Forecasting the Future for Columbus Water Distribution Using Advanced Statistical Tools

Joseph Clouse, PE, Columbus Division of Water
Seth R. Anderson, GISP, ARCADIS U.S., Inc.
Annie Vanreunterghem Raven, PhD, infraPLAN, LLC
Christopher Heltzel, ARCADIS U.S., Inc.
Agenda

- About Columbus Division of Water
- Risk-Based Replacement Planning
- Initial Planning (2009)
- Updated Planning (2013)
- Outcomes and Comparison
About the Columbus, OH Division of Water
Columbus, OH Water Distribution System

- **Water System:**
  - 3,500 miles
  - 140 to 210 max MGD

- **Challenges:**
  - Maintain system performance
  - Identify the right water mains for replacement
  - Quantify long-term investment
Water Distribution System Characteristics
Pipes <=16-inch

- 2,269 Miles
- Materials:
  - DIP = 54%
  - CIP = 36%
  - PVC, Galv. = 5%
  - Other = 5%
- 65% = 8-10 inch
- 73% post 1950
Project Timeline

• 2008 - Kickoff Water Master Plan Including Risk-Based Replacement Planning
• 2009 - Produce 50-Year Replacement Forecast and Near-Term Projects Over 5 Years
• 2010 - Recommendations for Improved Data Management
• 2013 - Enhanced Planning with More Data and LEYP Analysis
Risk-Based Replacement Planning
Risk-Based Planning

• Balance Limited Funds and the Long List of Capital Improvements
Risk = Likelihood of Failure * Consequence of Failure
Consequence of Failure

• Triple Bottom Line (TBL) Analysis

- Economic
- Social
- Environmental
Likelihood of Failure

- Structural Behavior
  - Break Rate Captured from Work Orders
  - Breaks per 100 miles per Year
- Performance
  - Hydraulic Model Results
  - Pipes Causing Low Fire Flow
Initial Replacement Planning
2009
Triple Bottom Line Evaluation For Consequence of Failure Using GIS

### Customer Criticality Criteria - Based On COF

<table>
<thead>
<tr>
<th>Service to Customer Type</th>
<th>Score=5</th>
<th>Score=4</th>
<th>Score=3</th>
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<tr>
<td>Adj. &amp; Dia.</td>
<td>Adj.</td>
<td>Adj. &amp; Dia.</td>
<td>Mains on property</td>
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<table>
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<tr>
<th>COF</th>
<th>Length (mi)</th>
<th>Percent</th>
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<tr>
<td>1</td>
<td>849.16</td>
<td>37.42%</td>
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<td>2</td>
<td>751.85</td>
<td>33.13%</td>
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<tr>
<td>3</td>
<td>519.70</td>
<td>22.90%</td>
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<tr>
<td>4</td>
<td>97.87</td>
<td>4.31%</td>
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<td>5</td>
<td>50.60</td>
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### Adjacency Criticality Criteria - Based On COF

#### Top 20 Users

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<td>Relatively</td>
<td>Intersecting</td>
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<td>w/in</td>
<td>w/in</td>
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<td>Water Bodies</td>
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<tr>
<td>Interstates</td>
<td>Intersecting</td>
<td>w/in</td>
<td>w/in</td>
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<tr>
<td></td>
<td>23.457</td>
<td>20.760</td>
<td>5.410</td>
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</table>

#### Pipe Criticality By Diameter

- Miles of 2,269.17 (100.00%)
Likelihood of Failure - Cohort Aging Curves
Break History Regression Analysis

- 30 Years of Break History
- One Aging Curve per Cohort

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<tr>
<th>Material</th>
<th>Miles</th>
<th>Percent</th>
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<tr>
<td>Cast Iron Pre 1920</td>
<td>239</td>
<td>10.53%</td>
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<tr>
<td>Cast Iron 1920-1940 &lt; 4”</td>
<td>8</td>
<td>0.33%</td>
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<tr>
<td>Cast Iron 1920-1940 6”</td>
<td>112</td>
<td>4.95%</td>
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<tr>
<td>Cast Iron 1920-1940 8”</td>
<td>70</td>
<td>3.06%</td>
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<tr>
<td>Cast Iron 1920-1940 10”-16”</td>
<td>36</td>
<td>1.59%</td>
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<tr>
<td>Cast Iron Post 1940 &lt; 4”</td>
<td>3</td>
<td>0.12%</td>
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<tr>
<td>Cast Iron Post 1940 6”</td>
<td>150</td>
<td>6.62%</td>
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<tr>
<td>Cast Iron Post 1940 8”</td>
<td>162</td>
<td>7.13%</td>
</tr>
<tr>
<td>Cast Iron Post 1940 10”-16”</td>
<td>36</td>
<td>1.59%</td>
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<tr>
<td>Ductile Iron Unwrapped</td>
<td>1,044</td>
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<td>Ductile Iron Wrapped</td>
<td>175</td>
<td>7.72%</td>
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<tr>
<td>Galvanized</td>
<td>71</td>
<td>3.13%</td>
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<tr>
<td>Other</td>
<td>72</td>
<td>3.20%</td>
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<tr>
<td>PVC</td>
<td>91</td>
<td>4.02%</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>2,269</strong></td>
<td><strong>100.01%</strong></td>
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Benchmarking To Establish System Wide Break Rate Service Level

Service Level
20 Breaks / 100 miles / Year

System Break Rate 2003-2007 (breaks / 100 miles / year)

Breaks: 5 yrs 2003-2007
- 2003 = 797 breaks
- 2004 = 658 breaks
- 2005 = 559 breaks
- 2006 = 551 breaks
- 2007 = 806 breaks

Large System Top Q = 32.4
National Top Q = 14.9
Target = 20 breaks / 100 miles / year
2009 Cohort Regression Analysis
50-Year Unlimited Budget

- Initial backlog of $227M
- Break Rate from 27 to 20 breaks/100mi/year
2009 Cohort Regression Analysis
50-Year Ramp up to $60M Budget

- Ramp up from $20M/year to $60M/year
- Break Rate from 27 to low of 20 breaks/100mi/year
GIS Selects “Right” Projects To Match Annual Budget And Goals
Initial Analysis Recommendations

- Planned investment increase to $30M is adequate for immediate needs
- Enhance initial cohorts analysis with pipe level detailed statistical analysis
- Assign breaks to pipes instead of addresses
- Maintain history of removed and abandoned pipes
Updated Replacement Planning Using LEYP 2013
Failure Forecasting Model
Linear Extended Yule Process (LEYP)

- Multi-variable regression model
- Predicts break numbers for each pipe in future
- Advantage: Takes all factors into account simultaneously, even pipes that never broke (90%?)
- Data Requirement:
  - Risk factors must be assigned to all pipes
  - Ideally pipes and break history must be available for all pipes (Active and Abandoned)
  - Breaks assigned to pipes – 5 years minimum
- Data must be cleaned up (50-75% of effort for first LEYP study)
- Preliminary statistical analysis is needed to calibrate model
Preliminary Statistical Analysis
Failure Forecasting Model

- Weibull Factor
- Yule Factor
- Cox Factor

Aging (time) → Break History → Risk Factors → Predicted Break Number (PBN - likelihood of failure) for every water main and for each year
The CASSES Software

Loading Pipes for Model Run

Loading Break History

Model Calibration

Validating Results

Final Data Output for Pipe Predicted Break Number (PBN)

<table>
<thead>
<tr>
<th>DT</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>ORN</th>
<th>AREU</th>
<th>MBER</th>
<th>PERM</th>
<th>PBN</th>
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<tr>
<td>P10</td>
<td>347</td>
<td>381</td>
<td>381</td>
<td>286</td>
<td>0.06</td>
<td>0.060</td>
<td>0.192</td>
<td>22.8</td>
<td>16.2</td>
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<tr>
<td>P47</td>
<td>474</td>
<td>509</td>
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<td>16.2</td>
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Increasing Priority

Likelihood

Highest

Lowest

Consequence

Copy table  Export results in CSV format
When to Replace COF Related to Aging Curve

Effective Useful Life (EUL)

Break Rate (Breaks/100mi/Year)

Pipe Age (Years)
2013 LEYP Analysis
50-Year Unlimited Budget

- Initial backlog of $189M
- Break Rate from 27 to 20 breaks/100mi/year
2013 LEYP Analysis
50-Year Ramp up to $30M Budget

- Ramp up from $20M/year to $30M/year
- Break Rate from 27 to 20 breaks/100mi/year
Comparison

2009 2013
Columbus Outcomes

- LEYP targets poor performing pipes
- GIS provides clearly defined projects
- Planning approach improved coordination with road paving
- Backlog reduced through risk-based prioritization
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Questions?

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