Risk-Based Asset Prioritization of Water Transmission/Distribution Pipes for the City of Tampa

Seung Park, Ramiro Vega, Zororai Choto, and Matthew Grewe

The city of Tampa Water Department (TWD) provides potable water service to over 600,000 customers via almost 11 million feet of transmission and distribution piping. Water and wastewater utilities that were constructed mostly during the mid 1900s, such as the TWD's system, are currently in the process of repairing and replacing pipes nearing their end of useful life.

To assist with the ranking of its repair and replacement program, TWD water transmission and distribution infrastructure was assessed using a geographical information system (GIS) risk-based asset management approach to identify critical assets as part of its water master plan. Asset inventories were assembled and a risk ranking system was developed and applied to each asset. The risk ranking system included likelihood of failure and consequence of failure, combined to estimate a risk score for each asset.

A number of physical, technical, and institutional factors were considered in developing risk scores for each asset and prioritizing repair and replacement needs. The level of detail and the reliability of data provided for each asset significantly affect the weighting and importance of each factor. GIS was utilized to assign scores to each asset accurately and efficiently, so availability of GIS data influenced scoring and weighting values.

This article describes the physical, technical, and institutional factors that were considered in developing the likelihood of failure, the consequence of failure scores, and ultimately, the overall risk score for each asset for the TWD. The detailed description of how these factors were combined and weighted will be beneficial to other utilities considering a similar program.

A GIS risk-based asset management approach provides an accurate, efficient way to assign risk scores to each asset. The level of detail and the reliability of GIS data for each asset can affect the weighting of each risk scoring factor significantly. This article will discuss the method used and factors considered in developing risk scores for each water transmission/distribution pipe within the Department's system, along with the detail and reliability of GIS data on the resulting risk scores.

Utilities are constantly in the process of repairing and replacing old and deteriorated pipe in order to prevent failures and address water-quality issues within the system. Asset risk scoring is a widely recognized way for a utility to prioritize risk and replacement needs—particularly important for utilities with limited repair and replacement budgets.

Risk is defined as a combination of the likelihood of failure and the consequence of failure (Ispass, 2008). Likelihood of failure is comprised of physical condition, historical failures, and capacity/performance (Ispass, 2008).

Physical condition is an estimation of the asset integrity and is employed to identify assets that could cause potential unexpected maintenance or service issues in the near future. Contributing factors of physical condition include pipe age, material and in the case of cast iron pipe, whether the pipe is lined or unlined.

Consequence of failure is a measure of the impact on the community and customers of the potable water system should physical failure of a component occur. The consequence of failure is determined based on a number of institutional factors, including public health, safety, security, and level of service (Ispass, 2008).

The GIS risk-based asset management approach combines the likelihood and consequence to develop an overall risk score (likelihood x consequence = risk). Resulting risk scores are divided into repair and replacement priority categories using a risk score matrix. Risk scores and priorities then can be assigned easily to GIS pipes and illustrated in maps, as needed.

Risk-based asset prioritization is an effective and proactive way utilities can use to manage pipe repair and replacement programs (Shaikh, 2010). By prioritizing system repair and replacement needs based on risk, a utility can avoid major service disruptions, damage to assets, public health and safety threats, and liability and remediation costs (Shaikh, 2010); therefore, a risk-based management approach for pipe repair and replacement is particularly beneficial to utilities on a limited budget.

Seung Yi Park, P.E., is the chief planning engineer for the Tampa Water Department. Ramiro Vega is a planning engineer for the Department. Zororai Choto, I.E., and Matthew Grewe are project engineers with the Winter Springs, Florida, office of Reiss Engineering Inc. This article was presented as a technical paper at the 2010 Florida Water Resources Conference.

Project Goals

Utilities are facing the challenge of expanding and maintaining their potable water supply, treatment, and transmission infrastructure to continue a high standard of service to their customers. Challenges that include aging pipes and equipment, new development and redevelopment, more stringent water-quality regulations, and rising labor and material costs must be addressed when allocation of available funding is prioritized.

To help meet these challenges, the TWD elected to complete a risk-based asset management project with the following goals: 1) prioritizing water system asset repair and replacement and 2) developing a comprehensive strategy for maintenance of existing infrastructure in order to update the Department's six-year capital improvement plan (CIP).

Risk-Based Approach

Risk-based asset prioritization is gaining momentum as a tool to manage assets comprehensively. Utility managers must manage the reliability of their assets without compromising risk to public and environmental health (Pollard, 2008). The TWD determined that a risk-based asset prioritization was suitable for its potable water system needs.

The risk-based asset prioritization approach included an asset risk matrix to group assets into priority groups. Asset inventories were assembled and a ranking system was applied to combine the likelihood and consequence of failure (likelihood x consequence =

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Table 1. Likelihood of Failure Scoring Basis

Category	Basis	Weighting	Likelihood of Failure Scoring				
			Low Probability →				High Probability
			1	2	3	4	5
Physical Condition	(Pipes) Pipe age, material and lining	40%	DIP	PVC or PCCP or HDPE	Unknown or >6" Lined CI	>6" Unlined CI	AC or <6" CI or GS
	(Treatment, Storage, Pumping) Condition		> 75% life remaining	50-75 % life remaining	25-50 % life remaining	0-10 % life remaining	<10 % life remaining
Historical Failures	Pipe breaks	20%	No breaks	–	1 break	–	2 or more breaks
Capacity/Performance	Hydraulic model output vs. capacity including fire flow	40%	Meets TWD Manual Sizing Requirements	–	–	–	Fails TWD Manual Sizing Requirements

AC = Asbestos Cement
CI = Cast Iron
DI = Ductile Iron
GS = Galvanized Steel
HDPE = High Density Polyethylene
PCCP = Prestressed Concrete Cylinder Pipe
PVC = Polyvinyl Chloride
Unknown = Pipe material not designated in TWD GIS map
Life remaining= remaining useful life

Table 2. Consequence of Failure Scoring Basis

Category	Basis	Weighting	Consequence of Failure Scoring				
			No Impact		Moderate Impact		Severe Impact
			1	–	3	–	5
Public Health, Safety, Security, Service	Key facilities, facility location, pipe size	40%	No illness, or loss of service	–	<1 day loss of service, boil water notice	–	Illness, injury, > 1 day loss of service
Financial Impact	Facility/pipe size	20%	Included in Budget	–	Fundable by re-prioritization	–	Requires Rate Increase
Regulatory Compliance	Compliance	20%	Compliant	–	–	–	Non-Compliant
Redundancy/Vulnerability	Backup facilities	20%	Full backup facilities		Emergency backup facilities		No backup facilities

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risk) for key TWD assets. Assets were prioritized on risk scores and reduction in risk score per unit cost. Useful life and remaining life were estimated where data was available to help generate repair and replacement (R&R) schedules. This asset management approach used GIS and graphical prioritization tools so that Department staff can maintain infrastructure prioritization.

The components of the risk-based asset prioritization approach included:

- Likelihood of failure
- Consequence of failure
- Risk-based priority matrix
- Asset prioritization
- Repair and replacement unit costs
- Repair and replacement scheduling

Asset Inventory

Risk-based asset prioritization analyses require the collection and processing of various sets of data. A more complete asset inventory is the key to reaching prioritization project goals. More detailed information provides for more detailed assessment results.

Detailed TWD water system information and data were collected for use in the risk-based asset prioritization program. Transmission and distribution pipe data collected included pipe condition (age, material and lining), pipe sizes, pipe locations, and historical pipe breaks. These pipe data were available in GIS format.

Other information required for the prioritization project included pipe sizing requirements, system demands and service area land use, state and federal compliance regulations, and TWD technical standards. A water hydraulic model and GIS software were used as an analysis tool to simulate varying system conditions in order to prioritize R&R projects. GIS software was also used as a tool to assign calculated pipe scores to the system pipes for prioritization.

Some asset data and system information were not available at the time of the analysis. The GIS pipe data did not contain all the pipe materials or age. Currently the TWD is updating this information in its utility services GIS database. The risk-based asset prioritization was conducted without the use of this data; instead, reasonable assumptions and engineering judgments were made.

Likelihood of Failure Scoring Components

Contributing components to likelihood of failure for the TWD risk-based asset water transmission/distribution prioritization analysis were grouped into physical condition, historical failures, and capacity/performance categories. A weighting factor was assigned to each category to generate a total likelihood of failure score, as shown in Table 1.

Transmission and distribution pipes physical conditions were assigned a score ranging from 1 to 5, as indicated in Table 1. Transmission and distribution pipes' physical conditions were derived from interviews with TWD distribution and engineering staff and from engineering judgment. Pipes' physical condition focused on pipe material, age, and the number of breaks.

Asbestos cement was a pipe material in the system that received high priority from the TWD staff, along with unlined cast iron pipe. Undersized lined cast iron pipes and lined cast iron pipes with frequent joint failures were also of great concern. Asset age rankings were considered, but since the city's GIS pipe shapefile (July 2008) did not have installation dates for the majority of the water mains, it was not one of the major component in the evaluation process. Remote pump station and storage tank condition rankings were based on estimated remaining service life.

An analysis of historical breaks over the last three years in the TWD distribution system was performed to help validate the condition ranking. The analysis indicated that most of the breaks occurred on 2" and 2¼" diameter pipes, and on galvanized steel, cast iron pipe and asbestos cement pipes, as shown in Figures 1 and 2, so these pipes were given a higher likelihood of failure score.

A review of the data indicated that 2" and 2¼" pipe breaks were co-mingled, so 2", 2¼", and 2½" pipe were grouped into the 2" pipe group. Likewise, ¾", 1", 1¼", and 1½" pipe were grouped into 1" pipe group. For the historical failure category, GIS was used to assign historical break data and risk scores to pipes as defined in Table 1. The historical break data received a lower weighting because of site-specific issues and some inconsistencies in the data regarding type of break, such as physical failure or accidental break.

A capacity assessment was performed for existing potable water infrastructure to rank the state of performance or capacity. TWD mains were assessed by comparing performance criteria with calculated hydraulic model results. The performance criteria are shown in Table 3. Production and treatment facilities were assessed in the DLT Water Treatment Facility Expansion Evaluation Report (HDR, 2008).

Table 3. Tampa Water Department Hydraulic Design Guidelines

Flow Condition	Transmission Mains				Distribution Mains			
	Minimum System Pressure (psi)	Maximum Pipeline Velocity [1] (fps)	Minimum Residual Pressure (psi)	Minimum Fire Flow [2] (gpm)	Minimum System Pressure (psi)	Maximum Pipeline Velocity [1] (fps)	Minimum Residual Pressure (psi)	Minimum Fire Flow [2] (gpm)
ADF	60	5	—	—	45	5	—	—
PHF	50	5	—	—	40	5	—	—
Transmission Main Fire Flow Conditions	—	—	35	4,000	—	—	—	—
Commercial Fire Flow Conditions	—	—	—	—	—	—	25	3,000
Residential Fire Flow Conditions	—	—	—	—	—	—	25	1,000

[1]All other system related velocities must not exceed 10 fps except in the case of fire flow.

[2]All fire flow evaluations must be performed using maximum daily flows.

Consequence of Failure Scoring Components

A consequence of failure ranking was applied to key potable water infrastructure assets to identify critical assets whose service outage would result in critical consequences. The following category groups of consequence of fail-

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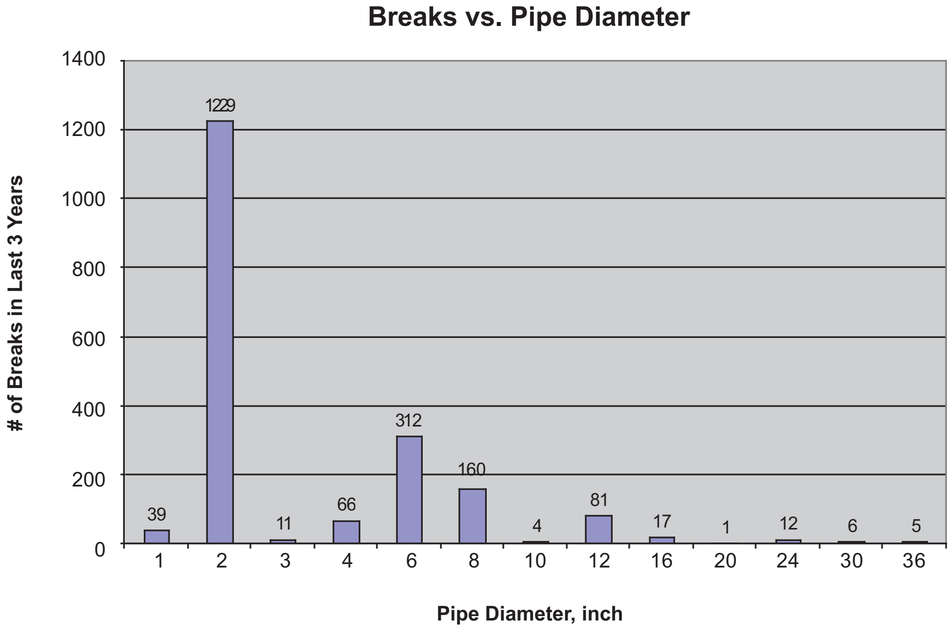

Figure 1. Historical Pipe Breaks vs. Pipe Diameter

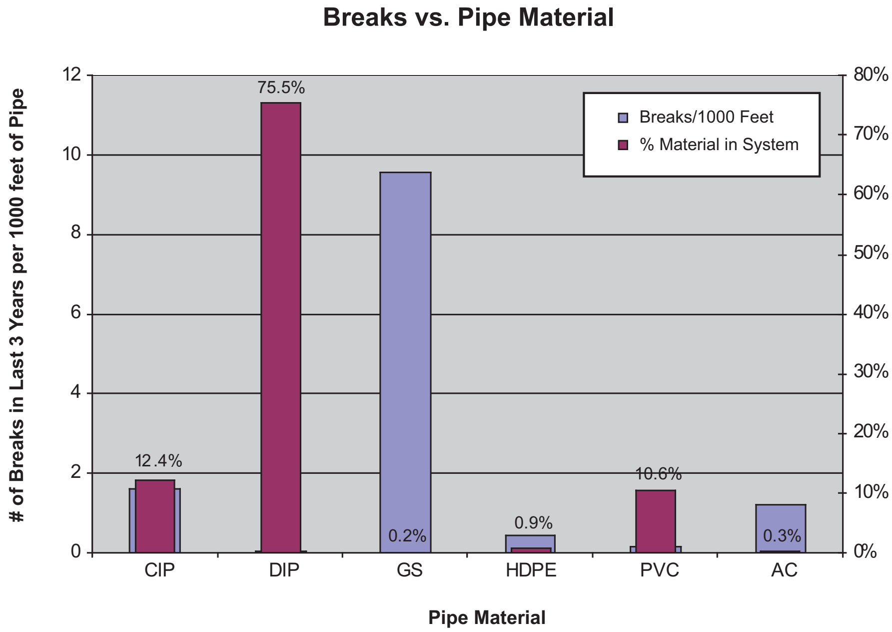

Figure 2. Historical Pipe Breaks vs. Pipe Material

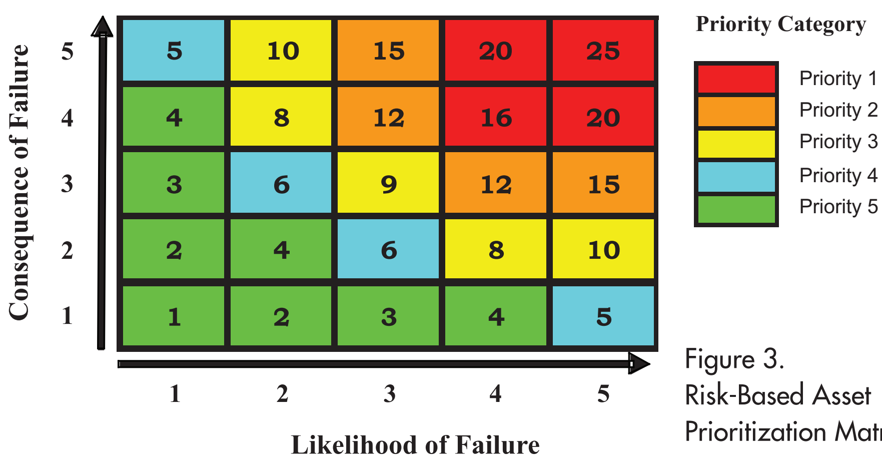

Figure 3. Risk-Based Asset Prioritization Matrix

ure were used for this assessment with percent weightings indicated:

- Public Health, Safety, Security, Service (40 percent weighting)
- Financial Impact (20 percent weighting)
- Regulatory Compliance (20 percent weighting)
- Redundancy/Vulnerability (20 percent weighting)

Consequence of failure for each asset was assigned a score ranging from 1 to 5 for each consequence of failure category group, as shown previously in Table 2. Public health, safety, security, and service category scoring was based on potential length of service loss, and illness or injury.

Key factors in the public health category included proximity to major roadways, parcels, water, hospitals, military bases, major high-rise buildings, emergency facilities, and pipe or equipment size. Failure near major roadways would cause significant damage and transportation issues.

Financial impact was based on the relative size of the component and whether repair/replacement cost could be covered within the existing budget, required City Council approval, or required a rate increase. Regulatory compliance was based on compliance or non-compliance, and redundancy/vulnerability scoring was based on the provision for reliability such as availability of backup facilities, including looped piping or a spare piece of equipment.

Risk Calculation & Prioritization

Likelihood and consequence of failure rankings were combined into a matrix to apportion assets into risk-based R&R categories. The resulting risk scores and priority categories are shown in the risk matrix in Figure 3. Priority categories were established based on the theoretical matrix as follows, noting that these priority categories can be adjusted based on the actual frequency distribution of assets in the prioritization schedule to follow:

- Priority 5: Asset ranking score of "4" or less (best condition and lowest risk)
- Priority 4: Asset ranking score of "5 to 6"
- Priority 3: Asset ranking score of "8 to 10"
- Priority 2: Asset ranking score of "12 to 15"
- Priority 1: Asset ranking score of "16 and 25" (worst condition and highest risk)

Results

Risk-Based Approach

A risk-based approach was developed to assess and prioritize the TWD's transmission and distribution pipe repair and replacement

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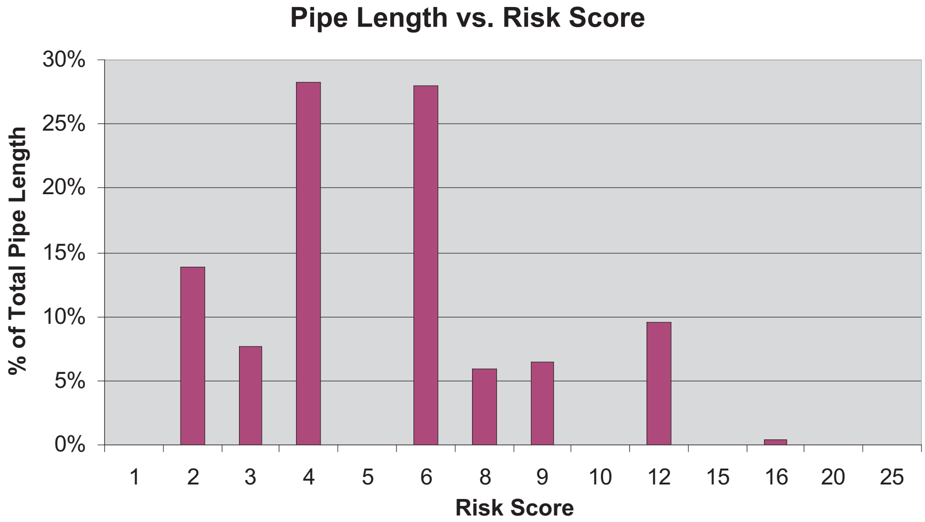

Figure 4. Distribution Frequency of Risk Scores

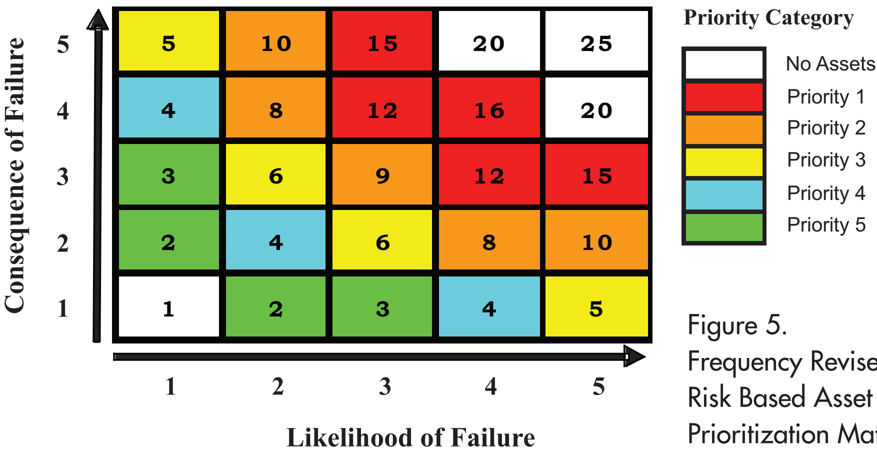

Figure 5. Frequency Revised Risk Based Asset Prioritization Matrix

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needs. This approach was customized to meet the TWD's needs based on the available data.

Scoring Components vs. Data Availability

The risk-based asset management assessment was based on the best available information at the time of the assessment.

Scoring components for likelihood of failure include pipes' physical condition, historical failures, and capacity/performance. Pipe material was used as a scoring component for pipe condition. In some cases the pipe material was unknown. The TWD currently is updating the pipe material information in the GIS database.

Pipe-age data was not available at the time of the analysis, so for this analysis, pipe age was not considered as a contributing factor in the risk scoring. Historical pipe breaks, which were available in GIS format, were also used as scoring components for likelihood of failure.

A hydraulic model was used to simulate system operations based on available system asset information (including treatment facilities, storage tanks and booster stations). Pipe capacity output from the hydraulic model simulation was compared to the TWD's sizing requirements to determine those pipes that met the sizing requirements and those that did not.

Scoring components for consequence of failure included public health, safety, security and service, financial impact of pipe failure, regulatory compliance, and redundancy. Data was available on key institution locations and TWD water system customer water demands. Key institutions included hospitals, schools, and commercial buildings.

Pipe location and sizes were available in GIS format and were used during risk scoring. The cost to repair or replace a broken pipe was also considered in risk scoring. Regulatory requirements were available and were used in the consequence of failure analysis.

The TWD hydraulic model included over 21,000 pipes. The Department was able to process hydraulic model output and populate the pipes with GIS scores, automatically, enabling the TWD to perform the risk-based prioritization analysis efficiently.

Risk Scores & Prioritization Grouping

The likelihood and consequence of failure scores were assigned and combined to estimate a risk score for each pipe. The resulting risk score frequency distribution is shown in Figure 4.

With the scoring criteria used, it is inherently unlikely for a pipeline to get 20 to 25 risk scores, so the R&R prioritization categories were re-formulated based on the frequency occurrence of risk scores, as shown in Figure 5. The revised prioritization assigned risk scores of 12 to 16 as Priority 1 and risk scores of 8 to 10 as Priority 2.

Conclusion

Risk-based asset prioritization provides a sound base for utilities to manage assets for R&R projects efficiently and proactively. This is particularly beneficial to utilities on limited budgets. GIS is a powerful tool that can be used to expedite risk-based asset prioritization projects. A hydraulic model is also a powerful tool that can be used in combination with GIS to accelerate a risk-based asset prioritization project.

This article offers a real-world example of how a utility can use a risk-based asset management program to prioritize system R&R. This effort was based on the best available information at the time of the analysis. Using a GIS risk-based asset management approach, the TWD was able to assess the condition of its transmission and distribution pipes, assign risk scores, and ultimately prioritize its R&R.

While a risk-based prioritization analysis is used to establish a baseline tool, it should not be the only decision-making tool in a utility's R&R plan. Other factors that may influence a utility's repair and replacement program include engineering judgment, staff and field crew knowledge, cost factors such as R&R costs, and improvement plan schedules/timelines. As with all asset management efforts, the process is iterative and should be re-evaluated as more data is collected.

References

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