Benefit-Function of Two- Identical Cold Standby Railway train System subject to Failure of Equipment - Permanent Way or brake failure

Ashok Kumar Saini

BLJS COLLEGE, TOSHAM (BHIWANI) HARYANA, INDIA
Email : drashokksaini2009@gmail.com

Abstract -(Gorakhdham Express collided…)

NEW DELHI: Railways today conceded that the Gorakhdham Express mishap on May 26 which claimed lives of 29 passengers was caused due to 'failure of the equipment'.

As per the preliminary report of the Commissioner of Railway Safety, North Eastern Circle, the accident was caused due to failure of rail and hence the accident was classified under the category of 'Failure of Equipment - Permanent Way', Railway Minister Sadananda Gowda said in a written reply in the Rajya Sabha.

Gorakhdham Express collided with a goods train near Sant Kabir Nagar in Uttar Pradesh leaving 29 passengers dead and 74 injured, 16 of them grievously, on May 26.

Gowda said medical relief and rescue teams were rushed to the accident site without delay.

In this paper we have taken 'Failure of Equipment - Permanent Way' or brake failure. When the main unit fails due to 'Failure of Equipment - Permanent Way' then cold standby system becomes operative. 'Failure of Equipment - Permanent Way' cannot occur simultaneously in both the units and after failure the unit undergoes very costly repair facility immediately. 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, 'Failure of Equipment - Permanent Way' or brake failure, first come first serve, MTSF, Availability, Busy period, Benefit -Function.

INTRODUCTION

Gorakhdham Express collision due to failure of equipment: Railways Fri Jul 11, 2014 | 15:45 IST

#Gorakhpur #Uttar Pradesh Railways on Friday conceded that the Gorakhdham Express mishap on May 26 which claimed lives of 29 passengers was caused due to 'failure of the equipment'.

As per the preliminary report of the Commissioner of Railway Safety, North Eastern Circle, the accident was caused due to failure of rail and hence the accident was classified under the category of 'Failure of Equipment - Permanent Way', Railway Minister Sadananda Gowda said in a written reply in the Rajya Sabha.

Gorakhdham Express collided with a goods train near Sant Kabir Nagar in Uttar Pradesh leaving 29 passengers dead and 74 injured, 16 of them grievously, on May 26.

Gowda said medical relief and rescue teams were rushed to the accident site without delay.

Railways has also announced an enhanced ex-gratia of Rs 2 lakh each to the kin of deceased, Rs 1 lakh each to grievously injured and Rs 20,000 each to those with simple injury.

In addition, Prime Minister Narendra Modi also announced ex-gratia relief of Rs 2 lakh each to the kin of deceased and Rs 50,000 each to the grievously injured.

Gorakhdham Express collision due to 'failure of equipment' PTI Jul 11, 2014, 03.47PM IST

Collision Investigation and Understanding Brake Failure

We often find in crash reports the phrase that “the brakes failed”.

But what does this mean, and how do an Accident Investigator/ Collision Reconstructionist go about establishing whether brake failure has been one of the contributing factors to the crash?

After the recent horrific crash at an intersection at Pinetown we decided to approach well known accident investigator Stan Bezuidenhout with questions to provide some clarity and insights on brake failure as a contributing factor to vehicle crashes.

We raised the following questions:

- What are the most important differences between the braking system on trucks and the brakes on a normal passenger vehicle?

The most important difference between "car" and "truck" brakes include the following:

1. Car brakes are essentially in a permanent state of non-engagement. There are no brakes until you apply foot pressure. This pressure is amplified by the brake booster (brake system components) and converted into pressure applied via two cylinders to a pair of brake "pads" that clamp down on the brake disk. Essentially, this means that there are no brakes until brakes are actively applied. The car brake system contains a fluid (brake fluid) that is used to transfer pressure from the operator's foot to the brake calipers.

2. Truck brakes essentially consist of TWO systems: Park (or Spring) brakes and Service (or Foot) brakes. The truck brake system has a cylinder that contains a strong spring and a vacuum chamber (booster). This is connected to a push-rod which is, in turn, connected to an arm (slack adjuster) which twists a shaft with a cam (S-Cam on it). The S-Cam causes two brake SHOES to expand (open up) and contact with the inside of a brake drum. So, a truck brake system would be permanently ENGAGED if there was no external influence. A truck brake system works with a vacuum. If there is NO VACUUM, the springs would actuate the push-rod, which will lever the slack adjuster, turning the S-cam (shaft), engaging the brakes. When vacuum is applied, the push-rod (end) is "sucked back" and then the brakes are released. Then - every time a driver ties to "brake" the vacuum would be released and the brakes would be applied. You can "essentially" say that the truck brake system (air brakes) work in "reverse" to car brakes.

- When we hear that the “brakes have failed” – What does this actually mean?

1. In the case of car brakes, this could mean a number of things, including:

a) There is a "leak" in the brake pipes, causing brake fluid to escape (leak out) and this would mean that there is no longer enough fluid to transfer pressure.

b) Seals could damage, resulting in some of the pressure "Escaping," reducing brake efficiency.

c) The brake linings (brake pads) could become worn, requiring more and more pedal actuation to engage brakes.

d) Brakes could overheat, resulting in poor brakes or even the brake fluid boiling or breaking down and reducing brake efficiency.

2. In the case of air brakes it gets a bit more complicated. The following things can lead to a "Failure:"

a) If there is ANY fault (leak) on the vacuum system and the vacuum is lost, the spring brakes will "actuate" and stop the vehicle.

b) If there is any fluid leak (bearing grease, etc), the friction surfaces can be compromised (made too slippery) and the vehicle could lose braking efficiency.

c) If the Slack Adjuster is not set (or adjusted) properly, the push rod might not be able to push the slack adjuster far enough to result in actuation.

d) If a booster is failing, operators sometimes removes the pipes, jacks off the brakes (this can be done) and seals the pipe so that the rest of the brake (boosters) can work; but this can lead to total brake failure due to overheating.

e) If the S-Cam turns too far, it can "flip over" and it then stops having any effect on brakes, while "everything looks fine." This is very dangerous and renders the brakes ineffective.

- As an expert witness in court – are there specific challenges from the prosecutor / defense lawyer you have come to experience with regards to testimony on brake failure?

One of the biggest issues with regards to brake failure is the actual towing and recovery. When tow companies want to tow a vehicle that was involved in a collision and the brake system has been compromised, they need to "jack off" all the brakes.

This then forces the brake system, to compress the spring (brake) and release the wheel brakes.

If this is done the original condition of the brakes cannot be checked effectively and therefore testimony becomes harder.

Also - if the truck (horse) is totally destroyed, the efficiency of the vacuum pump and regulators cannot be determined reliably. This means that SOME components of the brake system might remain unexamined - limiting the accuracy of testimony.

- Which brake components are the most likely to “fail”?

In cars it would be the brake pads (themselves), the master cylinder (main cylinder near the foot-brake that applies initial pressure) and the slave cylinder (the cylinder at the wheels that actuate the caliper) seals. But, as brake fluid gets older it also starts to deteriorate, and this also reduces braking efficiency.

In air brake systems the slack adjuster angles, vacuum (pressure) regulators and load sensors (not set properly) as well as worn brake linings are the most common causes of failure.

- When you are requested to investigate a crash with alleged brake failure – what do you specifically look for and what are the indicators that there has indeed been brake failure?

Drivers of cars must ALWAYS become alert and have their brakes seen to if:

a) The brakes become "spongy."

b) The brakes work fine, but "fade" and become less effective at time (normally after increased use).

c) They find that there is a "scraping" sound when they brake.

d) The vehicle pulls to either side while they are braking.

e) They have to "pump" the brakes to stop.

Drivers of trucks and buses must become alert and report faults when:

a) They have to wait too long for the spring brakes to release (after starting up).

b) The pressure (or vacuum - there is a gauge in most vehicles) fluctuates at times.

c) They can hear the brake system "unloading" intermittently while they are driving.

d) They smell or see smoke from any wheels or brake system while driving or stopping.

e) They are unable to stop effectively at any time.

f) Their trailer brakes lock up when they are loaded or partially loaded, when they stop.

g) They hear any mechanical knocking or banging sounds while driving or braking.

- What would you suggest as the most important steps for the trucking company and passenger vehicle driver to do to avoid brake failure?

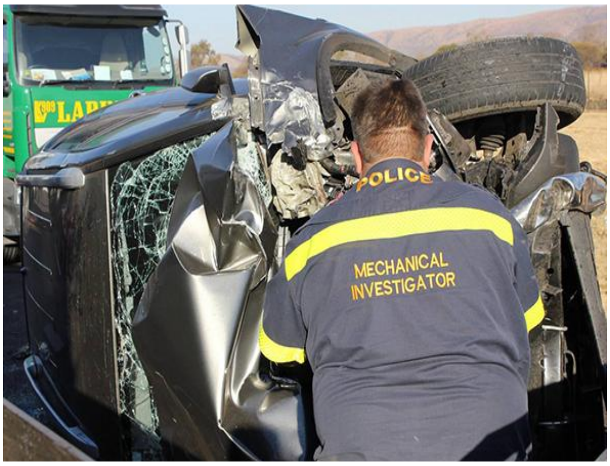
Drivers should have their vehicle tested and checked REGULARLY.

Drivers should report BRAKE SYSTEM ISSUES IMMEDIATELY (see those above) and PUT IT IN WRITING.

If you experience ANY issues with braking, hear any funny sounds, see any fluids run out anywhere (at wheels) or if your can see brakes are hot (steam, smoke, etc), REPORT IT or HAVE IT SEEN TO immediately.

How important is training on vehicle maintenance for the trucking company - van the accident investigator play an important role in preventative measures as well?

No person should be allowed to work on a vehicle brake (or any other safety) system who is not a qualified mechanic/technician.



- What role can the accident investigator / truck brake expert play in crash prevention?

We conduct regular technical fleet audits for clients. This having been said, these are NOT (mere) roadworthiness checks.

We examine a vehicle completely and our evaluation is so strict that we even "fail" new vehicles.

As crash reconstruction experts, we look not only at the functional elements but also the theoretical/legal ones.

We look at any and all items that could, might, would or may (one day) contribute to a collision.

With our Technical Fleet Audits, we assign a fault gravity value for each element we are able to predict as a possible cause or factor in COLLISIONS.

From this, we produce a chart, showing the components or aspects that need IMMEDIATE care (vehicle must be removed form service), urgent (fault/element must be repaired as soon as vehicle returns), serious (Fault must be repaired at next service) or general (it should be attended to at the next major service).

By being made aware of all the elements and seeing a chart (with red indicators) also enables a fleet owner to IMMEDIATELY evaluate the quality of his/her fleet and to determine how urgently they need to act.

Our system is so effective that we have seen clients recall and immediately repair 84 vehicles in three days (working overnight).

By having us do an independent technical fleet audit and acting on our recommendations, our clients are able to show (in the very unfortunate event of a collision) that they are SO SERIOUS about road safety, that they have appointed an independent EXPERT to examine all their vehicles and that they took immediate steps to eliminate all possible risks.

Stochastic behavior 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 'Failure of Equipment - Permanent Way 'or brake failure. When the main operative unit fails then cold standby system becomes operative. Brake failure cannot occur simultaneously in both the units and after failure the unit undergoes repair facility of very high cost in case of 'Failure of Equipment - Permanent Way' immediately. The repair is done on the basis of first fail first repaired.

Assumptions

1. λ_1 , λ_2, are constant failure rates for 'Failure of Equipment - Permanent Way', brake failure respectively. The CDF of repair time distribution of Type I and Type II are $G_1(t)$ and $G_2(t)$.
2. The failure due to 'Failure of Equipment - Permanent Way' is non-instantaneous and it cannot come simultaneously in both the units.
3. The repair starts immediately after the failure due to 'Failure of Equipment - Permanent Way' or brake failure works on the principle of first fail first repaired basis.
4. The repair facility does no damage to the units and after repair units are as good as new.
5. The switches are perfect and instantaneous.
6. All random variables are mutually independent.
7. When both the units fail, we give priority to operative unit for repair.
8. Repairs are perfect and failure of a unit is detected immediately and perfectly.
9. The system is down when both the units are non-operative.

Notations

λ_1, λ_2 are the Failure of Equipment - Permanent Way, brake failure respectively. $G_1(t)$, $G_2(t)$ – repair time distribution Type -I, Type-II Failure of Equipment - Permanent Way , brake failure respectively.

p, q - probability of Failure of Equipment - Permanent Way, brake failure respectively such that p+ q=1

$M_i(t)$ 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

Symbols for states of the System

Superscripts O, CS, EPF, BF

Operative, Cold Standby, Failure of Equipment - Permanent Way, brake failure respectively

Subscripts nepf, epf, bf, ur, wr, uR

No Failure of Equipment - Permanent Way', Failure of Equipment - Permanent Way, brake failure, under repair, waiting for repair, under repair continued from previous state respectively

Up states – 0, 1, 2, 7, and 8;

Down states – 3, 4, 5, 6

regeneration point – 0,1,2, 7, 8

States of the System

$0(O_{nepf}, CS_{nepf})$

One unit is operative and the other unit is cold standby and there is no failure due to Failure of Equipment - Permanent Way in both the units.

$1(EPF_{epf,\, ur}, O_{nepf})$

The operating unit fails due to Failure of Equipment - Permanent Way and is under repair immediately of very costly Type- I and standby unit starts operating with no Failure of Equipment - Permanent Way

2($BF_{bf,\, ur}$, O_{nepf})

The operative unit fails due to BF resulting from failure due to brake and undergoes repair of Type II and the standby unit becomes operative with no Failure of Equipment - Permanent Way .

3($EPF_{epf,uR}$, $BF_{bf,wr}$)

The first unit fails due to Failure of Equipment - Permanent Way and under very costly Type-I repair is continued from state 1 and the other unit fails due to BF resulting from failure due to brake and is waiting for repair of very costly Type -II.

4($EPF_{epf,uR}$, $EPF_{epf,wr}$)

The repair of the unit is failed due to EPF resulting from failure due to Failure of Equipment - Permanent Way is continued from state 1and the other unit failed due to EPF resulting from failure due to Failure of Equipment - Permanent Way is waiting for repair of very costly Type-I.

5($BF_{bf,\, uR}$, $BF_{bf,\, wr}$)

The operating unit fails due to failure due to brake (BF mode) and under repair of Type - II continue from the state 2 and the other unit fails also due to failure due to brake is waiting for repair of Type- II.

6($BF_{bf,uR}$, $EPF_{epf,wr}$)

The operative unit fails due to BF resulting from failure due to brake and under repair continues from state 2 of Type –II and the other unit is failed due to EPF resulting from failure due to Failure of Equipment - Permanent Way and under very costly Type-I

7(O_{nepf} , $EPF_{epf,ur}$)

The repair of the unit failed due to EPF resulting from Failure of Equipment - Permanent Way failure is completed and there is no failure due to brake and the other unit is failed due to EPF resulting from failure due to Failure of Equipment - Permanent Way is under repair of very costly Type-I

8(O_{nepf} , $BF_{bf,ur}$)

The repair of the unit failed due to EPF resulting from failure due to Failure of Equipment - Permanent Way failure is completed and there is no failure due to brake and the other unit is failed due to BF resulting from failure due to brake failure under repair of Type-II

Transition Probabilities

Simple probabilistic considerations yield the following expressions:

$p_{01} = p,\quad p_{02} = q,$

$p_{10} = pG_1^*(\lambda_1)+q\,G_1^*(\lambda_2)= p_{70}\,,$

$p_{20} = pG_2^*(\lambda_1)+q\,G_2^*(\lambda_2)= p_{80}\,,$

$p_{11}^{(3)}= p(1- G_1^*(\lambda_1))= p_{14} = p_{71}^{(4)}\ p_{28}^{(5)}= q(1- G_2^*(\lambda_2))= p_{25} = p_{82}^{(5)}$ (1)

We can easily verify that

$p_{01} + p_{02} = 1,\ p_{10} + p_{17}^{(4)} (= p_{14}) + p_{18}^{(3)} (=p_{13}) = 1,$

$p_{80} + p_{82}^{(5)} + p_{87}^{(6)} = 1$ (2)

And mean sojourn time is

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

Mean Time To System Failure

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

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

$Ø_2(t) = Q_{20}(t)[s]\, Ø_0(t) + Q_{25}(t) + Q_{26}(t)$ (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) & (2) it can be shown that $ø_0^*(0) =1$, which implies that $ø_0(t)$ is a proper distribution.

$$MTSF = E[T] = \left.\frac{d}{ds}\, ø_0^{\bar{}}(s)\right|_{s=0}$$

$$= (D_1'(0) - N_1'(0)) / D_1(0)$$

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

where

$\mu_0 = \mu_{01}+ \mu_{02}\,,$

$\mu_1 = \mu_{01} + \mu_{17}^{(4)} + \mu_{18}^{(3)},$

$\mu_2 = \mu_{02}+\mu_{27}^{(6)}+ \mu_{28}^{(5)}$

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

$M_0(t) = e^{-\lambda_1 t}e^{-\lambda_2 t}\,,$

$M_1(t) = p\, \overline{G_1(t)}\, e^{-(\lambda_1+\lambda_2)} = M_7(t)$

$M_2(t) = q\, \overline{G_2(t)}\, e^{-(\lambda_1+\lambda_2)} = M_8(t)$

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

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

$A_1(t) = M_1(t) + q_{10}(t)[c]A_0(t) +$

$q_{18}^{(3)}(t)[c]A_8(t) + q_{17}^{(4)}(t)[c]A_7(t)$

$A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) +$

$[q_{28}^{(5)}(t)[c]\ A_8(t) + q_{27}^{(6)}(t)]\ [c]A_7(t)$

$A_7(t) = M_7(t) + q_{70}(t)[c]A_0(t) +$

$[q_{71}^{(4)}(t)[c]\ A_1(t) + q_{78}^{(3)}(t)]\ [c]A_8(t)$ $A_8(t) = M_8(t) + q_{80}(t)[c]A_0(t)$

$+[q_{82}^{(5)}(t)[c]\ A_2(t) + q_{87}^{(6)}(t)]\ [c]A_7(t)$ (7-11)

Taking Laplace Transform of eq. (7-11) and solving for $\hat{A}_0(s)$

$$\hat{A}_0(s) = N_2(s) / D_2(s) \quad (12)$$

where

$N_2(s) = \widehat{M}_0 (1 - \hat{q}_{78}^{(3)} - \hat{q}_{87}^{(6)}) - \hat{q}_{82}^{(5)}$

$(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)} - \hat{q}_{71}^{(4)}$

$(\hat{q}_{17}^{(4)} + \hat{q}_{87}^{(6)} \hat{q}_{18}^{(3)}) + \hat{q}_{71}^{(4)} \hat{q}_{82}^{(5)}$

$(\hat{q}_{17}^{(4)} - \hat{q}_{27}^{(6)} \hat{q}_{18}^{(3)})] + \hat{q}_{01}[\widehat{M}_1(1 -$

$\hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) + \hat{q}_{71}^{(4)}(\widehat{M}_7 + \hat{q}_{78}^{(3)}$

$\widehat{M}_8) + \hat{q}_{18}^{(3)}(\widehat{M}_7 \hat{q}_{87}^{(6)} - \widehat{M}_8) -$

$\hat{q}_{82}^{(5)}(\widehat{M}_1(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)}) +$

$\hat{q}_{17}^{(4)} (- \widehat{M}_2(\hat{q}_{78}^{(3)} + \widehat{M}_7 \hat{q}_{28}^{(5)}) -$

$\hat{q}_{18}^{(3)}(\widehat{M}_2 + \widehat{M}_7 \hat{q}_{27}^{(6)})\}]\ \hat{q}_{02}[\widehat{M}_2(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) + \hat{q}_{27}^{(6)}($

$\widehat{M}_7 + \hat{q}_{78}^{(3)} \widehat{M}_8) + \hat{q}_{28}^{(5)}(\widehat{M}_7 \hat{q}_{87}^{(6)} + \widehat{M}_8) - \hat{q}_{71}^{(4)}(\widehat{M}_1(- \hat{q}_{27}^{(6)} - \hat{q}_{28}^{(5)} +$

$\hat{q}_{87}^{(6)}) + \hat{q}_{17}^{(4)} (\widehat{M}_2 + \hat{q}_{28}^{(5)} \widehat{M}_8) - \hat{q}_{18}^{(3)} (- \widehat{M}_2 \hat{q}_{87}^{(6)} + \widehat{M}_8 \hat{q}_{27}^{(6)})\}]$

$\hat{q}_{18}^{(3)}(\widehat{M}_2 + \widehat{M}_7 \hat{q}_{27}^{(6)})\}]$

$D_2(s) = (1 - \hat{q}_{78}^{(3)} - \hat{q}_{87}^{(6)}) - \hat{q}_{82}^{(5)}($

$\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)}) - \hat{q}_{71}^{(4)}$

$(\hat{q}_{17}^{(4)} + \hat{q}_{87}^{(6)} \hat{q}_{18}^{(3)}) + \hat{q}_{71}^{(4)} \hat{q}_{82}^{(5)} (\hat{q}_{17}^{(4)} \hat{q}_{28}^{(5)} - \hat{q}_{18}^{(3)})] + \hat{q}_{01}[- \hat{q}_{10} (1 -$

$\hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) - \hat{q}_{71}^{(4)}(\hat{q}_{70} + \hat{q}_{78}^{(3)}$

$\hat{q}_{80}) - \hat{q}_{18}^{(3)}(\hat{q}_{70} \hat{q}_{87}^{(6)} - \hat{q}_{80}) -$

$\hat{q}_{82}^{(5)}(- \hat{q}_{10}(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)}) +$

$\hat{q}_{17}^{(4)} (\hat{q}_{20} (\hat{q}_{78}^{(3)} - \hat{q}_{70} \hat{q}_{28}^{(5)}) +$

$\hat{q}_{18}^{(3)}(\hat{q}_{20} + \hat{q}_{70} \hat{q}_{27}^{(6)})\}]\ \hat{q}_{02}[- \hat{q}_{20}(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) - \hat{q}_{27}^{(6)}(\hat{q}_{70} + \hat{q}_{78}^{(3)} \hat{q}_{80}) - \hat{q}_{28}^{(5)}(\hat{q}_{70} \hat{q}_{87}^{(6)} + \hat{q}_{80}) -$
$\hat{q}_{71}^{(4)}($

$\hat{q}_{10} (\hat{q}_{27}^{(6)} + \hat{q}_{28}^{(5)} \hat{q}_{87}^{(6)}) - \hat{q}_{17}^{(4)} (\hat{q}_{20} -$

$\hat{q}_{28}^{(5)} \hat{q}_{80}) - \hat{q}_{18}^{(3)} (\hat{q}_{20} \hat{q}_{87}^{(6)} + \hat{q}_{80}$

$\hat{q}_{27}^{(6)})\}]$

(Omitting the arguments s for brevity)

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

$$A_0 = \lim_{s\to 0}\frac{N_2(s)+s\ N_2'(s)}{D_2'(s)} = \frac{N_2(0)}{D_2'(0)} \quad (13)$$

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

$$\lambda_u(t) = \int_0^{\infty} A_0(z)dz$$

So that $\overline{\lambda_u}(s) = \frac{\hat{A}_0(s)}{s} = \frac{N_2(S)}{SD_2(S)}$ (14)

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

$$\lambda_d(t) = t - \lambda_u(t)$$

So that $\overline{\lambda_d}(s) = \frac{1}{s^2} - \overline{\lambda_u}(s)$ (15)

The expected busy period of the server when there is EPF - 'Failure of Equipment - Permanent Way' or BF- Failure due to brake failure in (0,t]

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

$R_1(t) = S_1(t) + q_{10}(t)[c]R_0(t) +$

$q_{18}^{(3)}(t)[c]\ R_8(t) + q_{17}^{(4)}(t)[c]R_7(t)$

$R_2(t) = S_2(t) + q_{20}(t)[c]R_0(t) + q_{28}^{(5)}(t)$

$R_8(t) + q_{27}^{(6)}(t)][c]R_7(t)$

$R_7(t) = S_7(t) + q_{70}(t)[c]R_0(t) + Q_{71}^{(4)}(t)$

$R_1(t) + q_{78}^{(3)}(t)][c]R_8(t)$

$R_8(t) = S_8(t) + q_{80}(t)[c]R_0(t) + Q_{82}^{(5)}(t)$

$R_2(t) + q_{87}^{(6)}(t)][c]R_7(t)$ (16-20)

Taking Laplace Transform of eq. (16-20) and solving for $\overline{R_0}(s)$

$$\overline{R_0}(s) = N_3(s) / D_2(s) \quad (21)$$

where

$N_3(s) = \hat{q}_{01}[\hat{S}_1(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) +$

$\hat{q}_{71}^{(4)}(\hat{S}_7 + \hat{q}_{78}^{(3)} \hat{S}_8) + \hat{q}_{18}^{(3)}(\hat{S}_7$

$\hat{q}_{87}^{(6)} - \hat{S}_8)] - \hat{q}_{01} \hat{q}_{82}^{(5)}(\hat{S}_1 \hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)}) + \hat{q}_{17}^{(4)}$
$(\hat{S}_2 \hat{q}_{78}^{(3)} + \hat{S}_7 \hat{q}_{28}^{(5)}) -$

$\hat{q}_{18}^{(3)}(\hat{S}_2 + \hat{S}_7 \hat{q}_{27}^{(6)})] + \hat{q}_{02}[\hat{S}_2(1 -$

$\hat{q}_{78}^{(3)}\ \hat{q}_{87}^{(6)}) + \hat{q}_{27}^{(6)}(\hat{S}_7 + \hat{q}_{78}^{(3)}\hat{S}_8) + \hat{q}_{28}^{(5)}(\hat{S}_7\ \hat{q}_{87}^{(6)} + \hat{S}_8) - \hat{q}_{02}\hat{q}_{71}^{(4)}(\hat{S}_1(-$

$\hat{q}_{27}^{(6)} - \hat{q}_{28}^{(5)}\ \hat{q}_{87}^{(6)}\ \hat{q}_{17}^{(4)}(\hat{S}_2 + \hat{q}_{28}^{(5)}\hat{S}_8) - \hat{q}_{18}^{(3)}(-\hat{S}_2\ \hat{q}_{87}^{(6)} + \hat{S}_8\ \hat{q}_{27}^{(6)})]$

and

$D_2(s)$ is already defined.

(Omitting the arguments s for brevity)

In the long run, $R_0 = \dfrac{N_3(0)}{D_2{'}(0)}$ (22)

The expected period of the system under EPF - 'Failure of Equipment - Permanent Way 'or BF- Failure due to brake failure in (0,t] is

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

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

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

$H_1(t) = Q_{10}(t)[s]H_0(t)] + Q_{18}^{(3)}(t)[s]$

$H_8(t) + Q_{17}^{(4)}(t)] [s]H_7(t)$,

$H_2(t) = Q_{20}(t)[s]H_0(t) + Q_{28}^{(5)}(t) [s]$

$H_8(t) + Q_{27}^{(6)}(t)] [c]H_7(t)$

$H_7(t) = Q_{70}(t)[s]H_0(t) + Q_{71}^{(4)}(t) [s]$

$H_1(t) + Q_{78}^{(3)}(t)] [c]H_8(t)$

$H_8(t) = Q_{80}(t)[s]H_0(t) + Q_{82}^{(5)}(t) [s]$

$H_2(t) + Q_{87}^{(6)}(t)] [c]H_7(t)$ (23-27)

Taking Laplace Transform of eq. (23-27) and solving for $H_0^*(s)$

$H_0^*(s) = N_4(s) / D_3(s)$ (28)

In the long run , $H_0 = N_4(0) / D_3{'}(0)$ (29)

Benefit- Function Analysis

The Benefit-Function analysis of the system considering mean up-time, expected busy period of the system under failure due to Failure of Equipment - Permanent Way or failure due to brake failure, 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 busy period of the system under failure due to Failure of Equipment - Permanent Way or failure due to brake failure repairing the units in (0,t]

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

The expected total cost per unit time in steady state is

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

$= K_1A_0 - K_2R_0 - K_3H_0$

where

K_1 - revenue per unit up-time,

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

K_3 - 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 Failure of Equipment - Permanent Way or failure due to brake failure increases, the MTSF and steady state availability decreases and the Benefit-function decreased as the failure increases.

REFERENCES

[1] Dhillon, B.S. and Natesen, J, Stochastic Anaysis of outdoor Power Systems in fluctuating environment, Microelectron. Reliab. ,1983; 23, 867-881.

[2] Kan, Cheng, Reliability analysis of a system in a randomly changing environment, Acta Math. Appl. Sin. 1985, 2, pp.219-228.

[3] 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, pp. 373-378.

[4] Barlow, R.E. and Proschan, F., Mathematical theory of Reliability, 1965; John Wiley, New York.

[5] Gnedanke, B.V., Belyayar, Yu.K. and Soloyer , A.D. , Mathematical Methods of Reliability Theory, 1969 ; Academic Press, New York.

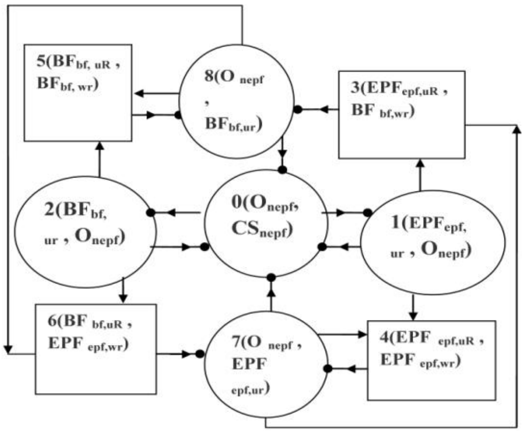


Fig. The State Space Diagram

○ Up state □ down state

● Regeration point

◆ ◆ ◆