Cost- Benefit Analysis of Two Dissimilar Warm Standby System subject to Failure due to Landslide caused by Heavy or Prolonged Rainfall, Earthquake and Human Activities.

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Abstract- In the majority of cases the main trigger of landslides is heavy or prolonged rainfall. Generally this takes the form of either an exceptional short lived event, such as the passage of a tropical cyclone or even the rainfall associated with a particularly intense thunderstorm or of a long duration rainfall event with lower intensity, such as the cumulative effect of monsoon rainfall in South Asia. In the former case it is usually necessary to have very high rainfall intensities, whereas in the latter the intensity of rainfall may be only moderate - it is the duration and existing pore water pressure conditions that are important. The importance of rainfall as a trigger for landslides cannot be underestimated. A global survey of landslide occurrence in the 12 months to the end of September 2003 revealed that there were 210 damaging landslide events worldwide. Of these, over 90% were triggered by heavy rainfall. One rainfall event for example in Sri Lanka in May 2003 triggered hundreds of landslides, killing 266 people and rendering over 300,000 people temporarily homeless. In July 2003 an intense rain band associated with the annual Asian monsoon tracked across central Nepal, triggering 14 fatal landslides that killed 85 people. The reinsurance company Swiss Re estimated that rainfall induced landslides associated with the 1997-1998 El Nino event triggered landslides along the west coast of North, Central and South America that resulted in over $5 billion in losses. Finally, landslides triggered by Hurricane Mitch in 1998 killed an estimated 18,000 people in Honduras, Nicaragua, Guatemala and El Salvador. So why does rainfall trigger so many landslides? Principally this is because the rainfall drives an increase in pore water pressures within the soil. Landslides have always existed on our planet. Generally classified as mass movements of rock, debris, and soil down a slope of land. While landslides are a naturally occurring environmental hazard they have recently increased in frequency in certain areas due to human activity.

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 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) landslide caused by heavy rainfall and (ii) landslide caused by Earthquakes (iii) landslide caused due to human activities requiring different types of repair facilities. Using semi Markov regenerative point technique we have calculated different reliability characteristics 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 landslide caused by heavy rainfall, failure due to landslide caused by Earthquakes, failure due to landslide caused by human activities.

INTRODUCTION

Seismicity
The second major factor in the triggering of landslides is seismicity. Landslides occur during earthquakes as a result of two separate but interconnected processes: seismic shaking and pore water pressure generation.

Seismic shaking
The passage of the earthquake waves through the rock and soil produces a complex set of accelerations that effectively act to change the gravitational load on the slope. So, for example, vertical accelerations successively increase and decrease the normal load acting on the slope. Similarly, horizontal accelerations induce a shearing force due to the inertia of the landslide mass during the accelerations. These processes are complex, but can be sufficient to induce failure of the slope. These processes can be much more serious in mountainous areas in which the seismic waves interact with the terrain to produce increases in the magnitude of the ground accelerations. This process is termed 'topographic amplification'. The maximum acceleration is usually seen at the crest of the slope or along the ridge line, meaning that it is a characteristic of seismically triggered landslides that they extend to the top of the slope.

 liquefaction
The passage of the earthquake waves through a granular material such as a soil can induce a process termed liquefaction, in which the shaking causes a
reduction in the pore space of the material. This densification drives up the pore pressure in the material. In some cases this can change a granular material into what is effectively a liquid, generating 'flow slides' that can be rapid and thus very damaging. Alternatively, the increase in pore pressure can reduce the normal stress in the slope, allowing the activation of translational and rotational failures.

**The nature of seismically-triggered landslides**

For the main part seismically generated landslides usually do not differ in their morphology and internal processes from those generated under non-seismic conditions. However, they tend to be more widespread and sudden. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes. However, almost every other type of landslide is possible, including highly disaggregated and fast-moving falls; more coherent and slower-moving slumps, block slides, and earth slides; and lateral spreads and flows that involve partly to completely liquefied material (Keefer, 1999). Rock falls, disrupted rock slides, and disrupted slides of earth and debris are the most abundant types of earthquake-induced landslides, whereas earth flows, debris flows, and avalanches of rock, earth, or debris typically transport material the farthest. There is one type of landslide that is essential uniquely limited to earthquakes - liquefaction failure, which can cause fissuring or subsidence of the ground. Liquefaction involves the temporary loss of strength of sands and silts which behave as viscous fluids rather than as soils. This can have devastating effects during large earthquakes.

(see here:[1] During the magnitude 8.6 Alaska earthquake of 1964 these houses were affected by a liquefaction induced lateral spread landslide in which the ground dropped on the average of 11 metres and houses slid about 150 to 180 m)

**Landslides caused by human activities**

INDISCRIMINATE tree felling, construction, mining and quarrying, combined with heavy rainfall, have increased the fragility of the Himalayan mountains, leading to an increase in the incidence of landslides in the region. Of all the world's landslides, 30 per cent occur in the Himalaya, according to a South Asian Association for Regional Cooperation (SAARC) study on the causes and consequences of natural disasters in the region and the protection and preservation of the environment.

The study, based on official reports, notes an average of about 75 major landslides occur annually in just central and western Nepal and this costs the country about $130,000 in damages to land and cattle alone.

The Nepalese government believes that indiscriminate mining and ill-planned road building are to blame for the widespread wastage of land resources, which forces rural communities to encroach into forests and further aggravates soil erosion. However, not all experts agree with this conclusion. Numerous studies argue that natural processes play a far greater role in the Himalayan region in causing landslides than human-induced ones.

In Sri Lanka, too, the government believes that landslides are increasing largely because of development projects that have spread even to steep hill slopes and other unstable locations in the country's central and southwestern regions. More intensive cultivation, which means more irrigation and more denudation of watersheds, also is being blamed.

Monsoon- and cyclone-induced rainfall are said to be major causes of landslides and land collapses, including riverbank erosion, in Bangladesh's hill districts, particularly the Chittagong region and parts of Sylhet. Experts say there is urgent need for a sound land-use policy in a land-hungry country like Bangladesh, if a halt is to be put to indiscriminate cutting of forests and poorly planned roads.

During the rainy season in Pakistan, landslides along highways in the Murree hills, Pir Panjal and the Hindu Kush are also triggered by dam construction and open-pit mining.

Besides natural factors, landslides in Bhutan have also been brought about by human activity, especially the building of roads and canals, which result in deep slope cutting and land saturation.

**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 landslide caused by heavy rainfall and failure due to landslide caused by earthquakes of first unit occurs respectively

And

- Type III, IV repair facility
- When failure due to landslide caused by heavy rainfall and failure due to landslide caused due to Earthquakes 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 landslide caused by heavy rainfall and failure due to landslide caused by Earthquakes as soon as the of the system become normal. The failure due to landslide caused by heavy rainfall and failure due to landslide caused by Earthquakes 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, FLSHR, FLSEQ, FLSHA

Operative, Warm Standby, Stops the operation, failure due to landslide caused by heavy rainfall, failure due to landslide caused by Earthquakes, failure due to landslide caused by human activities respectively

**Subscripts** nhrf, lshr, lseq, \( \text{ls}, \) ur, wr, uR

No heavy rainfall, landslide due to heavy rainfall, landslide due to Earthquakes, landslide due to human activities, 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 \( (O_{\text{nhrf}}, WS_{\text{nhrf}}) \)

One unit is operative and there is no heavy rainfall and the other unit is warm standby with no heavy rainfall in both the units.

1 \( (SO_{\text{hrf}}, O_{\text{nhrf}}) \)

The operation of the first unit stops automatically due to landslide caused by heavy rainfall and warm standby unit’s starts operating with no heavy rainfall.

2 \( (FLSHR_{\text{ur}}, O_{\text{nhrf}}) \)

The first unit fails and undergoes repair after failure due to landslide caused by heavy rainfall is over and the other unit continues to be operative with no heavy rainfall.

3 \( (FLSHR_{\text{ur}}, SO_{\text{hrf}}) \)

The repair of the first unit is continued from state 2 and the operation of second unit stops automatically due to landslide caused by heavy rainfall.

4 \( (FLSHR_{\text{ur}}, SO_{\text{nhrf}}) \)

The first unit fails and undergoes repair after the landslide caused by heavy rainfall is over and the other unit also stops automatically due to landslide caused by heavy rainfall.

5 \( (FLSHR_{\text{ur}}, FLSEQ_{\text{wr}}) \)

The repair of the first unit is continued from state 4 and the other unit is failed due to landslide caused due to Earthquakes is waiting for repair.

6 \( (O_{\text{nhrf}}, FLSEQ_{\text{ur}}) \)

The first unit becomes operative with no heavy rainfall and the second unit is failed due to landslide caused by Earthquakes is under repair.

7 \( (SO_{\text{nhrf}}, FLSHA_{\text{nhrf}, ur}) \)

The operation of the first unit stops automatically due to landslide caused by heavy rainfall and the second unit fails due to landslide caused by human activities and undergoes repair and there is no heavy rainfall.

8 \( (FLSEQ_{\text{wr}}, FLSHA_{\text{nhrf, ur}}) \)

The repair of failed unit due to landslides is continued from state 7 and the first unit is failed due to landslide caused by Earthquakes is waiting for repair.

9 \( (O_{\text{nhrf}}, SO_{\text{hrf}}) \)

The first unit is operative with no heavy rainfall and the operation of warm standby second unit is stopped automatically due to landslide caused by heavy rainfall.

10 \( (SO_{\text{hrf}}, FLSHR_{\text{ur}}) \)

The operation of the first unit stops automatically due to landslide caused by heavy rainfall and the second unit fails due to landslide caused by heavy rainfall undergoes repair after the heavy rainfall is over.

11 \( (FLSHR_{\text{hrf, wr}}, FLSHR_{\text{ur}}) \)

The repair of the second unit is continued from state 10 and the first unit is failed due to landslide caused by heavy rainfall is waiting for repair.

**Transition Probabilities**

Simple probabilistic considerations yield the following expressions:

\[
\begin{align*}
P_{01} &= \frac{\lambda_1}{\lambda_1 + \lambda_2 + \lambda_3}, \quad P_{07} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \lambda_3} \\
P_{09} &= \frac{\lambda_2}{\lambda_1 + \lambda_2 + \lambda_3}, \quad P_{12} = \frac{\lambda_1}{\lambda_1 + \lambda_3}, \quad P_{14} = \frac{\lambda_3}{\lambda_1 + \lambda_3} \\
P_{20} &= G_1^*(\lambda_1), \quad P_{22} = G_1^*(\lambda_1) p_{22}, \quad P_{72} = G_1^*(\lambda_4) \\
P_{72}^{(8)} &= G_2^*(\lambda_4) = p_{78}
\end{align*}
\]

We can easily verify that

\[
\begin{align*}
p_{01} + p_{07} + p_{09} &= 1, \quad p_{12} + p_{14} = 1, \quad p_{20} + p_{23} = p_{22} = 1, \\
p_{60} &= 1, \quad p_{72} + p_{72}^{(8)} + p_{4} = 1, \quad p_{810} = 1, \\
p_{10,2} + p_{10,2}^{(11)} &= 1, \quad (1)
\end{align*}
\]

And mean sojourn time is

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

**Mean Time to System Failure**

We can regard the failed state as absorbing

\[
\begin{align*}
\theta_0(t) &= Q_{01}(t)+Q_{07}(t)+Q_{09}(t) + Q_{07}(t) \\
\theta_1(t) &= Q_{12}(t) + Q_{14}(t) \\
\theta_2(t) &= Q_{20}(t) + Q_{22}(t) + Q_{23}(t) \\
\theta_4(t) &= Q_{s10}(t)
\end{align*}
\]

Taking Laplace-Stieltjes transform of eq. (3-5) and solving for
\[ Q_0^*(s) = \frac{N_1(s)}{D_1(s)} \] where
\[ N_1(s) = Q_{01}^*(s) \]
\[ Q_{12}^*(s) Q_{12}^{(2)}(s) + Q_{12}^*(s) \]
\[ Q_{00}^*(s) Q_{12}^{(3)}(s) + Q_{00}^*(s) \]
\[ D_1(s) = 1 - Q_{01}^*(s) Q_{12}^*(s) Q_{12}^{(2)}(s) \]

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 = \( E[T] = \frac{d/ds}{s} \theta_0^*(s) \)
\[ = \frac{(D_1(0) - N_1(0))}{D_1(0)} \]
\[ = (\mu_0^* p_{01} + \mu_1^* p_{01} p_{12} + \mu_2^* p_{09} + \mu_3^*) / (1 - p_{01} p_{12} p_{20}) \]
\[ \mu_0^* = \mu_{01} + \mu_{07} + \mu_{09}, \quad \mu_1^* = \mu_{12} + \mu_{14}, \quad \mu_2^* = \mu_{20} + \mu_{22}^{(3)}, \quad \mu_3^* = \mu_{310} \]

**Availability analysis**

Let \( M_0(t) \) be the probability of the system having started from state \( i \) at time \( t \) without making any other regenerative state. By probabilistic arguments, we have

The value of \( M_0(t) \), \( M_1(t) \), \( M_2(t) \), \( M_3(t) \) can be found easily.

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

\[ A_0(t) = M_0(t) + q_{01}(t)[c]A_1(t) + q_{02}(t)[c]A_2(t) + q_{03}(t)[c]A_3(t) \]
\[ A_1(t) = M_1(t) + q_{12}(t)[c]A_2(t) + q_{13}(t)[c]A_3(t) \]
\[ A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) + q_{22}(t)[c]A_2(t) \]
\[ A_3(t) = q_{46}^{(3)}[c]A_0(t) \]
\[ A_4(t) = q_{06}[c]A_0(t) \]
\[ A_5(t) = (q_{25}^{(1)} + q_{22}^{(8)}[c]A_2(t) + q_{24}(t)[c]A_3(t) \]
\[ A_6(t) = M_4(t) + q_{010}(t)[c]A_0(t), \quad A_10(t) = q_{102}(t)[c]A_2(t) + q_{102}^{(11)}(t)[c]A_3(t) \]

Taking Laplace Transform of eq. (7-14) and solving for \( \hat{A}_0(s) \)
\[ \hat{A}_0(s) = \frac{N_2(s)}{D_2(s)} \]

where
\[ N_2(s) = (1 - q_{22}^{(8)}[c]) \{ M_{00}(s) + \hat{q}_{00}(s) M_{10}(s) + \hat{q}_{01}(s) \hat{q}_{12}(s) + \hat{q}_{02}(s) \hat{q}_{22}(s) + \hat{q}_{72}(s) \} + \hat{q}_{90}(s) \hat{q}_{910}(s) \hat{q}_{102}(s) + \hat{q}_{102}^{(11)}(s) \]
\[ D_2(s) = (1 - q_{22}^{(8)}[c]) \{ 1 - q_{46}^{(3)}[c] \hat{q}_{06}(s) \hat{q}_{10}(s) \hat{q}_{44}(s) + \hat{q}_{40}(s) \hat{q}_{74}(s) \}
\[ - q_{20}(s) \{ \hat{q}_{00}(s) \hat{q}_{12}(s) + \hat{q}_{07}(s) \hat{q}_{72}(s) + \hat{q}_{72}(s) + \hat{q}_{90}(s) \hat{q}_{910}(s) \hat{q}_{102}(s) + \hat{q}_{102}^{(11)}(s) \} \]

The steady state availability
\[ \lambda_0 = \lim_{t \to \infty} A_0(t) \]
\[ = \lim_{s \to 0} \frac{N_2(s)}{D_2(s)} \]

Using L’ Hospitals rule, we get
\[ \lambda_0 = \lim_{s \to 0} \frac{N_2(s)+\epsilon N_2(s)}{D_2(s)} = \frac{N_2(0)}{D_2(0)} \]

Where
\[ N_2(0) = p_{02} M_0(0) + p_{01} M_1(0) + p_{00} M_0(0) + M_2(0) \]
\[ (p_{00} p_{12} + p_{07} + p_{72}^{(8)} + p_{09}) \]
\[ D_2(0) = p_{02}( \mu_0^* + \mu_4^* + p_{01} p_{14} + p_{07} p_{14} + \mu_4^* + \mu_7^* + p_{09} p_{45} + p_{10} + p_{12} \{ 1 - ((p_{00} + p_{07}) p_{14}) \} \]
\[ \mu_4^* = \mu_{46}^{(3)}, \quad \mu_7^* = \mu_{72}^{(3)} + \mu_{74}^{(3)} + \mu_{74}^{(4)} \]

The expected up time of the system in \( (0,t] \) is
\[ \lambda_0(t) = \int_0^t A_0(z) dz \]

So that \[ \lambda_0(t) = \frac{N_2(s)}{D_2(s)} \]

The expected down time of the system in \( (0,t] \) is
\[ \lambda_0(t) = t - \lambda_0(t) \]

So that \[ \lambda_0(t) = \frac{1}{s^2} - \lambda_0(t) \]

The expected busy period of the server for repairing the failed unit due to landslide caused by Earthquakes in \( (0,t] \)
\[ R_0(t) = S_0(t) + q_{01}(t)[c]R_1(t) + q_{02}(t)[c]R_2(t) + q_{03}(t)[c]R_3(t) \]
\[ R_1(t) = S_1(t) + q_{12}(t)[c]R_2(t) + q_{13}(t)[c]R_3(t) \]
\[ R_2(t) = q_{20}(t)[c]R_0(t) + q_{22}(t)[c]R_2(t) \]
\[ R_3(t) = q_{46}^{(3)}[c]R_0(t) \]
\[ R_4(t) = q_{06}[c]R_0(t) \]
\[ R_5(t) = (q_{25}^{(1)} + q_{22}^{(8)}[c]R_2(t) + q_{24}(t)[c]R_3(t) \]
\[ R_6(t) = S_0(t) + q_{010}(t)[c]R_0(t) \]
\[ R_7(t) = q_{102}^{(11)}[c]R_0(t) \]

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Taking Laplace Transform of eq. (19-26) and solving for \( \hat{R}_0(\mathbf{s}) \)

\[
\hat{R}_0(\mathbf{s}) = N_0(s) / D_2(s) \tag{27}
\]

Where

\[
N_0(s) = (1 - \hat{q}_{22}^{(3)(s)}) \{ \hat{S}_0(s) + \hat{q}_{01}(s) \hat{S}_1(s) + \hat{q}_{09}(s) \hat{S}_9(s) \} \text{ and } D_2(s) \text{ is already defined.}
\]

In the long run, \( R_0 = \frac{N_0(0)}{D_2(0)} \) \tag{28}

where \( N_0(0) = p_{20}\hat{S}_0(0) + p_{01}\hat{S}_1(0) + p_{09}\hat{S}_9(0) \) and \( D_2(0) \) is already defined.

The expected period of the system under Earthquakes in (0,t] is

\[
\lambda_{\text{rep}}(t) = \int_0^t R_0(z) \, dz \quad \text{So that } \quad \hat{\lambda}_{\text{rep}}(\mathbf{s}) = \frac{\hat{R}_0(\mathbf{s})}{\mathbf{s}}
\]

The expected Busy period of the server for repairing the unit failed due to landslide caused by heavy rainfall by the repairman in (0,t]

\[
B_0(t) = q_{01}(t)[cB_1(t) + q_{09}(t)[cB_9(t) + q_{09}(t)[cB_9(t)]
\]

\[
B_0(t) = q_{11}(t)[cB_1(t) + q_{19}(t)[cB_9(t) + q_{22}(t)[cB_2(t)
\]

\[
B_0(t) = \hat{T}_d(t) + \hat{q}_{46}(t)[cB_6(t) \text{ and } B_0(t) = \hat{T}_d(t) + \hat{q}_{46}(t)[cB_6(t)
\]

\[
B_0(t) = \hat{T}_d(t) + \hat{q}_{46}(t)[cB_6(t) \text{ and } B_0(t) = \hat{T}_d(t) + \hat{q}_{46}(t)[cB_6(t)
\]

\[
\hat{\lambda}_{\text{rep}}(\mathbf{s}) = \frac{\hat{R}_0(\mathbf{s})}{\mathbf{s}}
\]

The expected Busy period of the server for repair of the unit when failure is due to landslide caused by human activities in (0, t]

\[
P_0(t) = q_{01}(t)[cP_1(t) + q_{09}(t)[cP_9(t) + q_{09}(t)[cP_9(t)]
\]

\[
P_0(t) = q_{11}(t)[cP_1(t) + q_{19}(t)[cP_9(t) + q_{22}(t)[cP_2(t)
\]

\[
P_0(t) = \hat{T}_0(t) \text{ and } \hat{\lambda}_{\text{rep}}(\mathbf{s}) = \frac{\hat{R}_0(\mathbf{s})}{\mathbf{s}}
\]

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

\[
H_0(t) = Q_{01}(t)[cH_1(t) + Q_{09}(t)[cH_9(t) + Q_{09}(t)[cH_9(t)]
\]

\[
H_0(t) = Q_{11}(t)[cH_1(t) + Q_{19}(t)[cH_9(t) + Q_{22}(t)[cH_2(t)
\]

\[
H_0(t) = \hat{T}_0(t) \text{ and } \hat{\lambda}_{\text{rep}}(\mathbf{s}) = \frac{\hat{R}_0(\mathbf{s})}{\mathbf{s}}
\]

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

\[
H_0(t) = Q_{01}(t)[cH_1(t) + Q_{09}(t)[cH_9(t) + Q_{09}(t)[cH_9(t)]
\]

\[
H_0(t) = Q_{11}(t)[cH_1(t) + Q_{19}(t)[cH_9(t) + Q_{22}(t)[cH_2(t)
\]

\[
H_0(t) = \hat{T}_0(t) \text{ and } \hat{\lambda}_{\text{rep}}(\mathbf{s}) = \frac{\hat{R}_0(\mathbf{s})}{\mathbf{s}}
\]
- $Q_{20}^{*}(s)\{Q_{00}^{*}(s)Q_{12}^{*}(s)+Q_{09}^{*}(s)$
  
  
  $(Q_{72}^{*}(s)+Q_{72}^{*}(s)+Q_{99}^{*}(s)Q_{9,10}^{*}(s)(Q_{09}^{*}(s)$
  $+Q_{10,2}^{*}(s)))$

In the long run, $H_0 = \frac{N_0(0)}{D_0(0)}$ (60)

where $N_0(0) = p_20(p_{01} + p_{09})$ and $D_3'(0)$ is already defined.

The expected number of visits by the repairman for repairing the unit when failure is due to caused by heavy rainfall in $(0,t]$

$V_d(t) = Q_{00}(t)[c|V(t) + Q_{09}(t)[c|V(t) + Q_{09}(t)[c|V(t)$

$V_1(t) = Q_{12}(t)[c|V(t) + Q_{19}(t)[c|V(t) , V_2(t) = Q_{20}(t)[c|V(t) + Q_{22}(t)[c|V(t)$

$V_4(t) = Q_{45}(t)[c|V(t)$

$V_6(t) = Q_{60}(t)[c|V(t)$

$V_7(t) = (Q_{20}(t)[1+V(t)] + Q_{22}(t)) [c|V(t) + Q_{24}(t)[c|V(t)$

$V_{7}(t) = Q_{99}(t)[c|V(t)$

$V_{10}(t) = (Q_{10,2}(t) + Q_{10,2}(t)) [c|V(t)$

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

$V_0^{*}(s) = \frac{N_0(s)}{D_0(s)}$ (69)

where $N_0(s) = Q_{00}^{*}(s)Q_{72}^{*}(s)(1 - Q_{22}^{*}(s))$ and $D_0(s)$ is the same as $D_3(s)$

In the long run, $V_0 = \frac{N_0(0)}{D_0(0)}$ (70)

where $N_0(0) = p_{20}p_{07}p_{72}$ 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 failure due to repair due to heavy rainfall when the units stops automatically, expected busy period of the server for repair due to landslide caused by human activities, expected number of visits by the repairman for unit failure, expected number of visits by the repairman for failure due to landslide caused by heavy rainfall.

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

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

- expected busy period of the system when the units failure due to landslide caused by human activities in $(0,t]$
- expected number of visits by the repairman for repairing the unit fails due to landslide caused by human activities in $(0,t]$
- expected number of visits by the repairman for repairing the units in $(0,t]$

The expected total cost per unit time in steady state is

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

$= K_1A_0 - K_2B_0 - K_3R_0 - K_4V_0 - K_5H_0$

Where

$K_1$ - revenue per unit up-time,

$K_2$ - cost per unit time repair of the system when failure due to landslide caused by heavy rainfall when units automatically stop.

$K_3$ - cost per unit time for which the system is under repair when failure due to landslide caused by earthquakes

$K_4$ - cost per unit time for which the system is under repair when failure due to human activities,

$K_5$ - cost per visit by the repairman for repair when the failure is due to landslide caused by heavy rainfall,

$K_6$ - 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 landslide caused by heavy rainfall, failure rate due to landslide caused by Earthquakes and failure due to landslide caused by human activities increases, the MTSF and steady state availability decreases and the cost function decreased as the failure increases.

REFERENCES