 2 of Type –II and the other unit is also failed owing to thunderstorm and is waiting for repair of Type-II and there is no glitch in the telemetry system.

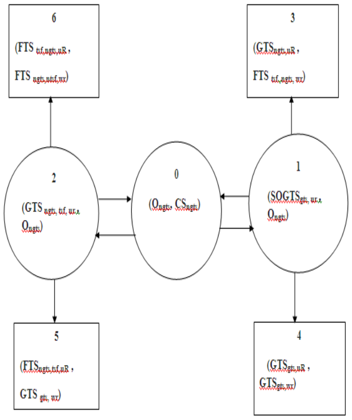

Figure 1: The State Transition Diagram

● Rregeneration point -states 0, 1, 2 ○Up State ☐ Down State

TRANSITION PROBABILITIES

Simple probabilistic considerations yield the following expressions:

$p_{01} = \int_0^\infty \overline{F}_2(t)dF_1(t)$, $p_{02} = \int_0^\infty \overline{F}_1(t)dF_2(t)$

$p_{10} = \int_0^\infty \overline{F}_2(t)dG_1(t)$, $p_{13} = p_{11}^{(3)} = p_{11}^{(4)} = \int_0^\infty \overline{G}_1(t)dF_2(t)$

$p_{25} = p_{22}^{(5)} = p_{22}^{(6)} = \int_0^\infty \overline{G}_2(t)dF_1(t)$

clearly

$p_{01} + p_{02} = 1,$

$p_{10} + p_{13} = (p_{11}^{(3)}) + p_{14} = (p_{11}^{(4)}) = 1,$

$p_{20} + p_{25} = (p_{22}^{(5)}) + p_{26} = (p_{22}^{(6)}) = 1$ (1)

And mean sojourn time is

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

MEAN TIME TO SYSTEM FAILURE

$Ø_0(t) = Q_{01}(t)[s]\, Ø_1(t) + Q_{02}(t)[s]\, Ø_2(t)$

$Ø_1(t) = Q_{10}(t)[s]\, Ø_0(t) + Q_{13}(t) + Q_{14}(t)$

$Ø_2(t) = Q_{20}(t)[s]\, Ø_0(t) + Q_{25}(t) + Q_{26}(t)$ (3-5)

We can regard the failed state as absorbing

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

$ø_0^*(s) = N_1(s) / D_1(s)$ (6)

where

$N_1(s) = Q_{01}^*[\, Q_{13}^*(s) + Q_{14}^*(s)\,] + Q_{02}^*[\, Q_{25}^*(s) + Q_{26}^*(s)\,]$

$D_1(s) = 1 - Q_{01}^*\, Q_{10}^* - Q_{02}^*\, Q_{20}^*$

Making use of relations (1) and (2) it can be shown that $ø_0^*(0) = 1$, which implies that $ø_0^*(t)$ is a proper distribution.

$$\text{MTSF} = E[T] = \frac{d}{ds}\, ø_0^*(s)\Big|_{s=0} = (D_1'(0) - N_1'(0)) / D_1(0)$$

$= (\mu_0 + p_{01}\mu_1 + p_{02}\mu_2) / (1 - p_{01}\, p_{10} - p_{02}\, p_{20})$

where

$\mu_0 = \mu_{01} + \mu_{02},\ \mu_1 = \mu_{10} + \mu_{13} + \mu_{14}$

$\mu_2 = \mu_{20} + \mu_{25} + \mu_{26}$

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 $M_0(t)$, $M_1(t)$, $M_2(t)$ can be found easily.

The point wise availability $A_i(t)$ have the following recursive relations

$A_0(t) = M_0(t) + q_{01}(t)[c]A_1(t) + q_{02}(t)[c]A_2(t)$

$A_1(t) = M_1(t) + q_{10}(t)[c]A_0(t) + q_{11}^{(3)}(t)[c]A_1(t)+ q_{11}^{(4)}(t)[c]A_1(t),$

$A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) + [q_{22}^{(5)}(t)[c]+ q_{22}^{(6)}(t)] [c]A_2(t)$ (7-9)

Taking Laplace Transform of eq. (7-9) and solving for $\hat{A}_0(s)$

$\hat{A}_0(s) = N_2(s) / D_2(s)$ (10)

where

$N_2(s) = \tilde{M}_0(s)(1 - \hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s)) (1- \hat{q}_{22}^{(5)}(s)- \hat{q}_{22}^{(6)}(s)) + \bar{q}_{01}(s)\tilde{M}_1(s)$
$[1- \hat{q}_{22}^{(5)}(s)- \hat{q}_{22}^{(6)}(s)] + \hat{q}_{02}(s)\tilde{M}_2(s)(1- \hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s))$

$D_2(s) = (1 - \hat{q}_{11}^{(3)}(s)- \hat{q}_{11}^{(4)}(s)) \{ 1 - \hat{q}_{22}^{(5)}(s) - \hat{q}_{22}^{(6)}(s))[1-(\hat{q}_{01}(s) \hat{q}_{10}(s))(1-$
$\hat{q}_{11}^{(3)}(s)- \hat{q}_{11}^{(4)}(s))]$

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

$A_0 = \lim_{s\to 0}\frac{N_2(s)+s\ N_2'(s)}{D_2'(s)} = \frac{N_2(0)}{D_2'(0)}$ (11)

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

$\lambda_u(t) = \int_0^\infty A_0(z)dz$ So that $\bar{\lambda}_u(s) = \frac{\bar{A}_0(s)}{s} = \frac{N_2(S)}{SD_2(S)}$ (12)

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

$\lambda_d(t) = t- \lambda_u(t)$ So that $\bar{\lambda}_d(s) = \frac{1}{s^2} - \bar{\lambda}_u(s)$ (13)

The expected busy period of the server when there is GST- glitch in the telemetry system in (0, t]

$R_0(t) = q_{01}(t)[c]R_1(t) + q_{02}(t)[c]R_2(t)$

$R_1(t) = S_1(t) + q_{01}(t)[c]R_1(t) + [q_{11}^{(3)}(t) + q_{11}^{(4)}(t)[c]R_1(t),$

$R_2(t) = q_{20}(t)[c]R_0(t) + [q_{22}^{(6)}(t)+q_{22}^{(5)}(t)][c]R_2(t)$ (14-16)

Taking Laplace Transform of eq. (14-16) and solving for $\bar{R}_0(s)$

$\bar{R}_0(s) = N_3(s) / D_3(s)$ (17)

Where

$N_3(s) = \hat{q}_{01}(s)\,\hat{S}_1(s)$ and

$D_3(s)= (1 - \hat{q}_{11}^{(3)}(s)- \hat{q}_{11}^{(4)}(s)) – \hat{q}_{01}(s)$ is already defined.

In the long run, $R_0 = \frac{N_3(0)}{D_3'(0)}$ (18)

The expected period of the system under GST- glitch in the telemetry system in (0, t] is

$\lambda_{rv}(t) = \int_0^\infty R_0(z)dz$ So that $\bar{\lambda}_{rv}(s) = \frac{\bar{R}_0(s)}{s}$

The expected Busy period of the server when there is failure owing to thunderstorm in (0,t]

$B_0(t) = q_{01}(t)[c]B_1(t) + q_{02}(t)[c]B_2(t)$

$B_1(t) = q_{01}(t)[c]B_1(t) + [q_{11}^{(3)}(t)+ q_{11}^{(4)}(t)] [c]B_1(t),$

$B_2(t) = T_2(t) + q_{02}(t)[c] B_2(t) + [q_{22}^{(5)}(t)+ q_{22}^{(6)}(t)] [c]B_2(t)$

$T_2(t) = e^{-\lambda_1 t}G_2(t)$ (19- 21)

Taking Laplace Transform of eq. (19-21) and solving for $\bar{B}_0(s)$

$\overline{B_0}(s) = N_4(s) / D_2(s)$ (22)

Where

$N_4(s) = \hat{q}_{02}(s)\,\hat{T}_2(s))$

And $D_2(s)$ is already defined.

In steady state, $B_0 = \frac{N_4(0)}{D_2'(0)}$ (23)

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

$\lambda_{ru}(t) = \int_0^{\infty} B_0(z)\,dz$ So that $\widetilde{\lambda_{ru}}(s) = \frac{\hat{B}_0(s)}{s}$ (24)

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

$H_0(t) = Q_{01}(t)[s][1+ H_1(t)] + Q_{02}(t)[s][1+ H_2(t)]$

$H_1(t) = Q_{10}(t)[s]H_0(t)] + [Q_{11}^{(3)}(t)+ Q_{11}^{(4)}(t)] [s]H_1(t),$

$H_2(t) = Q_{20}(t)[s]H_0(t) + [Q_{22}^{(5)}(t) +Q_{22}^{(6)}(t)] [c]H_2(t)$ (25-27)

Taking Laplace Transform of eq. (25-27) and solving for $H_0^*(s)$

$H_0^*(s) = N_6(s) / D_3(s)$ (28)

In the long run, $H_0 = \frac{N_6(0)}{D_3'(0)}$ (29)

COST-BENEFIT ANALYSIS

The Cost-Benefit analysis of the system considering mean up-time, expected busy period of the system when glitch in the telemetry system when the units stops automatically, expected busy period of the server for repair of unit when failure owing to thunderstorm, expected number of visits by the repairman for unit failure.

The expected total Benefit-Function incurred in (0, t] is

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

- expected total repair cost when glitch in the telemetry system in (0,t]
- expected total repairing cost of the units when failure owing to thunderstorm in (0,t]
- expected busy period of the system when the units automatically stop in (0,t]
- expected number of visits by the repairman for repairing of identical units in (0,t]

The expected total cost per unit time in steady state is

$C = \lim_{t\to\infty}(C(t)/t) = \lim_{s\to 0}(s^2 C(s))$

$= K_1A_0 - K_2R_0 - K_3B_0 - K_4H_0$

Where

K_1: revenue per unit up-time,

K_2: cost per unit time for which the system is under repair of type- I

K_3: cost per unit time for which the system is under repair of type-II

K_4: cost per visit by the repairman for units repair.

CONCLUSION

After studying the system, we have analyzed graphically that when the glitch rate in telemetry system, failure rate owing to thunderstorm increases, the MTSF and steady state availability decreases and the Cost-Benefit function decreased as the failure increases.

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