VULNERABILITY ASSESSMENT FOR REDUCING RISKS DURING WATER DISTRIBUTION

Berrin Tansel, Ph.D., P.E.
Associate Professor, Civil and Environmental Engineering Department
Florida International University, Miami, Florida, USA

Abstract

Lifeline systems are those facilities which provide the main utility or transportation services to a community. The lifeline vulnerability analysis (LLVA) developed in this study is a flexible, risk-based approach which can be used to develop strategies to minimize risks of system failure which may lead to a service disruption. The risk-based approach incorporates the important hazard elements into a framework to estimate a set of vulnerability priority numbers (VPN) that can be used for risk management and decision-making. The LLVA can be used and periodically revised for updating the system risks. The periodic upgrades in the system can be incorporated into the system evaluation and the sequential improvements based on the calculated risk factors. A sample risk analysis algorithm was presented to evaluate the vulnerability of the water distribution system components (i.e., buried pipes, pump stations, storage tanks and electrical and mechanical equipment). The vulnerability priority numbers were developed for comparative risk analysis, assessment relative risks, and assessment of interdependence of key components which may result into domino effect consequences.

Keywords
Disaster, risk assessment, lifeline, hazards, water distribution, domino effect.

1. Introduction

Risk assessment is a systematic process used to describe sources, causes and consequences of a risk. Its purpose is to provide information to decision makers in a way to allow comparisons of different risk reduction alternatives and associate those alternatives with costs. In most cases risks cannot be eliminated, only reduced to an acceptable level, when weighed against the advantages and benefits of the activity or the process (Solomon et al., 1993). The severity of the effects of a disaster may vary according to the susceptibility of a community to damage. Damage is often defined in terms of life and/or property. Risk assessment is a systematic process used to identify, describe sources, causes and consequences of a risk. Its purpose is to provide information to decision makers in a way to allow comparisons of different risk reduction alternatives and associate those alternatives with costs. As the demographic and land use characteristics of a community change, the environmental goals and their relative significance for the community also change. Lifeline systems are those facilities which provide the main utility or transportation services to a community. The lifeline systems may include electric power transmission and distribution, natural gas transmission and distribution, potable water transmission and distribution, wastewater transmission and treatment, highways, seaports and inland waterway, air transportation and telecommunication facilities.

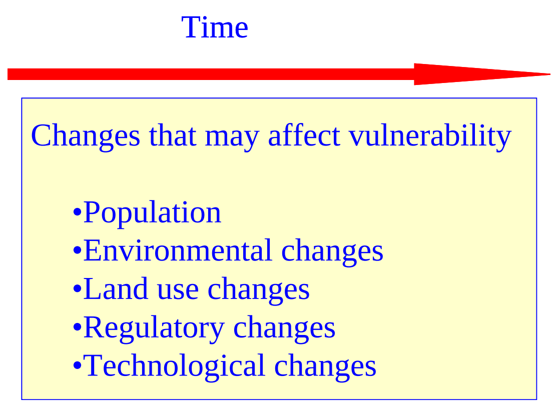

Figure 1. Vulnerability of a community is time dependent.

The magnitude of the risk depends on a combination of factors such as awareness of hazards, the land use and infrastructure conditions, public policy and administration, the wealth of the given society, and the level of organization for disaster and risk management. The extent of interdependency of the lifeline systems plays a significant role on the vulnerability of a community as one or more systems begin to fail leading to a domino effect which would could result in a major disaster. Planning for disaster preparedness is a comprehensive effort that involves establishment of goals in relation to communities' needs for the lifeline systems. As the demographic and land use characteristics of a community change, the environmental goals and their relative significance for the community also change.

This paper presents a simple approach for assessing the vulnerability lifeline systems. The lifeline vulnerability analysis (LLVA) is a flexible, risk-based approach which can be used to develop strategies to minimize risks of system failure for water distribution systems. The LLVA can also be used for periodically revising and updating the system risks. The periodic upgrades in the system can be incorporated into the system evaluation and the sequential improvements in the risk factors can be incorporated into the risk analysis. A numerical vulnerability risk analysis was presented to evaluate the vulnerability of the components of water distribution systems.

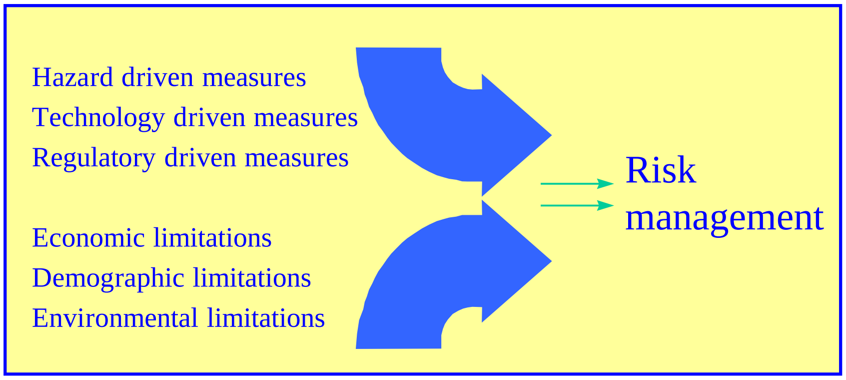

Figure 2. Risk management for lifeline systems depends on time dependent factors

2. Lifeline Vulnerability Analysis (LLVA)

Risk assessment is a systematic process used to describe sources, causes and consequences of a risk. Its purpose is to provide information to decision makers in a way to allow comparisons of different risk reduction alternatives. In most cases risks cannot be eliminated, only reduced to an acceptable level, when weighed against the advantages and benefits of the activity or the process. Occurrence of a service break in a lifeline system usually takes combinations of several elements to go wrong at the same time (Tansel et al., 2001; Tansel, 1995; Simbo, 1993). The consequence of the service break could be significant depending on the vulnerability of the impacted locations. Hence, the assessment of the system risks requires consideration of hazard factors, detactability measures, and vulnerability of the service area.

What is domino effect?

- Events are linked by time.
- A subsequent event requires a preceding event to happen.
  - How do the stages, steps, phases or events relate to one another?
  - What happens if an event does not take place?
  - What is the final outcome?
  - Can we establish check points?

Figure 3. Occurrence of service break in a lifeline system could lead to a domino effect.

The lifeline vulnerability analysis (LLVA) developed in this study is a flexible, risk-based approach which can be used to develop strategies to minimize risks of system failure. This risk-based approach incorporates the important hazard elements into a framework to estimate a set of vulnerability priority numbers (VPN) that can be used for risk management and decision-making.

Figure 1 presents the general flow diagram for LLVA for water transport. The LLVA involves the following steps:

1. *Identification of failure modes:* This step involves the identification of the failure modes for each element of the system. For example, a pipe may rupture; or a given system component may shear because of stress.

2. *Identification of causes of causes:* Typical causes might include design failures such as equipment stresses during operation, aging and wear out, human errors, or operator-and-maintenance-induced factors.

3. *Identification of failure detection means:* If the likelihood of a system failure can be detected at an early stage, efforts can be taken to prevent any further damage.

4.*Identification of effects of failure (Consequence rating):* In this step, the potential consequences from a failure are identified. These consequences could include damages in terms of population affected or costs.

5.*Allocation of weights for component failure frequency:* This step addresses the frequency of occurrence of failure in a system conponent. For the purposes of quantification, a scale of 1 to 10 was used as follows.

a) Remote (component failure is unlikely) = 1,
b) Low (relatively low possibility of component failure) = 2 to 3
c) Moderate (occasional component failures are likely) = 4 to 6
d) High (component failures would occur) = 7 to 8
e) Very high (component failure is inevitable) = 9 to 10.

6.*Allocation of weights for failure mode detection probability:* For the purposes of quantification, again a scale of 1 to 10 was used with very high detectability being 1 to 2, high being 3 to 4, moderate being 5 to 6, low being 7 to 8, very low being 9, and absolute certainty of non-detection being 10.

7. *Allocation of weights for failure severity:* This refers to the seriousness of the effect or impact of a particular failure. For the purpose of quantification, the degree of severity may be expressed quantitatively on a scale of 1- 10 with minor effects being 1 and very sever effects being 9 to 10.

8. *Analysis of failure modes:* This step involves the analysis of information from the preceding steps to quantify the possible failure scenarios due to each failure process. A vulnerability priority number (VPN) is calculated based on severity, frequency, and probability of detection and can be calculated as:

VPN = (failure mode frequency rating) x (detectability rating) x (severity rating)

2. Numerical Example

To illustrate application of LLVA, a numerical example for a water distribution system is presented below. For this example, the vulnerability associated with the water distribution system is evaluated. Table 1, presents the ranking of individual risk factors and the corresponding VPNs.

Table 1. Ranking of risk factors and the VPNs for a water distribution system example.

Origin	Failure Risk Factor	Risk Factor Score	Detectability Score	Consequence Score	VPN
Design	No. of Components	2	2	5	20
	Age	10	4	5	200
	Pipe Material	4	1	6	24
	Pipe Length	10	6	5	300
	Pipe Capacity	2	2	6	24
	System Redundancy	2	2	6	24
	Degree of Automation	4	2	5	40
	Pipe Pressure	4	2	4	32
Operational	No. of People Employed	2	1	4	8
	Training Program	1	1	4	4
	Frequency of Inspection	4	1	4	16
	Work Hours	5	3	3	45
	Morale	6	1	8	48
	Work Ethics	5	1	10	50
Environmental	Geology	2	3	4	24
	Geography	2	3	4	24
	Weather	2	5	4	40
	Vibration	3	2	4	24
	Nearby Activities	3	5	4	60
Acts of God	Earthquake	2	9	9	162
	Arson	2	4	9	72
	Flood	5	8	9	360
	Hurricane	2	3	9	54

3. Conclusions

Vulnerability is determined by a combination of factors including awareness of hazards, the condition of human settlements and infrastructure, public policy and administration, the wealth of a society and organized abilities in all fields of disaster and risk management (Commission of Sustainable Development, 2002). The extent of interdependency of the lifeline systems plays a significant role on the vulnerability of a community as one or more systems begin to fail leading to a domino effect which would could result in a major disaster. The periodic upgrades in the system can be incorporated into the system vulnerability evaluation and improvement plans (Moussa, 1998; Brazier and Greenwood, 1998). The risk analysis algorithm developed to evaluate the vulnerability of the components (i.e., for water distribution systems these would include buried pipes, pump stations, storage tanks and electrical and mechanical equipment) can be used for comparative risk analysis, assessment relative risks, and assessment of interdependence of key elements which may result into domino effect consequences in relation to the changing needs of the communities.

4. **References**

Commission of Sustainable Development, 2002, Notes from Thematics Meetings, www.unisdr.org/eng/risk-reduction/wssd/rd-wssd-eng.htm

Brazier A.M., Greenwood R.L., Geographic information systems: a consistent approach to land use planning decisions around hazardous installations, *Journal of Hazardous Materials*, Vol. 61, pp. 355-361, (1998).

Moussa, W.A., Risk-Based Reliability Evaluation of Multi-Site Damage in Pipeline, *Computers Industrial Engineering*, Vol. 35, No 3-5, pp. 595-598, 1998

Simbo, A.K.; Catastrophe Planning and Crisis Management", *Risk Management*, Vol. 40, pp. 64-66, 1993.

Solomon, K.A.; W.E. Kastenberg, P. Nelson, Dealing with Uncertainty Arising out of Probabilistic Risk Assessment, Rand Publications Series, Prepared for Oak Ridge National Laboratory (R-3045-ORNL), 1993.

Tansel, B., Nakhate, M., Sevimoglu, O., “Spill Prevention Priority Analysis for Reducing Accidental Release Risks During Pipeline Transport,” *Journal of Environmental Systems,* Vol. 28, No. 4, pp. 319-335, 2001.

Tansel, B., "Natural and Manmade Disasters: Accepting and Managing Risks," *Journal of Safety Science*, Vol 20, No. 1, pp. 91-99, 1995.