RISK-AWARE INFRASTRUCTURE MAINTENANCE

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This article is part of an ongoing series about financial sustainability, based on GFOA's new financial sustainability framework. You can learn more about the framework at www.gfoa.org/financialsustainability.

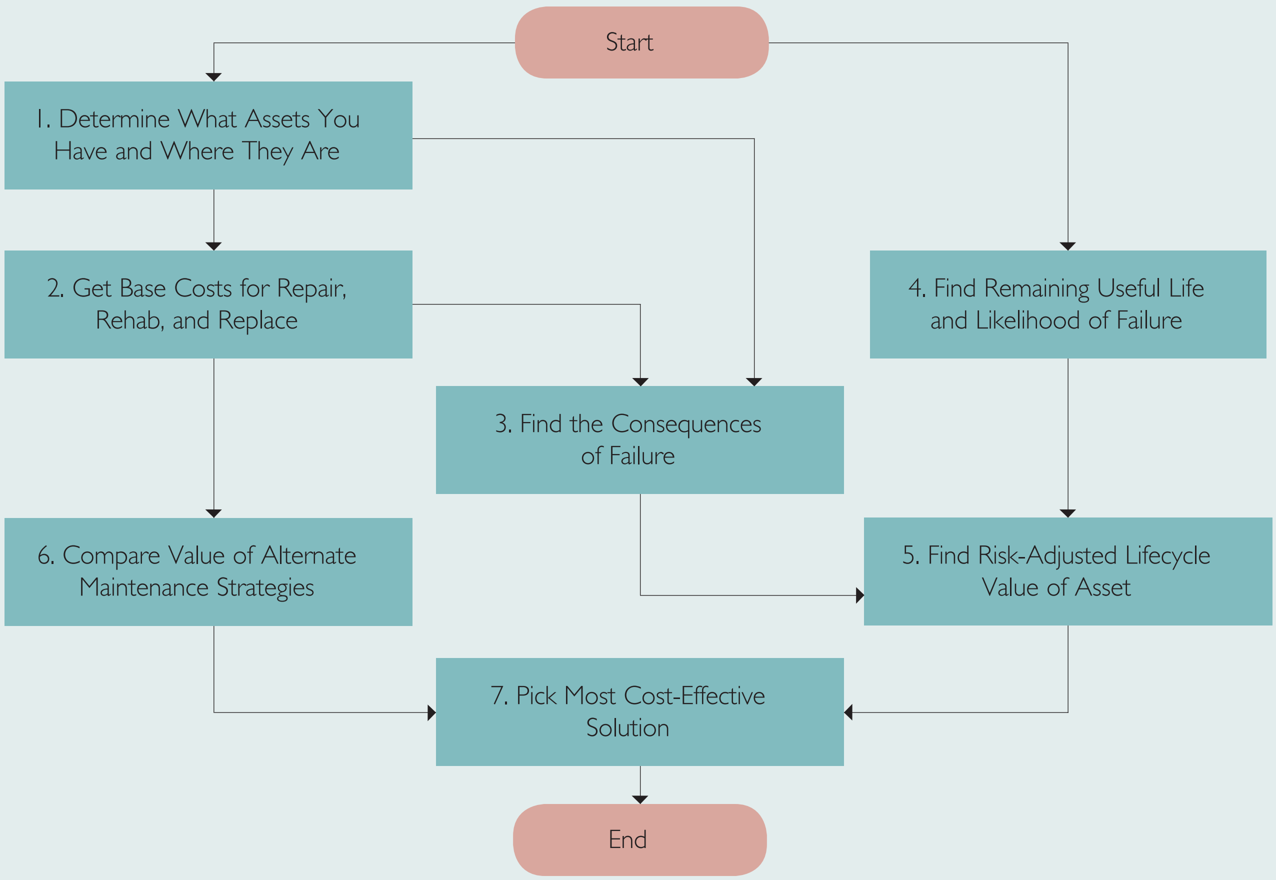
Funding asset maintenance is hard. Cities and other agencies rarely have sufficient funding, so they have to make choices about where to direct available funds. The classic approach is to fund asset maintenance according to a predetermined maintenance schedule. However, this falls apart when there isn't enough money to complete all scheduled work.

The most common fallback has been a "worst-first" approach, where the assets that are in the worst shape are maintained. Worst-first can be quite expensive, though, because the worst assets often require costly reconstruction. This approach also overlooks the fact that some assets are more important than others, and it's hard to predict exactly when one may fail. It may be wise to delay repairing an asset that is in poor condition, but is less consequential, when compared to an asset that is also in poor condition that is highly consequential to the health, safety, and/or welfare of the community.

An alternative approach is "risk-aware" infrastructure maintenance. This approach optimizes the use of funding across the different assets that a local government owns by comparing likelihoods and consequences of failure. This article lays out the basics of such an approach, modeled on practices used by the Bureau of Environmental Services (BES) in City of Portland, Oregon, to analyze wastewater collections system infrastructure.[1]

Exhibit 1 offers an overview of the process. It's not sequential — you can estimate the costs of current fixes while also figuring out estimated failure rates at the same time. We'll approach each section, number by number, on the following pages.

Exhibit 1: Process for Risk-Aware Asset Maintenance



Where to Apply Risk-Aware Asset Management

This article focuses on Portland's sewer infrastructure to illustrate risk-aware asset management. Risk-aware asset management can be applied to other asset classes, but it generally works best when a rich data set is available to asses the assets and the assets are relatively uniform (e.g., all sewer pipes in a system are similar). The importance of the first point is addressed in this the article. The second may need some explanation. If the assets are highly variable, it will become more difficult to compare risk. For instance, comparing the roof of a community center playground with a neighborhood park would be more difficult than comparing two sewer pipes. These kinds of challenges are not insurmountable, but they do show that risk-aware asset management is more promising for some asset classes than others.

1. DETERMINE YOUR ASSETS — WHAT AND WHERE

Figuring out what assets you own is a logical first step to a more informed allocation of maintenance resources. A less obvious, but no less critical, step in a risk-aware asset strategy is to learn about local conditions that impact the cost of maintenance and the consequences of failure.

Three types of environmental conditions that could impact sewer pipes, for example, are:

- **Transportation infrastructure.** Pipes near rail lines are difficult to access and can wreak havoc on rail service if they fail. Different types of streets have different reconstruction costs and impacts to citizens. It's a bigger problem when sewer pipes fail near a busy avenue than a side street, for example.
- **Sensitive areas.** This might include areas where hazardous materials are stored, that are environmentally sensitive (e.g., a nature preserve), or that have a prevalence of low-income households, which may have fewer resources to cope with an infrastructure failure.
- **Utilities.** At best, the presence of other utilities complicates repairs; at worst, they could introduce safety hazards (e.g., natural gas line explosion).

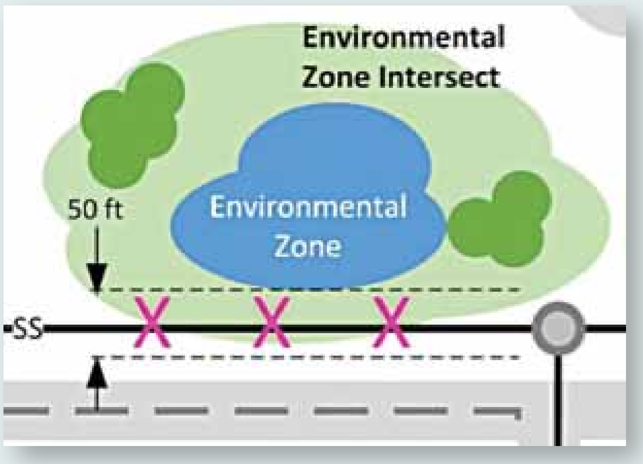
Exhibit 2 shows a section of Portland's sewer pipe intersecting a sensitive environmental area. A red "X" indicates a location where pipes cross an environmental feature that will affect the cost of pipe repair and the consequence of failure. The pipe is evaluated in 10-foot segments. Many utility databases track pipes in much larger increments, such as the segment between manholes (250 to 300 feet).

The advantage of a more granular system is that serious defects could be clustered in sections between a 300-foot pipe check. A less granular tracking system would offer less precise guidance on where exactly problematic areas lay, while a more granular system would flag areas that are more likely to fail over those that are less likely. Hence, risk-aware asset management must inventory assets with sufficient granularity to allow a government to understand where problems are, with enough precision to deploy precise repair, rehabilitation, and replacement strategies.

2. GET BASE COSTS FOR REPAIR, REHABILITATION, AND REPLACEMENT

A government's response to a compromised asset typically focuses on three key options: repair, rehabilitation, and replacement. Cost estimates for all three are necessary to estimate the consequences of infrastructure failure, to determine the most cost-effective response, and to budget for an appropriate course of action.

Exhibit 2: Sewer Pipeline in a Sensitive Area



The information from sub-process No. 1 helps calculate direct costs associated with repair, replacement, and rehabilitation. If a sewer pipe runs under a train track, building, or highway, for example, a fix would involve a more expensive bore or tunnel to access the pipe. Elsewhere, a less expensive open trench might suffice. All methods might share other common repair or replacement costs, such as replacement pipe material.

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Ancillary costs also need to be factored in, and are also location dependent. A broken pipe near an environmentally-sensitive area might incur environmental mitigation costs. A section near a roadway might require traffic controls to reroute passing motorists.

Finally, don't forget inspection, testing, and design costs. Portland applies a cost multiplier to account for environmental conditions that might make work more difficult, such as locations that are downtown, within 25 feet of a train track, or on steep ground.

All these costs together form an estimate for repair, replacement, or rehabilitation options. Governments should use standardized cost formulas and assumptions across all calculations. Portland generates cost estimates for spot repairs, lining, and whole-pipe replacement based on the asset inventory data and GIS data for a pipe segment and bid tab data from similar construction projects. They also make some unit cost assumptions based on prior city project history. To illustrate: The cost of each instance where sewer lines intersect another utility line totals $5,000 per utility crossed. The formulas for other types of costs can be more detailed. Portland's formula for a water line relocation, for example, includes the diameter and depth of the water line to be relocated. Exhibit 3 shows how sewer lines intersecting city features might raise costs.

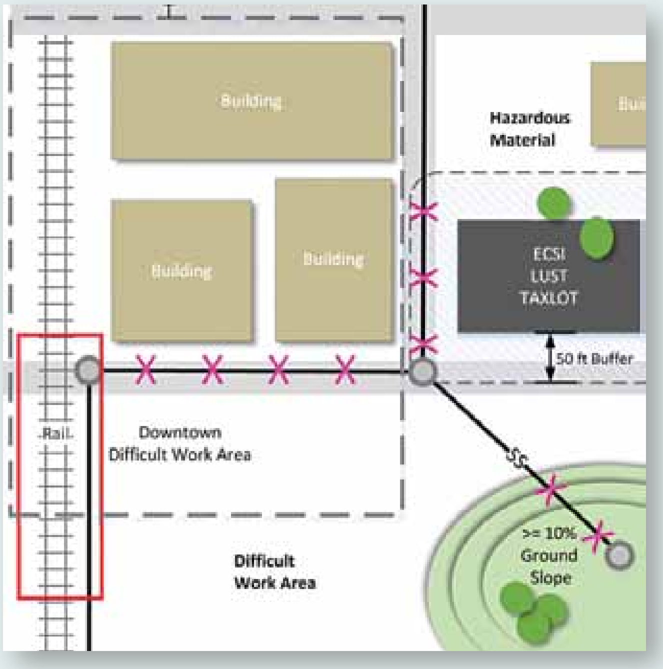
3. FIND THE CONSEQUENCES OF FAILURE

When an asset fails, it's not just the direct costs of emergency repair or replacement that comes into play. Failure could affect valuable environmental features such as a park or historical building, harm a government's reputation, or threaten public health and safety. Calculations of the potential consequences of failure should include all these possibilities.

Portland analyzes three categories of consequences: economic, environmental, and social.

Economic consequences include the direct cost the government incurs to repair, replace, or rehabilitate an asset. Environmental consequences address damage to the physical habitat, such as clean-up costs, and the costs of violating environmental regulations, such as fines. The social category includes public inconvenience, public perception, and public health and safety. In some cases, especially social ones, the costs don't necessarily represent direct costs to the government. Rather, they represent costs to the broader community as a consequence of an asset failure. For instance, traffic delays wouldn't require the government to write a check, but the costs to citizens are very real.

Exhibit 3: Sewer Lines In Areas that Increase Cost of Repair, Rehabilitation, Replacement



Portland monetizes these indirect costs using standardized formulas developed by city staff based on reviews of literature, planning studies, and customer impact data, so indirect costs are fully considered. For example, the formula for inconvenience from traffic delays is $2 per vehicle per day of construction, where the number of vehicles is based on generalized traffic flow for the type of street in question.

Figuring out what assets you own is a logical first step to a more informed allocation of maintenance resources. A less obvious, but no less critical, step in a risk-aware asset strategy is to learn about local conditions that impact the cost of maintenance and the consequences of failure.

Portland also considers consequences across three phases of response to an asset failure. First comes the initial failure, then the city's efforts to stabilize the situation, such as putting up traffic barricades, and bypass pumping for a broken sewer line. Emergency repairs come next. These three phases are overlaid with the three consequences to create a 3x3 matrix that helps Portland think more comprehensively about the impacts of failure. For example, a sinkhole's emergency repair includes the social impact of traffic delays.

4. FIND THE REMAINING USEFUL LIFE AND LIKELIHOOD OF FAILURE

Risk equals the likelihood of failure multiplied by the consequences of failure.[2] Finding the likelihood of failure starts with assessing physical condition — assets with more defects are more likely to fail sooner. Gathering data on the condition of assets is a major undertaking for all municipalities. Portland's CCTV program corrals data on the condition of sewer collection system pipes.

Portland summarizes the condition of wastewater collection system assets, and other assets, on a 5-point scale:[3]

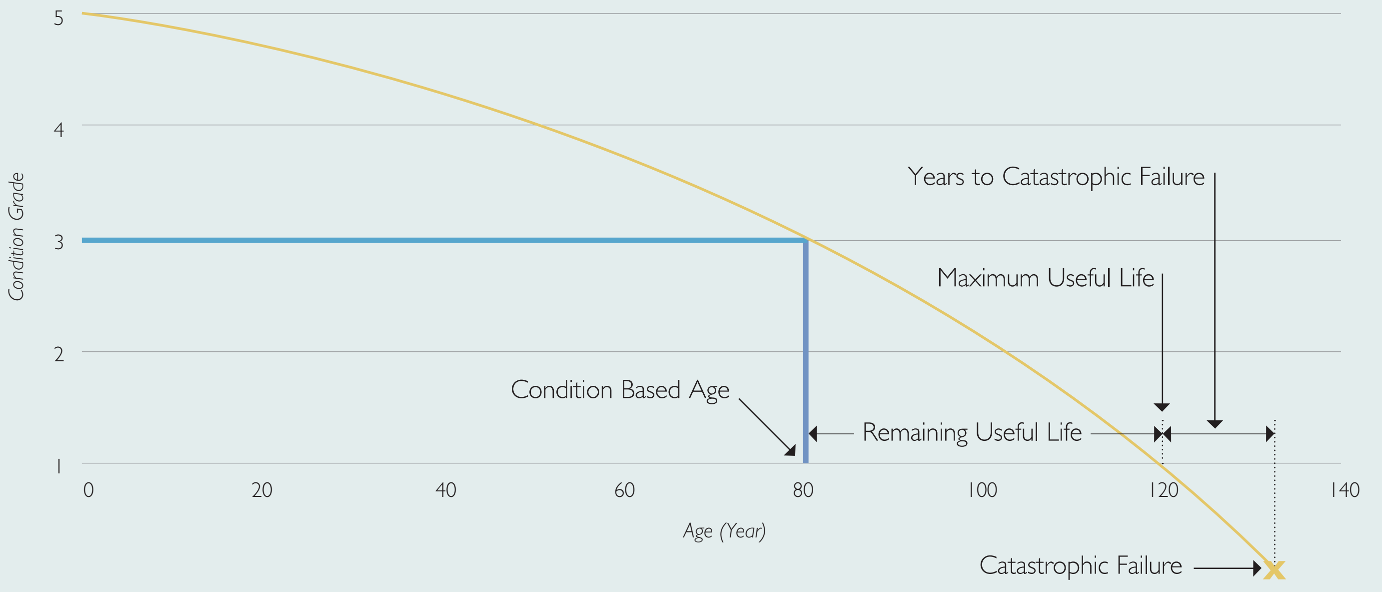
1. **Excellent.** No defects or minor defects.
2. **Good.** Minor defects or a few moderate defects.
3. **Fair.** Moderate defects that will continue to deteriorate.
4. **Poor.** Severe defects that will soon become Grade 5 defects.
5. **Very Poor, or Immediate Attention Required.** Defects requiring immediate attention.

After assessing an asset's condition, the next step is to find the remaining useful life. Portland uses a standardized grade and age curve, shown in Exhibit 4. It was developed by an external consultant that used utility data from different cities. The pipe score and grade is converted to a remaining useful life rubric using an equation that generates the curve shown in Exhibit 4. To read the curve, find the condition score on the vertical axis and then follow it down to "condition-based age."

Grading on a Curve

A curve like the one shown in Exhibit 4 could be developed for asset classes other than sewers. It is not a small feat to develop a relationship between asset condition and remaining useful life, though — it requires data and experience with asset failures, informed by asset condition.

Exhibit 4: Remaining Useful Life Curve



A pipe's maximum useful life is the point at which the curve crosses the horizontal axis, or a 5 on the condition scale, and the condition-based age may not match the asset's calendar age. For example, a sewer pipe with a condition grade of 3 has a condition-based age of about 80 years. The difference between the condition-based age and the maximum useful life is the remaining useful life, or just under 40 years in this case. Portland's score system uses an equation that's a function of the number and type of defects found on an asset, so a pipe could have a remaining useful life grade of 4.7 or 4.23.

Of course, an asset doesn't stop functioning at the end of its estimated useful life. It may continue until a catastrophic failure hits. For the pipes we're discussing, Exhibit 4 shows that catastrophic failure will likely occur about a decade after the end of a pipe's useful life. On average, the year a given segment of pipe is expected to fail is the year it was inspected, plus the remaining useful life, plus the estimated years until catastrophic failure. So, a pipe inspected in 2010 that received a grade of 3 would have about 40 years of useful life, then 10 more years until catastrophic failure, making its average (or mean) failure year 2060.

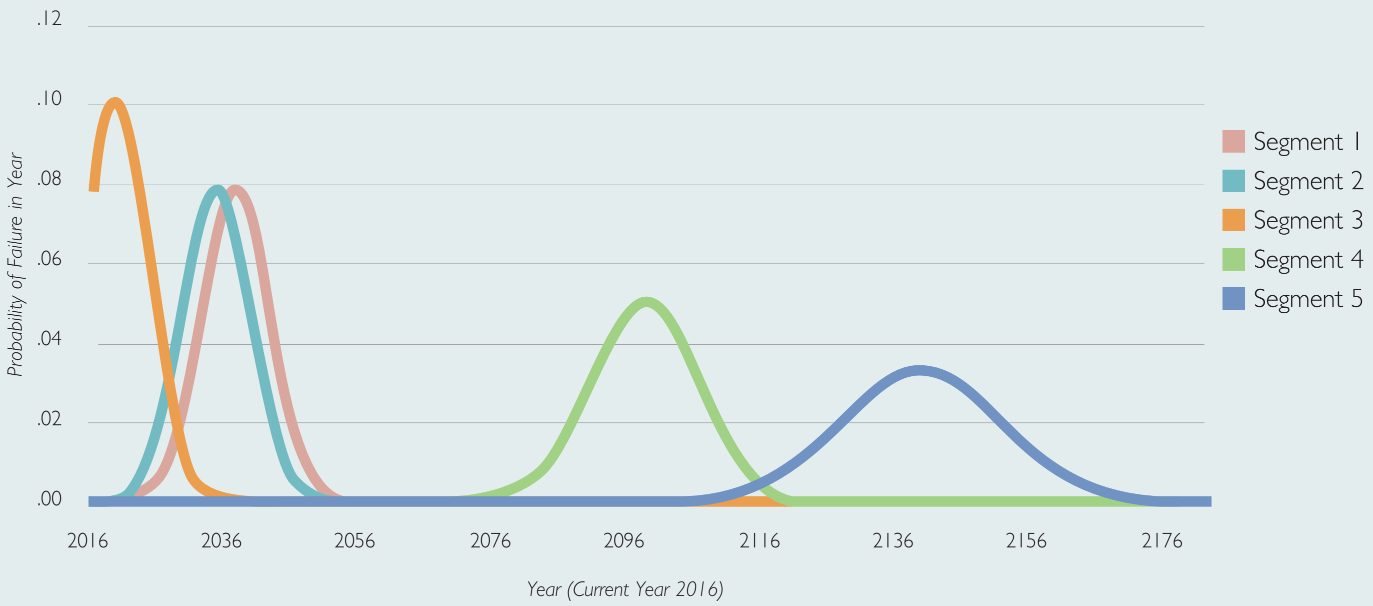
A government's response to a compromised asset typically focuses on three key options: repair, rehabilitation, and replacement.

The problem with an average is that it obscures the underlying variability. Though our grade 3 pipe might be expected to fail in 2060, on average, it could fail well before or after that. The next step is to translate the life and failure data into the statistical likelihood of failure in any given year. This is done by assuming that actual failure dates are normally distributed around the mean failure date. In pictorial form, this means the likelihood of failure takes the shape of a normal distribution or bell curve.

Exhibit 5 shows five normal distributions for five segments of pipe. The middle of the curve is where the average falls, the most likely outcome. Other possible outcomes are shown, extending out from the middle.

Not only does Portland center a normal distribution of failure probabilities around the mean failure date, but city experts also figure how wide the distribution will be. All the curves in Exhibit 5 are normal distributions. Portland's formula draws on the remaining useful life of an asset to determine how wide the distribution will be. Assets with a shorter remaining life have a narrower curve, since the city is more confident that

Exhibit 5: Normal Distributions for Sewer Pipe Failures



catastrophic failure will occur in the foreseeable future. Assets with a longer useful life have a wider curve because there is more uncertainty about when catastrophic failure will occur. With these curves, it's possible to give a probabilistic estimate of failure for any given date. For example, it's 50 percent likely that the pipe will fail before 2060.

5. FIND THE RISK-ADJUSTED LIFECYCLE VALUE OF THE ASSET

The consequences of failure (sub-process No. 3) and the likelihood of failure (sub-process No. 4) are multiplied to quantify risk for an asset. If a failure costs $50,000 and the probability of failure was 20 percent for the current year, then the expected value of the risk in that year is $10,000.

This is a fairly basic representation of failure value, and most governments will want to expand it to get a more realistic picture. For example, city leaders might consider the risks faced by parts of a whole system, not just one piece. They might model proactive maintenance strategies instead of just responding to failure.

> When an asset fails, it's not just the direct costs of emergency repair or replacement that comes into play. Failure could affect many other areas.

Portland uses a "reactive/proactive" risk model. This model assumes that if a 10-foot pipe section fails, the city will also take the opportunity to fix nearby sections that are in poor condition — there are economies of scale in fixing multiple segments at the same time. The value of rehabilitating proximate pipes is discounted based on the probability of failure, meaning it would be more worthwhile to rehabilitate a pipe with a higher risk of failure than it would to rehabilitate one at lower risk. By taking into account multiple pipe segments and considering value of rehabilitation over a multiyear period, Portland addresses lifecycle risk.

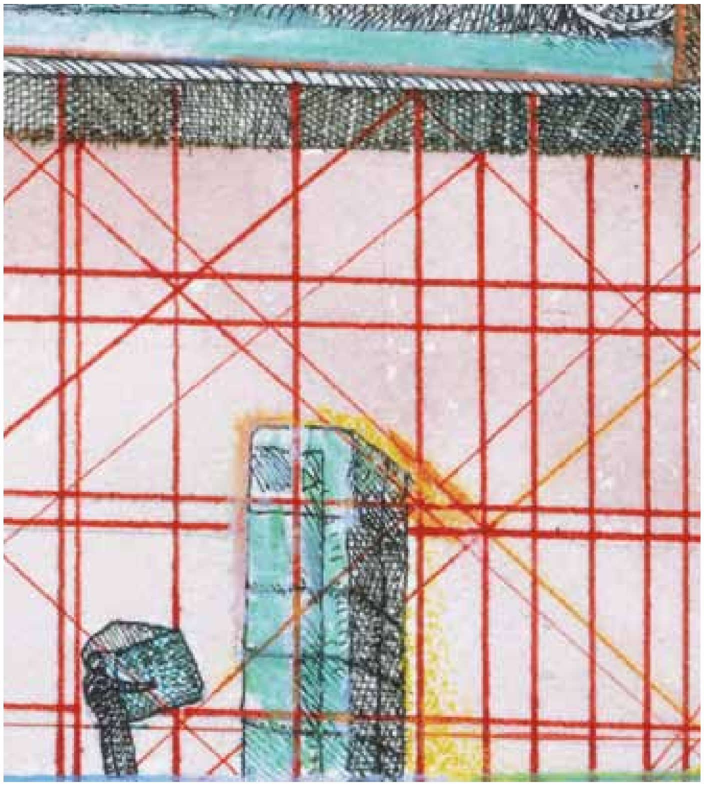
6. COMPARE THE VALUE OF ALTERNATIVE MAINTENANCE STRATEGIES

The discussion in sub-process No. 5 was based, in large part, on responding to failure. Of course, it might be more cost-effective to rehabilitate an asset prior to failure. For example, a government could repair a risky spot on a sewer pipe, it could rehabilitate an entire pipe, or it could proactively replace an entire section.

Portland models three standard rehabilitation scenarios for pipes, based on these three alternatives, calculating the cost of each and taking into consideration the pipe's age — remediating a pipe whose failure risk is far into the future isn't as valuable as remediating one with more near-term risk. For example, if a 40-foot length of pipe is replaced and three 10-foot segments were in poor condition, but one was in good condition, then the one segment represents a loss in value to the city.

Comparing the cost of fixes can determine what to do about an asset. The goal is to identify those requiring immediate attention, and those that can wait.

For assets requiring immediate attention, the lifecycle costs and benefits of rehabilitation and repair options can be weighed to plan the best solution. Rehabilitation that extends the life of an existing asset will generally be more cost-effective, but some assets may need a full replacement. Portland has created guidelines to identify assets that must be replaced instead of repaired, based on GIS information and the asset's condition ratings.



7. PRIORITIZE THE MOST COST-EFFECTIVE SOLUTIONS

Comparing the cost of fixes can determine what to do about an asset. The goal is to identify those requiring immediate attention, and those that can wait. Portland translates the benefits and costs of all aspects of the pipe repair or failure into dollars, and uses that amount to evaluate a net Benefit Cost Ratio (nBCR) of repairing a pipe, or letting it fail. The nBCR is used to help prioritize the work.

Allowing a pipe to fail means accepting the higher costs of an emergency repair and the risks to customers from issues like sinkholes. Because a government can't fix everything at once, there's always some risks that remain while government works on addressing the highest-risk infrastructure. Portland tries to repair pipes before they fail because of the potential impact on customers. The nBCR comparison helps the City prioritize pipes to repair sooner by quantifying and comparing the risks of different maintenance strategies, like those developed in sub-process No. 5, above.

Portland uses GIS data and asset condition data to automatically highlight wastewater collections system assets that pose the highest risk of failure, both in terms of the likelihood of failing soon and the consequence of that failure. Portland's approach automates a comparison of the options to remediate risk: based on the pipe's location, condition, problem severity, and the costs of repair, what is the best option for repairs based on the lifecycle of the pipes?

These tools allow Portland to analyze over 2,000 miles pipe to identify where and how to spend limited resources on repairs, rehabilitation and replacement. The end result is better customer service, focusing resources where they're most needed and avoiding catastrophic infrastructure failures.

CONCLUSIONS

A risk-aware asset maintenance strategy helps governments make the best use of limited maintenance dollars by directing those dollars to assets, with the worst combination of likelihood of failure and consequence of failure. This approach emphasizes the value of maintenance strategies that prevent outright failure. Portland has seen the benefits of this approach by minimizing the dollars spent responding to costly asset failures. The city uses this risk-aware perspective to plan for the long term — based on age and condition, the city can budget for sustainable asset management and reinvestment. This method does have drawbacks, however. It requires sophisticated analysis and access to data beyond more traditional asset management methods.

> Finding the likelihood of failure starts with assessing physical condition. Assets with more defects are more likely to fail sooner.

The City of Portland manages more than $35 billion of assets and is developing similar risk-aware approaches for other assets such as pump stations. Portland will continue to invest in robust asset management approaches to maximize investments in repairing and maintaining city infrastructure.

Risk-aware infrastructure investment strategies take time and data to inform. The payoff comes with putting each dollar to work on the highest risk asset first, which ultimately provides better services to the public at a lower lifecycle cost. ▮

Notes

1. The Asset Systems Management division in BES, which includes engineers Joe Hoffman and Issac Gardner, has pioneered the development of Portland's sophisticated in-house tools used for analyzing and planning sewer rehabilitation work. Portland spends $30 million to $50 million per year on collections system rehabilitation through its Large Scale Sewer Rehabilitation Program.
2. *In The Failure of Risk Management*, author Doug Hubbard defines risk as the probability and magnitude of a loss, disaster, or other undesirable event. See Douglas W. Hubbard, *The Failure of Risk Management: Why It's Broken and How to Fix It* (John Wiley and Sons, 2009).
3. This system is derived from the National Association of Sewer Service Companies.

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