Innovative Methods to Assess Water Main Risk and Improve Replacement Planning Decisions

Celine Hyer

Infrastructure management has been identified as a national issue due to the current lack of planning and funding for future renewal and replacements to maintain system reliability. The extremely large funding needs and poor infrastructure conditions across the United States have been documented over the last 10 years in various publications from the American Society of Civil Engineering (ASCE), American Water Works Association (AWWA), and U.S. Environmental Protection Agency (EPA). Current needs are estimated in the 2012 AWWA report, "Buried No Longer: Confronting America's Water Infrastructure Challenge," at more than $1 trillion over the next 25 years for water and wastewater systems.

The overall age of infrastructure continues to increase; however, in most areas additional funds are not being applied toward renewal and replacement (R&R), and reactive work is most common. This is generally due to the poor economy, as well as the lack of asset data available to make effective decisions and manage risk.

Implementing a risk assessment framework can assist utilities in identifying and mitigating risk, and determining where to apply their limited funds to achieve the most risk reduction. A complete risk framework includes the elements of the probability of failure, or the asset condition, and the consequence of failure, or the asset criticality to the system in terms of financial, social, and environmental impacts. Risk can also be expressed by this simple equation:

*Asset Risk = Probability of Failure (Condition) * Consequence of Failure*

Methodologies for Assessing Condition and Risk

One of the main challenges for calculating buried infrastructure risk is that it is very costly and time consuming to inspect these assets; in addition, some condition assessment techniques do not provide any standardized scoring or specific data on remaining asset life. A piping system with gravity sewer pipes is the easiest system to address since cameras can easily be used for inspections while pipes remain in service. There is also a standardized Pipeline Assessment and Certification Program (PACP) scoring that can be assigned for condition ratings that also relates to remaining life expectancies. The most difficult piping system to address has pressure mains, since these pipes typically cannot be taken out of service, the condition assessment technologies available are still evolving, there is no standardized condition scoring, and costs are still high (but becoming more reasonable).

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Figure 1 illustrates a replacement planning process that can be used by any utility for pressure mains to calculate overall asset risk. Condition scoring is based on a combination of analysis of existing failure or condition data, targeted additional field condition assessment to fill the data gaps and validate modeling, and the use of forecasting models to identify the future condition for each pipe segment. A tool based in a geographic information system (GIS) is then utilized to assign the consequence of failure and condition decay curves for each pipe and calculate a risk score. Unit costs for R&R methodologies assigned to pipes allow for financial forecasting. The benefit of this approach is that the right projects can be selected to be completed first for the least amount of inspection costs, and an overall view of future funding needs can be evaluated.

The models in Step 4 of the replacement planning process include the Linear Extended Yule Process (LEYP) and GompitZ. These models come from Europe and have been applied to pipes and other long-lasting infrastructure such as roads and bridges, and are just now starting to be applied in the U.S.

The LEYP is a failure forecasting model and is the model of choice for pipes that are not inspected and have only failure records—typically, water distribution mains. It predicts breaks for each pipe and each year in the future. It is a multivariable regression model (taking into account all variables at once and avoiding redundancy) of a survival nature; this means that it can take into account the history of the pipes that have been removed, a feature that is typically overlooked in classic statistics that focus on the active population, but can play an important role in predictions.

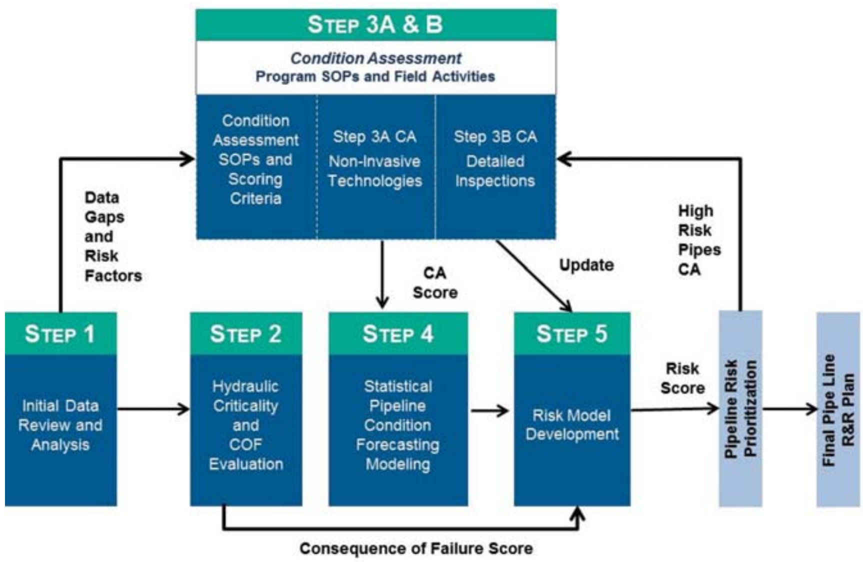
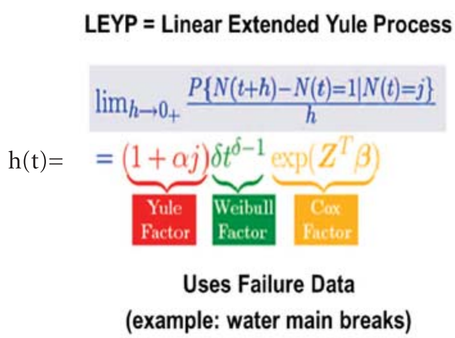


Figure 1. Optimized Replacement Planning Approach

The variables considered are typically:

- Time (Weibul component of the model)
- Physical characteristics, including period and quality of installation, material, diameter, and eventually pressure (Cox Proportional Hazard Model component)
- Environmental characteristics, if available, such as soil, traffic, and density (Cox)
- Previous breaks; Five-year minimum (Yule)

The instantaneous risk in function of time, h(t), is expressed as follows.



Two input files are needed to run the model:

- Pipes and their attributes, which comes typically from the pipe GIS
- Breaks; they must be assigned to pipes

The output results are the predicted break number (PBN), rate (per pipe, per year), and pipe-effective useful life by pipe class.

The GompitZ is a physical condition forecasting model and is the model of choice for inspected pipes for which the state of physical condition can be measured and given a certain score, such as applying it to gravity sewers or large-diameter water or force mains. It allows for prediction of the physical condition for each pipe and each year in the future based solely on inspection results of a small percent of the network. For GompitZ, inspection could also have been produced at one single year (if enough pipes have been inspected). The framework of the GompitZ model is a Markov chain. It is assumed that the probabilities of jumping from one physical condition state to the next can be calculated and organized in matrices. Then, following a nonhomogeneous Markov chain procedure (nonhomogeneous means that scores depend on time), the states and scores at a future time can be produced.

The Markov chain probabilities can be computed using simple statistics or more elaborate ones, such as the Gompertz model (a form of regression used for data for which results are available solely for a portion of the population where one measurement suffices as the regression draws inferences from the variables of all the pipes inspected at once). The GompitZ approach is the combination of a Gompertz regression and a Markov chain.

The variables considered in the model are:

- Time
- Physical characteristics, including period and quality of installation, material, diameter, and eventually depth
- Environmental characteristics, if available and relevant, such as soil, traffic, and density
- Inspections results; with at least 10 percent of the population, one inspection is enough

Two input files are needed:

- Pipes and their attributes, which comes typically from the pipe GIS
- Inspection results assigned to the pipe

The output results are for each pipe and for each year. Computed for all the pipes in a cohort, or for the overall system, the results show the percent of length (or the probability to be) in a certain state at a certain year.

Condition assessment techniques and technologies are advancing quickly and there are several free EPA publications that provide a good overview of what is available, as well as several Water Environment Research Foundation (WERF) reports that are available to subscribers. In general, the methodologies can be classified as internal and external, with some of the internal methods requiring pipe shutdowns, and some that have free swimming devices that can be inserted into a live pipe. Table 1 summarizes the current technologies by the most common water pipe materials and the project experience of ARCADIS in applying these tools.

In applying these technologies, the approach typically taken is to use the least-cost screening methods first, and then the detailed, more-costly ones if poor-condition areas are detected. The case studies presented for the Columbus Department of Public Utilities (DPU) in Ohio and Lee County Utilities (LCU) in Florida both utilized this overall approach. Columbus has also recently incorporated the LEYP model into its water distribution main replacement planning and has revised its risk scores and financial projections, which actually were less than originally anticipated.

Replacement Planning Case Study: Columbus Department of Public Utilities

Columbus DPU began its water distribution main replacement planning as part of an overall water master plan in 2009 and updated this plan in 2014 utilizing the LEYP model to provide the condition scores for the pipes.

The key objectives of this project were as follows:

- Define the desired service levels for water pipes in terms of breaks per 100 mi per year.
- Assign a replacement methodology and cost for each pipe.
- Assign a condition score to each so that a risk score could be calculated.
- Define the near-term projects that may be included in the five-year capital improvement program (CIP) based on risk.
- Evaluate the future funding scenarios needed to maintain the level of service.
- Validate the risk model using limited acoustic wall integrity testing.
- Validate the accuracy of the acoustic testing by laboratory analysis.

As shown in the replacement planning process model, a risk score was calculated for each pipe using a triple-bottom-line consequence of failure analysis and condition scores were initially created by performing a basic statistical analysis on the past 25 years of break

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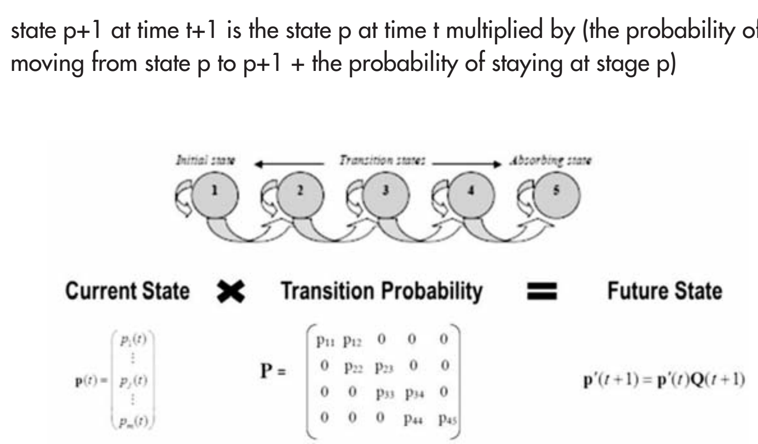

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data. Pipe decay curves were generated based on an established service level of 20 breaks per 100 mi per year, which represented the pipe's end of life. Once the risk scores were established and the high-risk areas were identified, a pilot area was chosen to perform external acoustical wall integrity testing for Echologics. This testing is accomplished by placing two microphones on two consecutive valves, introducing a noise by opening a hydrant or valve, and measuring the time it takes to travel between those points. Through advanced math, the pipe hoop stiffness or wall integrity can be calculated and compared with the original material to provide an average wall loss over that pipe section. The testing of DPU's predicted poor-condition pipes confirmed that there was significant wall loss of 40-50 percent in the cast-iron pipe, meaning it was in poor condition. Since DPU was unfamiliar with this type of testing, it took it one step further and collected pipe coupons to send out for laboratory analysis along the same pipelines in multiple locations. The laboratory testing confirmed in 85 percent of the areas that the pipe had corrosion and wall loss similar to what the acoustical testing determined.

The deliverables for the project included the identification of risk maps (Figure 2) and an optimized funding scenario (Figure 3) for long term R&R needs. In addition, the GIS replacement planning tool was provided to DPU, along with training so that it can be used for planning purposes to create the CIP each year. The 2014 project revised this tool to include the results from the LEYP modeling and provided the LEYP model and training for DPU staff so that it can also be updated annually during the CIP planning process.

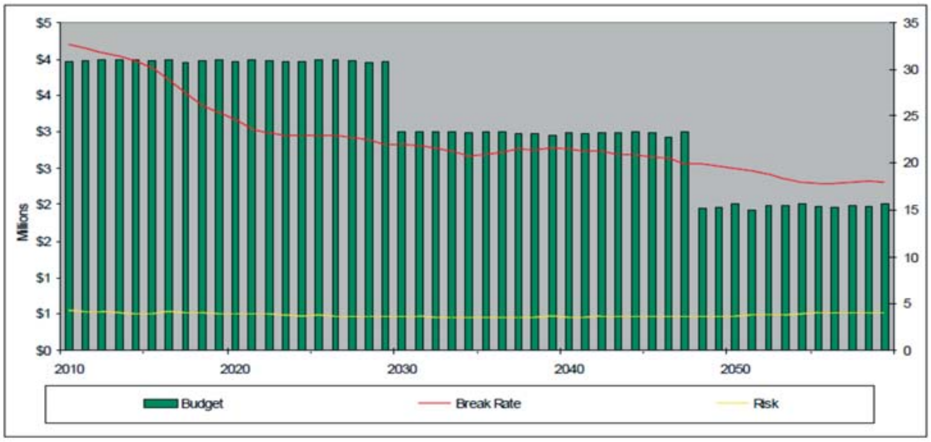

Figure 2. Risk Map Identifying Areas for Field Inspection and Projects

Condition Assessment Technology	Pipe Material	Type of Tool (Screening or Detailed)	External or Internal	Pipe Stays in Service
Echologics Acoustical Wall Integrity Testing	cast-iron, ductile-iron, asbestos-cement, PCCP (in testing), steel	Screening – provides average wall integrity between test points	External	Yes
Echologics Magnetic Flux Leakage (MFL)	cast-iron, steel	Detailed - corrosion damage and wall thickness for a 3 to 4 foot section	External	Yes
Rock Solid Broadband Electromagnetic (BEM)	cast-iron, ductile-iron, steel	Detailed – exact wall thickness for a 3 to 4 foot section	External	Yes
Condition Assessment Technology	**Pipe Material**	**Type of Tool (Screening or Detailed)**	**External or Internal**	**Pipe Stays in Service**
Ultrasonic Wall Thickness	cast-iron, ductile-iron, steel	Detailed – exact wall thickness in small area.	External	Yes – external coatings need to be removed
Pure Technologies Smart Ball	cast-iron, ductile-iron, steel, asbestos-cement	Screening – detects leaks only	Internal free swimming	Yes
Pure Technologies – Sahara	cast-iron, ductile-iron, steel cylinder, asbestos-cement	Screening – detects, leaks, gas pockets and bends	Internal tethered – multiple insertions required	Yes
Pure Technologies – Pipe Diver	cast-iron, ductile-iron, steel, PCCP	Detailed - corrosion and large anomalies or wire breaks	Internal Free Swimming	No for most situations
Pure Technologies – Magnetic Flux Leakage	ductile-iron, steel	Detailed – corrosion damage and wall thickness	Internal	No for most situations
Pure Technologies Remote Field Eddy Current Testing	PCCP	Screening – detects wire breaks	Internal	No for larger diameters
Pica Corp See Snake	cast-iron, ductile-iron, steel	Detailed – corrosion damage and wall thickness	Internal Free Swimming	No for most situations

Table 1. Water Main Condition Assessment Methods

Replacement Planning Case Study: Lee County Utilities

Lee County Utilities completed its water main replacement planning project as part of an overall asset management program implementation during 2011.

The key objectives of this project were as follows:

- Define the desired service levels for water pipes in terms of breaks per 100 mi per year.
- Assign a replacement methodology and cost for each pipe.
- Refine the current useful life table for each pipe material/group.
- Assign a condition score to each pipe so that a risk score could be calculated.
- Define the near-term projects that may be included in the five-year CIP based on risk.
- Evaluate the future funding scenarios needed to maintain the level of service.
- Identify high-risk areas for future field condition assessments.

As shown in the replacement planning process model, a risk score was calculated for each pipe using a triple-bottom-line consequence of failure analysis and condition scores created by performing a basic statistical analy-

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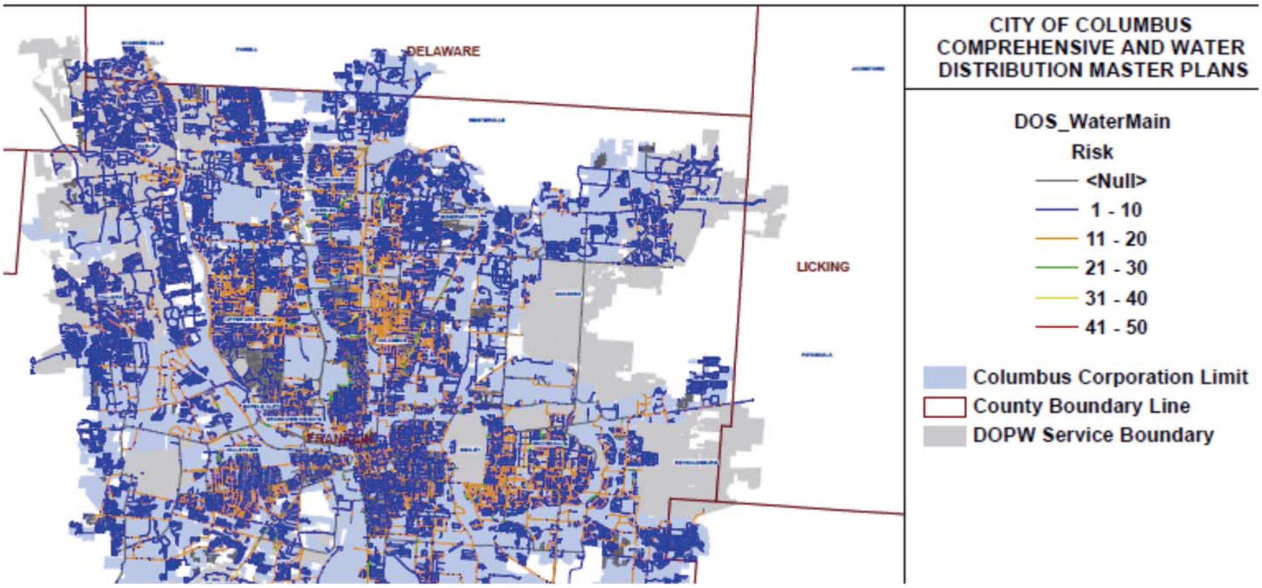

Figure 3. Optimized Funding Scenario Showing a Decrease in Funds to Maintain Service Levels

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sis on the past nine years of break data. For pipe classes with no data, industry standard effective useful life was applied. Pipe decay curves were generated based on an established service level of 20 breaks per 100 mi per year, which represented the end of life. This process was performed strictly as a desktop assessment using GIS, so there was no field condition assessment associated with validating the risk scoring and project selections. However, through workshops with knowledgeable staff, the high-risk poor-condition areas seemed to match up with their assumptions. A future phase of the project will include select condition assessments to further validate the projects and funding projections, beginning with lower-cost screening tools, such as acoustical wall integrity testing from Echologics.

The deliverables for the project included the identification of risk maps (Figure 4) and an optimized funding scenario (Figure 5) for long term R&R needs. In addition, the GIS replacement planning tool was provided to LCU along with training so that it can be used for planning purposes to create the CIP each year.

Conclusions

Other utilities can easily adopt this type of a risk methodology for their R&R planning and apply new techniques to assess buried pressure pipe asset conditions to ease the burden of deciding where to apply their limited funds to get the best risk reduction and maintain their service levels. Leveraging existing GIS and work-order data provides the basis to start this process and can later evolve into using advanced modeling, such as LEYP or GompitZ, and targeted field condition assessments to refine the initial results.

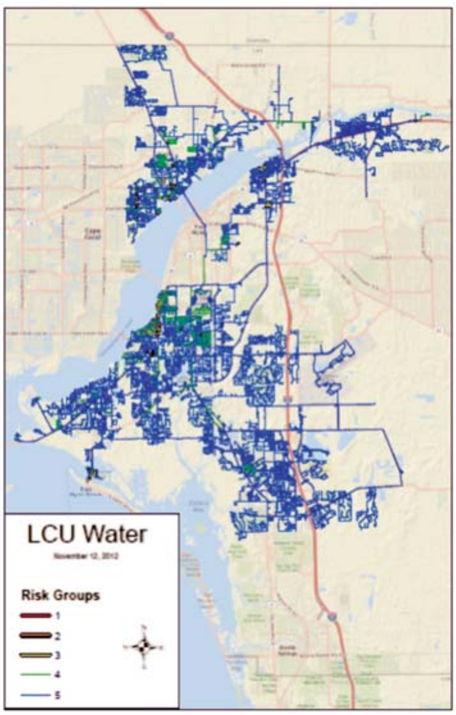

Figure 4. Risk Map Showing Areas for Future Field Inspections

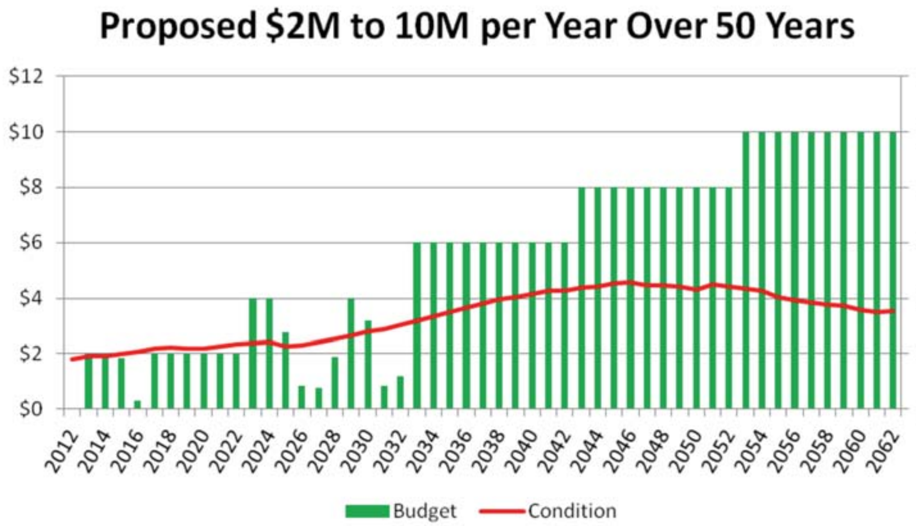

Figure 5. Optimized Funding Scenario Ramping Up Over Time to Maintain Service Levels