Improved Pipeline Renewal Planning Using Advanced Risk Assessment Practices

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Conveyance Market Sector Leader

Imagine the result
Discussion Agenda

• Overview of the Current State of Aging Infrastructure
• Evolution of Asset Management Standards and Best Practices
• Risk Based Replacement Planning Approaches and Methods
• Case Studies:
  • Dallas Large Interceptor Replacement Planning Program
  • New York City Pipeline Risk and Replacement Program
• Questions/Discussion
Water Infrastructure Grades

Independent Engineering Organizations Issued the Following Grades…

2010

Water: B-

Sewer: B-

Storm: C

2012

Water: Good

Sewer: Good

Storm: Very Good

2014

Water: B

Sewer: B

Storm: B

2013

Water: D+

Sewer: D+

Storm: D+
Aging Pipe Infrastructure Requires Innovative Solutions

- Water and sewer network infrastructure requires significant investments
- Water utilities realize the need to prioritize their capital investment programs to target spending of their limited funds

**US DRINKING WATER**
Estimated pipe replacement cost > $1 Trillion

**US WASTE & STORM WATER**
Estimated capital investment for waste and stormwater networks ~ $225 Billion
Timeline of Global Asset Management Standards and Practices for Pipe Networks

- **2004**
  - Predictive Modeling developed by Kanew, LEYP, others

- **2006**
  - British Standard PAS 55-1

- **2008**
  - IMM International Infrastructure Management Manual
  - USEPA Effective Utility Management

- **2011**
  - IMM International Infrastructure Management Manual Update

- **2012**
  - Predictive Modeling applied to US utilities

- **2014**
  - ISO 55000 International Standards Organization

- **2015**
  - IMM International Infrastructure Management Manual Planned

- **2016**
  - PAS 55 To be Withdrawn

ISO 55000 New Asset Management Standard

Three Documents

1. **ISO 55000** provides an overview of asset management and std. terms and definitions.

2. **ISO 55001** provides the Requirements for an Integrated, Effective Management System for Asset Management.

3. **ISO 55002** provides general guidance for the implementation of such a system.
## ISO 55000- 7 Asset Management System Requirements

<table>
<thead>
<tr>
<th>Category</th>
<th>Requirements</th>
</tr>
</thead>
</table>
| **Context of Organization**     | • Stakeholder needs/expectation  
                                  | • Goals and objectives                                                      |
| **Leadership**                  | • Roles and responsibilities  
                                  | • AM Policy                                                                 |
| **Planning**                    | • Risk assessment  
                                  | • Asset Management Plans (capital & O&M)                                   |
| **Support**                     | • IT systems& data  
                                  | • Training, communications and documentation                                |
| **Operation**                   | • SOP’s  
                                  | • Change management and outsourcing                                         |
| **Performance Evaluation**      | • Performance measures and tracking  
                                  | • Program audits (internal or external)                                     |
| **Improvement**                 | • Process for implementing corrective actions  
                                  | • Preventative and predictive actions                                       |
ISO 55000 Does Not Provide Examples and Methodologies for Implementation

International Infrastructure Management Manual 2011

- AM Policy Levels of Service Examples
- Roles & Responsibilities
- Asset Hierarchy & Attributes
- Condition Scoring
- Criticality & Risk Scoring
- O&M strategies
- Capital Strategies
- Funding Strategies
- Asset Mgmt Plans
- IT Tools
What is the Value of Using Asset Management Standards?

- ISO implementation can help with organizational change since there are prescriptive things that need to be accomplished
- ISO certification can help with bond ratings and funding opportunities
- IIMM provides case studies to support actual implementation
Risk Based Replacement Planning is Key to Successfully “Doing More With Less”

Risk is a Simple Equation:
Risk = Probability * Consequence
Consequence of Failure: Evaluate by Triple Bottom Line (TBL) Analysis
Triple Bottom Line Evaluation For Consequence of Failure Using GIS for Pipes

<table>
<thead>
<tr>
<th>CUSTOMER CRITICALITY</th>
<th>Service to Customer Type</th>
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<tbody>
<tr>
<td>Score=5</td>
<td>Score=5</td>
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<tr>
<td>M</td>
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<table>
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<th>Adjacency to</th>
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</thead>
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<tr>
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<td>Adj. &amp; Dia.</td>
</tr>
<tr>
<td>Intersecting</td>
<td>20.762</td>
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<td>16</td>
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<tr>
<td>Water Bodies</td>
<td>Adj. &amp; Dia.</td>
</tr>
<tr>
<td>Intersecting</td>
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</tr>
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<td></td>
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</tr>
<tr>
<td>Interstates</td>
<td>Adj. &amp; Dia.</td>
</tr>
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<td>Intersecting</td>
<td>23.457</td>
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<tr>
<td></td>
<td>20</td>
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</tbody>
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<table>
<thead>
<tr>
<th>PIPE CRITICALITY By DIAMETER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>4</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>2</td>
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<tr>
<td>1</td>
</tr>
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</table>
Buried Pressure Pipes are the Greatest Challenge- cannot easily access and take out of service

Probability of Failure: Evaluate By Condition Assessment

Utility Assets

- Vertical
  - Plants
  - Pump Stations
- Linear
  - Gravity Mains
  - Pressure Mains

Condition Assessment Difficulty

- Low
- Moderate
- High
New Inspection Technologies Overcome Traditional Barriers

- Minimally or Non-Invasive
- Infrastructure stays in service
- Cost competitive for normal use
- R&D is increasing (Canada, UK, Australia)
Pressure Pipe Condition Assessment Methods - Internal and External tools

**External Water**
- Acoustic Leak and Wall Integrity - Echologics
- Magnetic Flux Leakage (MFL)
- Broadband Electromagnetic (BEM)

**Internal Water/Sewer**
- Acoustic Leak – Smart Ball, Sahara
- Smart Pigs – Pipe Diver, See Snake
- Manned Entry with MFL or BEM

**External Sewer**
- Acoustic Leak - Echologics
- Magnetic Flux Leakage (MFL)
- Broadband Electromagnetic (BEM)
Evolving Best Practices For Utility Renewal Planning

Program Efficiency

Condition Assessment

Validation & Risk-Based Planning

Predictive Models

Smart Data
Right Projects
Lowest Cost
Best Performance
Why Use Predictive Models?

Capital/Financial Planning
- Service Level Driven Process
- Determines Rate Affordability

Prioritization of CIP
- Defensible Projects
- Coordination with Others

Savings
- Less Inspection
- Full EUL of assets
Predictive Models – Three Examples for Different Purposes

**KANEW**

Water or Sewer Financial Forecast

**Linear Extended Yule Process**

\[
\lim_{h \to 0+} \frac{P\{N(t+h) - N(t) = 1 | N(t) = j\}}{h} = (1 + \alpha j) \delta t^{\delta - 1} \exp(Z^T \beta)
\]

Yule Factor, Weibull Factor, Cox Factor

**GompitZ = Markov Chain**

\[
Q(t) = \begin{pmatrix}
q_1 & 1-q_1 & 0 & \cdots & 0 \\
0 & q_2 & 1-q_2 & \cdots & 0 \\
0 & 0 & q_j & 1-q_j & \cdots \\
\vdots & \ddots & \ddots & \ddots & \ddots \\
0 & \cdots & 0 & q_{m-1} & 1-q_{m-1} \\
0 & \cdots & 0 & 0 & 1
\end{pmatrix}
\]

Water or Sewer Condition Data

Predicted Break Number (PBN) for every pipe and for each year

Predicted probability a Pipe will be at a given condition in any year
KANEW Model - Predicts Funding Needs Over Time by Pipe Cohorts

- Requires effective useful life by pipe cohort and cost
- Model contains probabilistic aging function
LEYP - Linear Extended Yule Process Failure Forecasting Model

Multi-Variable Regression Analysis for Failure Prediction

Predicted Break Number (PBN) for every pipe and for each year
GompitZ - Condition Prediction Forecasting Model

GompitZ Input Data Fields

- Install Date
- Material
- Diameter
- Inspection Date
- Condition Grade

GompitZ = Markov Chain

\[ Q(t) = \begin{pmatrix}
q_1 & 1-q_1 & 0 & \cdots & 0 \\
0 & q_2 & 1-q_2 & 0 & \cdots \\
0 & 0 & q_j & 1-q_j & 0 & \cdots \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & 0 & 0 & \cdots & q_{m-1} & 1-q_{m-1}
\end{pmatrix} \]

Probability a Pipe will be at a given condition in any year
GIS-based Asset Management Tools Optimize Infrastructure Replacement Planning

- Output from predictive condition models incorporated
- Calculate risk from condition and consequence for every pipe in each year
- Help selecting the right projects to match annual budget and service level goals
- Assist with grouping pipes to make logical projects
- Coordinate with other infrastructure projects (roads, etc.)
Case Study: Inspection and Implementation Prioritization for Dallas Large Sewer Interceptors

Challenge

- Create upgrade program for 250 miles of large interceptors never inspected

Approach

- Desktop risk assessment to prioritize inspection areas
- Tiered inspection tools to maximize money spent
- Use of GIS for risk calculation, and decision support tool to select projects
- Use of GompitZ to predict condition for future
Approach: Desktop Risk Assessment to Prioritize Field Inspection Work

250 Miles Considered
74 Miles Prioritized for Inspection
Approach: Three Tier Inspection Approach Saves Time and Money
Initial Findings: Other Factors Contribute to Condition Results Other Than Age and Material
Inspections Are Limited Due to Accessibility

- Older Sewer Interceptors Typically Designed:
  - Close proximity to main channel of parallel creeks and/or waterways to minimize depth of cover.
  - Widening of creeks and/or waterways due to erosion not considered.
  - ≈50% Accessible, 30% Temporary Access can be Provided leaving 20% of system not accessible.
Approach: GompitZ Statistical Modeling Fills in Gaps for Condition

- Saves $’s on Inspection & Temporary Access
- Analyzes Environmental Factors
- Determines Remaining Useful Life & Decay Curves

GompitZ Input Data Fields

<table>
<thead>
<tr>
<th>Install Date</th>
<th>Material</th>
<th>Diameter</th>
<th>Inspection Date</th>
<th>Condition Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Factors:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Soil corrosivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Soil stability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Operational Factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Traffic loadings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Groundwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Etc.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Normalized Condition vs Age Data
Inspection and Implementation Prioritization for Dallas Large Sewer Interceptors

Outcome/Benefits

- Saved millions on inspection & access
- System in better condition than anticipated
- Access Issues solved through technology
  - Use of long reach CCTV robotics
  - Use of GompitZ model where inaccessible to fill in gaps
- Risk based decision support and project tracking tools create CIP
Case Study: Buried Infrastructure 50 Year Needs Assessment for New York City

**Challenge**

- Understand the 50 Year funding needs for water, sewer, and stormwater pipes including 12,000 miles of mains

**Approach**

- GIS analysis to determine Consequence of Failure
- Maintenance data analysis to establish service levels and condition
- Useful life determination and funding needs in KANEW model
- GIS risk maps of pipes for future inspection programs
Overall Approach: Leverage Existing Pipe Break and Condition Data and Use Modeling

1. Review GIS/Hansen Data and Resolve Gaps
2. Identify Level of Service Acceptable
3. Prepare GIS Data – Match Breaks (water) and Work Orders (sewers) to Pipes
4. Identify Consequence of Failure and Assign Criteria Scores to Pipes
5. Develop Probability of Failure/Useful Life by Pipe Class and Assign Condition Scores to Pipes
6. Identify R&R Options and Cost/Foot
7. Run KANEW Model Scenarios to Develop 50-Yr Replacement Needs
8. Assign Risk Scores to Pipes
Consequence of Failure Defined and Evaluated in GIS

Modified WRc Criteria Used in Analysis

**Class A**
- Consequence of failure very high
- At least two times as expensive as rehab
- Social costs and potential health hazards

**Class B**
- Less critical
- Preemptive action still desirable

**Class C**
- Not necessarily cost effective to avoid collapse

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### Example Criteria – Sanitary (Combined) Sewer Gravity Mains

<table>
<thead>
<tr>
<th>Class</th>
<th>Example Criteria</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class A</strong></td>
<td>Sewers/Pipes larger than 48-inches.(combined or sewer only).</td>
<td>3</td>
</tr>
<tr>
<td><strong>Class B</strong></td>
<td>Sewers/Pipes above 24-inch to 48-inch. (combined or sewer only)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Sewers/Pipes intersecting arterial roads or bridge/tunnel access roads.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sewers/Pipes where collapse would pollute wetlands or water bodies intersecting or within 100 foot buffer zone.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sewers/Pipes intersecting buildings, subways and buffer zones, railways, and airports.</td>
<td></td>
</tr>
</tbody>
</table>
Establishing Service Levels to Define End of Pipe Life

- Service Levels can be established for different COF values

<table>
<thead>
<tr>
<th>Utility</th>
<th>Service Level (SL)</th>
<th>SL Measure</th>
<th>AWWA Study - Large Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Reliability (Break Rate)</td>
<td>Breaks / 100 miles / year</td>
<td>Top Q = 16&lt;br&gt;Median = 33&lt;br&gt;Bottom Q = 68</td>
</tr>
<tr>
<td>Sewer</td>
<td>Efficiency (Work Order Rate)</td>
<td>WOs / 100 miles / year</td>
<td>N/A Internal Comparison</td>
</tr>
<tr>
<td>Stormwater</td>
<td>Efficiency (Work Order Rate)</td>
<td>WOs / 100 miles / year</td>
<td>N/A Internal Comparison</td>
</tr>
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</table>
Assigning Sewer Main Condition Scores

- Condition Score 1 (very good) to 5 (very poor)
- Scores assigned based on performance versus current system average service level

<table>
<thead>
<tr>
<th>Condition Criteria</th>
<th>Metric: Service Level</th>
<th>Current WO Efficiency Rate</th>
<th>Work Orders /100 mi / yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current WO Efficiency Rate</td>
<td></td>
<td></td>
<td>&lt; 1.6</td>
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<td></td>
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<td>1.7 to 2.24</td>
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<td></td>
<td></td>
<td></td>
<td>2.25 to 3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.3 to 4.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt; 4.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>Current WO level</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tbody>
<tr>
<td>7.9 WO/100 mi/year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.16 WO/100 mi/year</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Sample Risk Results

Figure 6 - Sanitary Risk Range

- Brooklyn
- Manhattan
- Queens
- Staten Island
- Bronx

1) Low 1-7  
2) Moderate 8-10  
3) High 11-15

Risk Matrix

Criticality

Water Main

\[ \sum \text{Condition} \]  
(total probability)
How Does the KANEW Model Work

- Defines EUL for each pipe cohort
- Probabilistic ageing model embedded
- Spreads mains life over time - a certain % will reach it earlier; a certain after..

% of Length of cohort

Resistance Time = 100% pipes survived

50% pipes survived

10% pipes survived
KANEW Output Example: Needs, Costs and Failure Rates for Pipe Groups
Case Study: Inspection and Implementation Prioritization for New York City Sewer Infrastructure

**Outcome/Benefits**

- Provided GIS and Modeling tools for staff
- Defined Service Levels
- Ability to look at future funding needs for pipe for next 50 years
- Ability to compare to existing funding levels
- Identified high risk areas for future inspections
Conclusions

• A Significant Amount of Money Needs to Be Spent to Upgrade Sewer Infrastructure
• Best Asset Management Practices Include Risk Based Decision Making To Determine Where to Spend Your Money First
• New Condition Assessment Tools for Modeling and Field Work Support Cost Effective Risk Assessment Programs
• Using Asset Management Standards Can Help Focus Your Program Implementation
Questions & Discussion
Imagine the result

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