RISKY BUSINESS

Quantifying Risk is Fundamental to any Physical Asset Management Program

Roderick Lovely

Water and wastewater infrastructure managers make decisions every day that are aimed at reducing the risk of costly failures. To most, the decision process is ingrained, based on years of experience and knowledge of the system being managed, but over time systems change, people retire, the knowledge base is lost, assets age, and the probability of costly failures increases. This is especially true in developed countries where underground utilities have been in place for over a hundred years, and the people who manage them are nearing retirement.

As a new generation of managers emerges, they are being asked to manage assets nearing the end of their useful life with fewer resources, and tougher regulatory requirements (such as California's Sanitary Sewer Management Plan, or SSMP). To cope with these challenges, savvy managers are turning to computer applications with Physical Asset Management (PAM) features to allocate limited resources more strategically.

Fundamental to PAM is prioritizing assets based on a risk model. At a minimum, this involves knowing how assets might fail and what would happen if a failure were to occur. The following discussion presents how this information can be obtained and used to assess risk.

In PAM we define "how assets might fail" as the probability of failure (PoF) and "what would happen a failure were to occur" as the consequence of failure (CoF). Risk is simply the product the Probability of Failure and Consequence of Failure.

Risk = PoF x CoF

Probability of Failure

To determine the probability of failure of any asset, we must first determine how it may fail in terms of failure modes. When we categorize how an asset may fail, there are at least four failure modes to consider that are common to all assets:

1) ***Condition*** – Condition may be put in terms of a condition rating by quantifying the number and extents of defects, or by direct measures such as a vibration analysis. It may be helpful to measure condition in both O&M condition and physical condition. O&M condition can be addressed through tasks such as cleaning and lubrication, while physical condition may call for capital remedies such as overhaul and replacement.

2) ***Age*** – For age to have meaning we must first determine the life expectancy of any asset. Life expectancy can be influenced by many factors such as the surrounding environment, construction material, and installation techniques. Although age is often a good predictor of condition, an asset that appears to be in good condition may start to deteriorate rapidly or suddenly fail as it approaches the end of its useful life. Knowing how close your assets are to their life expectancy may influence how often you inspect them or how you develop a replacement strategy to avoid costly failures.

3) ***Capacity*** – Does the demand placed on the asset exceed its original design capacity? Influences such as population increases can certainly affect capacity. You must know what the demands are on your assets to measure capacity. Bear in mind that assets which are substantially under-utilized could lead to a higher PoF as well.

4) ***Level of Service*** – Perhaps the asset was put into place before new regulatory requirements were enacted. Stakeholder expectations for issues such as noise, odor, and safety may be more stringent now. Also, newer alternatives may have been developed that reduce the cost of operation to the point at which it is less costly to replace the asset than to continue to operate it. Establishing acceptable levels of service will help you make these determinations.

Roderick Lovely, P.E., is the vice president of product management at VUEWorks Inc., developers of GIS-integrated work order and asset management solutions. He also serves as chair of the New England Water and Environment Association's Asset Management Committee. Versions of this article were published previously in Underground Infrastructure Management, Stormwater Solutions, Water & Wastes Digest, *and* Trenchless Technology International.

Your actual list of failure modes will vary depending on the asset types you are rating, but they will all most likely fall into one of these four categories. As you develop your criteria, take into account that "failure" does not always mean a catastrophic failure, but it does mean that continuing to operate the asset without taking action will be more costly than doing something about it.

Quantifying Probability of Failure

When it comes to age, we humans inherently know that the probability of end of life increases as we grow older, and that probability increases at an accelerating rate, but we have no way of determining precisely when the end will occur. The same is true for physical assets, but we can apply a probability based on experience and historical data when available. Table 1 shows how one might interpret levels of probability in a risk model.

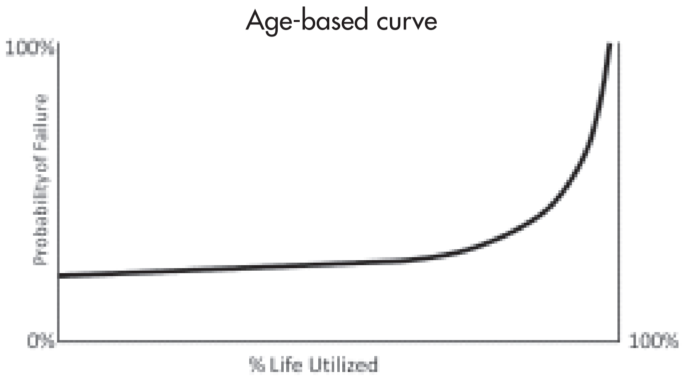
For the failure mode of age, the graph for static assets such as pipes and manholes where failure rarely occurs early in life can be illustrated in an age-based curve:

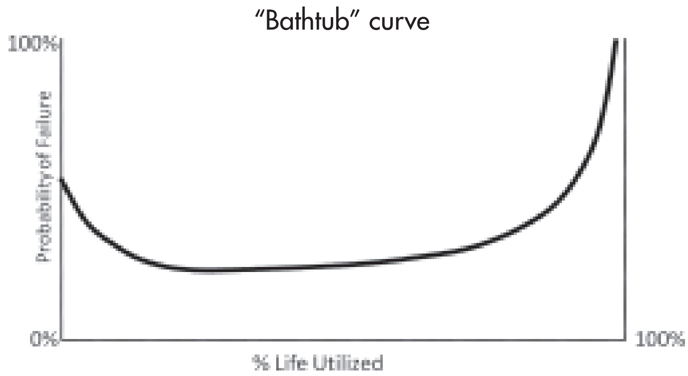
Mechanical and electrical assets are more prone to failures early in life, and hence the probability of failure curve associated with these types of assets is often referred to as a "bathtub" curve:

Continued on page 64

Table 1: Interpreting Probability Levels in a Risk Model

Probability	What it means
100%	Failure likely to occur within a year
90%	90% chance of Failure in any year – Failure likely within 2 years
50%	50% chance of Failure within any year
20%	20% chance of Failure within any year
10%	10% chance of Failure within any year – 90% chance it won't
2%	2% chance of Failure within any year - 98% chance it won't





Regarding Criticality

An asset that would cause severe consequences if it failed is inherently more critical to the operation of a system than assets that do not receive a high CoF rating—thus, CoF ratings can be used to determine an asset's criticality rating.

For example, if a 30-inch water transmission line failed, it could flood out businesses, disrupt service for thousands, ruin public relations, and cost a significant amount to repair, so it would get a high CoF rating.

In comparison, a six-inch distribution line at the end of a residential street would not be anywhere nearly as consequential if it failed; therefore, its criticality rating would be lower than the rating for the 30-inch pipe.

Continued from page 62

If reliable historical data is available then PoF should be based on the percent of failures actually experienced. Similar curves can be created for other failure modes, such as capacity, where the PoF may plot as a bathtub curve because an asset that operates significantly under capacity is often more likely to fail than one operating at 50 percent to 75 percent capacity.

Consequences of Failure

Consequences of failure are often put in terms of the cost to fix and/or recover from a failure. In this sense it would be ideal to measure all consequences in terms of actual costs, but for most it is impractical to forecast the cost of all failures accurately; therefore, most systems rate CoF on an arbitrary scale.

Other traits of CoFs are that they tend to reflect the service level expected and the priorities of stakeholders. For instance, the public places a high value on the environment (as does the EPA); therefore, a sanitary sewer overflow that spills into a natural water body would be highly consequential when one considers environmental impact, aesthetic impact, and other impacts, including the cost to contain and clean the spill. Some CoF examples include:

- Threat to employee life and health
- Threat to public life and health
- Environmental Damage
- Regulatory Compliance
- Disruption of Service
- Property Damage
- Cost to Repair
- Loss of Revenue
- Public Relations

Generally it is more difficult to affect consequences than failure probabilities, but factors such as backup and redundancy should be considered when rating them. To develop CoF ratings for the types of assets you manage, you should:

- Develop a list of consequences that could occur if an asset fails. Typically all assets of the same type should be assigned the same list of consequences for comparison purposes.
- Rank the importance of each consequence relative to other consequences in the list. This is done in recognition that some consequences carry higher costs than others (for instance "life and health" typically would be weighted higher than "public relations").
- Develop criteria for determining a CoF rating for each asset. For instance, if a sewer manhole is within a certain distance and upstream of a water body then the CoF rating for "environmental damage" will be higher than a manhole located further away from the water body.

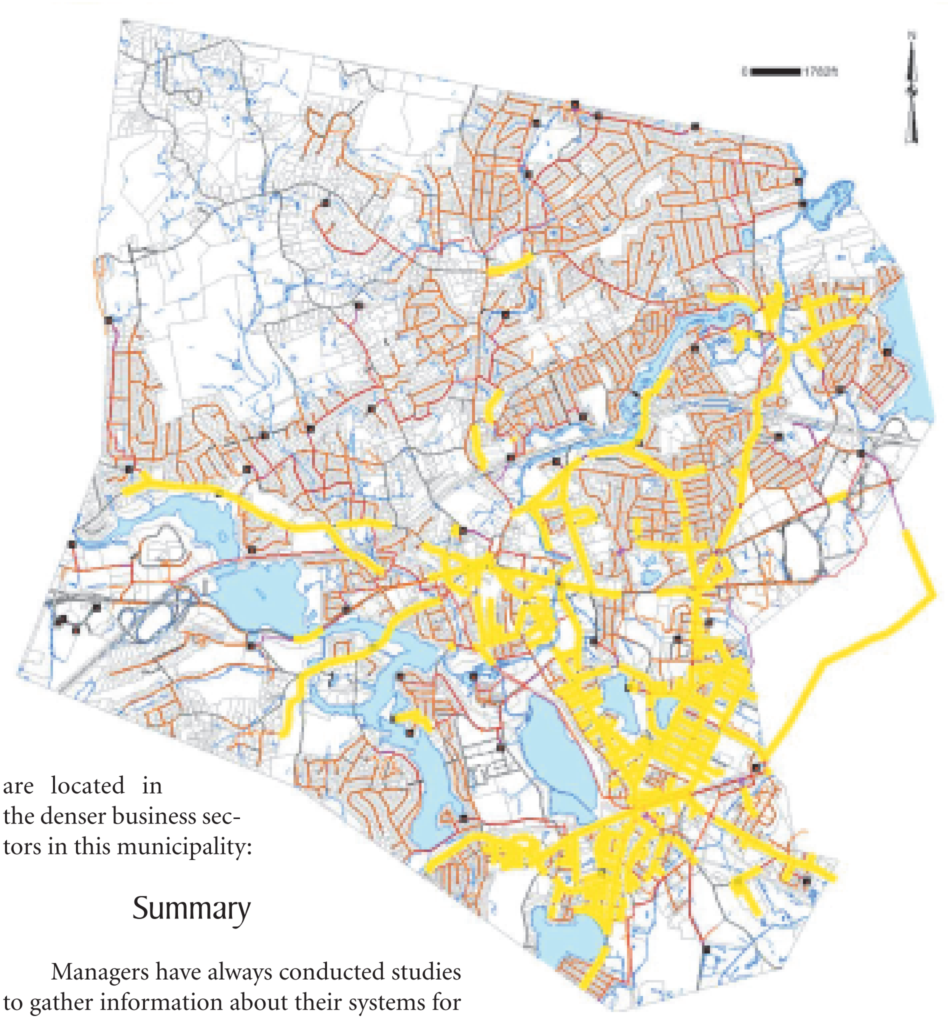
Table 2: Calculating Asset Risk in a Matrix

Asset: Sanitary Sewer Pipe 1234

Consequence of Failure (CoF)				Failure Modes and Probabilities (PoF)				Risk
				15%	31%	75%	30%	
Consequences	Priority	Rating	CoF Score	% Life Left	Condition	Capacity	Service Levels	High Scores
Life and Health	10	Low – 5	5.00	0.75	1.55	3.75	1.50	3.75
Environmental Damage	8	Med – 8	6.40	0.96	1.98	4.80	1.92	4.80
Regulatory Compliance	8	Med – 8	6.40	0.96	1.98	4.80	1.92	4.80
Disruption of Service	5	Low – 5	2.50	0.38	0.78	1.88	0.75	1.88
Property Damage	7	High – 10	7.00	1.05	2.17	5.25	2.10	5.25
Cost To Repair	5	Low – 5	2.50	0.38	0.78	1.88	0.75	1.88
Lost Revenue	5	Low – 5	2.50	0.38	0.78	1.88	0.75	1.88
		Consequence Factor:	7.00	Probability of Failure: 75%			Risk Factor:	5.25

A Risk matrix accounts for all the CoFs and PoFs to calculate the Risk for each asset

High-risk sewer pipes are concentrated in the business sectors of this municipality



Quantifying Risk

Once you have determined failure modes, PoFs, consequences, and CoF ratings, you can combine this information to calculate risk in a matrix for each asset. Table 2 is an example of this calculation.

In this example the consequences, along with their relative priorities, are listed on the left. The asset is then rated according to the potential for each consequence to occur if the asset were to fail. The CoF score is calculated by multiplying the priority by the rating and adjusted to an arbitrary scale of 10 (where 10 signifies the highest consequence).

Failure probabilities are developed from measures on the asset and entered into the table for each failure mode. Each CoF score is then multiplied by each PoF to generate risk scores. The highest risk score for each consequence is highlighted in red. The highest risk value falls out of the table as the risk factor (In this case, 5.25 on a scale of 10).

From this example we can say that the most concerning consequence for this pipe is property damage caused by a failure in capacity. The probability of this occurring in any year is 75 percent, and the consequence factor is 7.00 out of 10.

Developing the risk model requires this same analysis to be performed on each asset. If you are dealing with just a few assets, you could perform the calculation by hand, but if you are dealing with hundreds or thousands of assets, you should consider using a computer application to develop the model. Once the model is developed, you should see patterns emerge. The map of high-risk sewer pipes was generated with VUEWorks software with GIS data and illustrates how these pipes are located in the denser business sectors in this municipality:

Summary

Managers have always conducted studies to gather information about their systems for decision-making purposes, but with the advent of physical asset management, we now have a means to utilize this information qualitatively in a risk model as a basis for strategic decision making. When dealing with a large number of assets, the use of computer software with PAM capabilities can help you develop a risk model and assist in prioritizing your O&M and capital project activities.

Risk assessment should be central to any asset management program, since there are many tactics in physical asset management that use the same information pool generated from the risk model, including cost/benefit analysis, triple bottom line analysis, optimized budget forecasting, and reliability centered maintenance. To learn more about physical asset management, a good place to start is the EPA Web site at **http://epa.gov/owm/asset manage/index.htm.** ◊