Fundamentals of Asset Management

Step 2. Assess Condition, Failure Modes
A Hands-On Approach
Tom’s bad day...
First of 5 core questions, continued

1. What is the condition of my assets?
   - *Why* should we assess condition?
   - *How* do we assess condition?
   - What are the *four major failure modes*?
AM plan 10-step process

1. What is the current state of my assets?

- Develop Asset Registry
- Assess Condition, Failure Modes
- Determine Residual Life
- Determine Live Cycle & Replacement Costs
- Set Target Levels of Service (LOS)

- Determine Business Risk (“Criticality”)
- Optimize O&M Investment
- Optimize Capital Investment
- Determine Funding Strategy
- Build AM Plan

Condition Assessment Protocol; Rating Methodologies
All assets deteriorate and eventually fail

Pipe sediment build-up progressively constricts flow and reduces service

Cleaning and relining restores service and extends useful life, perhaps 50 years

Condition guides timing of *maintenance and renewal investment*
Fundamental principle of condition assessment

Condition assessment is important only to the extent it provides insight into…

- *Nature* of possible failure
  - Root cause
  - Pattern (shape of the deterioration curve)
- *Timing* of possible failure (residual functional life)
Typical condition assessment techniques

- Visual inspection
- Non-destructive testing
- Destructive testing
Methods to assess collection system conditions

- Smoke testing
- Dye testing
- Lamping
- Video inspection (CCTV)
- Sonar
- Ground-penetrating radar

CCTV is closed-circuit television
Evolution of condition technology

More condition information, faster, at lower cost from technological advances
Early forms of condition definition and ranking

**Example One**

<table>
<thead>
<tr>
<th>Condition Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition Class 1</td>
<td>Damage to be repaired immediately</td>
</tr>
<tr>
<td>Condition Class 2</td>
<td>Damage to be repaired within 1 year</td>
</tr>
<tr>
<td>Condition Class 3</td>
<td>Damage to be repaired within 3 years</td>
</tr>
<tr>
<td>Condition Class 4</td>
<td>Damage to be repaired within 7 years</td>
</tr>
<tr>
<td>Condition Class 5</td>
<td>Damage to be repaired in the course of other construction work</td>
</tr>
<tr>
<td>Condition Class 6</td>
<td>No damage</td>
</tr>
</tbody>
</table>
Early forms of condition definition and ranking

Example Two

1. **Urgent repairs**
   - To meet emergency situations
   - To meet legal requirements

2. **Necessary repairs**
   - To eliminate safety hazards and code violations
   - To meet contractual obligations
   - To perform required renovations and repair

3. ** Desired repairs**
   - To replace equipment
   - To extend or enhance service
   - To match funds

4. **Ongoing repairs**
   - To continue work in progress

5. **Deferrable repairs**
   - To perform non-essential renovations/improvements
   - To perform projects with questionable need or with timing problems
More evolved form of condition ranking system

- **Pipe Rise/Joint Offset**
  1. Minor – not critical
  2. Moderate – not critical to flow pattern
  3. Significant – possible infiltration source
  4. Severe – pipe offset impeded/obstructed flow, probable infiltration source

- **Pipe Dip**
  1. Length 0-10 feet – not critical
  2. Length 11-20 feet – causes minor velocity reductions
  3. Length 21-30 feet – causes solids to settle in pipe
  4. Length >31 feet – can cause significant solids buildup

- **Joint Infiltration**
  1. Slow drip
  2. Steady drip
  3. Continuous flow – moderate
  4. Continuous flow – severe

- **Mineral Buildup (at joint)**
  1. Deposit on wall without any noticeable flow restriction – not critical
  2. 0.25 Reduction in pipe diameter, some flow restriction
  3. 0.25-0.5 Reduction in pipe diameter, significant flow restriction
  4. >0.5 Reduction in pipe diameter, camera unable pass – severe flow Reduction

- **Laterals with Roots (house lateral)**
  1. Some root penetration – no blockage
  2. More established root presence – minimal blockage
  3. 0.5 of lateral is blocked – possible infiltration and flow restriction
  4. Near total blockage – probable infiltration and flow restriction

- **Joints with Roots**
  1. Some root penetration – no blockage
  2. More established root presence – minimal blockage
  3. 0.5 of pipe blocked – possible infiltration and flow restriction
  4. Near total blockage – probable infiltration and flow restriction

- **Pipe Break**
  1. Minor Break – no structural impairment
  2. Break with separation – structural impairment not immanent
  3. Break with separation/partial collapse immanent structural failure
  4. Severe breakage requiring immediate attention to maintain flow

- **Debris Blocking Pipe**
  1. Minor debris – minimal flow restriction
  2. Moderate debris – minor flow restriction
  3. Significant debris – moderate flow restriction
  4. Severe debris – near total flow restriction

- **Pipe Cracks**
  1. Hairline no structural impairment
  2. Crack with separation structural impairment not immanent
  3. Crack with separation/partial collapse immanent structural failure
  4. Severe crack requiring immediate attention to maintain flow

- **Lateral protrusion**
  1. <1” minimal flow restriction
  2. >1” moderate but not critical to flow pattern
  3. 0.5-0.75 full pipe blocked – severe flow restriction
  4. 0.75 full pipe blocked – severe flow restriction
Emerging national standards for pipes

Pipe Assessment Certification Program (PACP)

From National Assoc. of Sewer Service Companies (NASSCO) & Water Research Center (WRC), *Manual of Defect Classification*
Emerging national standards for pipes

*Structural defect scores - Pipe sewers

<table>
<thead>
<tr>
<th>Defect</th>
<th>MCC Code</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinally OJM</td>
<td></td>
<td>Medium &lt; 1&quot; pipe thickness</td>
<td>1</td>
</tr>
<tr>
<td>Radially displaced JDM</td>
<td></td>
<td>Medium &lt; 1&quot; pipe thickness</td>
<td>1</td>
</tr>
<tr>
<td>Cracked CC</td>
<td></td>
<td>Circumferential</td>
<td>10</td>
</tr>
<tr>
<td>Fractured FC</td>
<td></td>
<td>Circumferential</td>
<td>40</td>
</tr>
<tr>
<td>Broken B</td>
<td></td>
<td>Radial extent &lt; 1/4</td>
<td>80</td>
</tr>
<tr>
<td>Hole H</td>
<td></td>
<td>Radial extent 1/4+</td>
<td>165</td>
</tr>
<tr>
<td>Collapsed X</td>
<td></td>
<td></td>
<td>165</td>
</tr>
<tr>
<td>Radially displaced JDL</td>
<td></td>
<td>Large &gt; 1&quot; pipe thickness</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 10% diameter &amp; soil visible</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Abstract from Sewerage Rehabilitation Manual (Fourth Edition)

From National Assoc. of Sewer Service Companies (NASSCO) & Water Research Center (WRC), *Manual of Defect Classification*
Condition assessment protocol (CAP)

*Which assets? What information? How used?*

- **CAP 1** Simple scoring system, e.g., 1-5, or 1-10
- **CAP 2** Matrix scoring system with multiple distress factors and weightings to derive a score
- **CAP 3** Use of sophisticated techniques to determine the *residual life to intervention* or end of physical life
Characteristics of a good CAP

- Focused on *remaining useful life*, rather than just condition score
- Carefully defined, with good written protocol
- Built around *business risk assessment* (of critical assets)
- Consistently applied (across time, across inspectors)
- Cost effective, using smart *data collection techniques*
## Example CAP 1

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Maintenance Level</th>
<th>Percent Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>New</td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Perfect/excellent condition</td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Minor defects only</td>
<td>Minor</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Backlog maintenance required</td>
<td>Significant</td>
<td>10-20</td>
</tr>
<tr>
<td>4</td>
<td>Major renewal required</td>
<td>Renew</td>
<td>20-40</td>
</tr>
<tr>
<td>5</td>
<td>Asset nearly unserviceable</td>
<td>Replace</td>
<td>&gt;50</td>
</tr>
</tbody>
</table>
Example of expanded CAP 1.5

Refining CAP scale to fit relative distress of assets

6-Point Scale

0  
1  
2  
3  
4  
5

Expanded 6-Point Scale

4.0  
4.1  
4.2  
4.3  
4.4  
4.5  
4.6  
4.7  
4.8  
4.9  
5.0

CAP is condition assessment protocol
## Example CAP 2

<table>
<thead>
<tr>
<th>Distress Mode</th>
<th>Rating (1-5)</th>
<th>Weighting (1-3)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Vibration</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Leakage</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Heat</td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Performance</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Noise</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Condition Rating** 27

**Normalized Rating (27/90)** 30
Example CAP 3

Makes use of vibration, sonic, thermal, electrical, oil residue, electromagnetic, and performance signatures—or information

<table>
<thead>
<tr>
<th>C</th>
<th>Use</th>
<th>Motor Hours Run</th>
<th>&lt; 10,000</th>
<th>&gt; 10,000</th>
<th>&gt; 50,000</th>
<th>&gt; 100,000</th>
<th>&gt; 200,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Symptoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Noise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
<th>Unplanned Outages</th>
<th>Avg No./Year</th>
<th>&lt; 0.5 / Year</th>
<th>&lt; 2 / Year</th>
<th>&lt; 5 / Year</th>
<th>&lt; 10 / Year</th>
<th>&gt; 10 / Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Efficiency</td>
<td>Flow Output</td>
<td>Flow within 5% of duty points</td>
<td>Flow within 10% of duty points</td>
<td>Flow within 20% of duty points</td>
<td>Flow within 40% of duty points</td>
<td>Flow &gt; 40% of duty points</td>
</tr>
</tbody>
</table>
Seven smart ideas for condition data collection

1. *Business risk-driven*, with focus first on high risk, high consequence assets
2. *Problem assets-profiled*, noting that 20% of assets cause 80% of problems
3. *Sampling approach*
4. *Stepped approach*, applying more sophisticated assessment techniques to higher-cost, higher business risk-assets
5. *Failure mode-guided*, do I need condition data?
6. *Root cause-driven*, (Bayesian probability, SCRAPS)
7. *Valued judgment/Delphi approach*, as supplement to minimal data

BRE is business risk exposure; SCRAPS is Sewer Cataloging, Retrieval, and Prioritization System
Idea 1, business risk-driven

What is probability of failure? What is consequence of failure?

Look for high probability-high consequence assets
Idea 2, problem assets-profiled

Do we know which are our problem assets?

Troubled assets—the 20% causing 80% of the problems, the “80/20 rule”
Idea 3, sampling approach

Statistically-sound, validated sampling can render high level of decision confidence at relatively low cost…

- Using *larger* sample size for *more critical* assets and *smaller* size for *less critical*

- Building sample collection around *root causes* of failure—understanding your *failure modes*
Idea 4, stepped approach

Levels of sophistication in condition assessment

- **CAP 1**: Basic
  - Level 1 BRE 1
  - 100% of Assets

- **CAP 2**: Intermediate
  - Level 2 BRE 2
  - 20% of Assets

- **CAP 3**: Advanced
  - Level 3 BRE 3
  - 5% of Assets

BRE is business risk exposure, CoF is consequence of failure, PoF is probability of failure, MTBF is mean time between failures.

Fundamentals of Asset Management
# Idea 5, failure mode-guided

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Definition</th>
<th>Tactical Aspects</th>
<th>Management Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>Volume of demand exceeds design capacity</td>
<td>Growth, system expansion</td>
<td>(Re)design</td>
</tr>
<tr>
<td><strong>LOS</strong></td>
<td>Functional requirements exceed design capability</td>
<td>Codes &amp; permits: NPDES, CSOs, OSHA, noise, odor, life safety; service, etc.</td>
<td>(Re)design</td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td>Consumption of asset reduces performance below acceptable level</td>
<td>Physical deterioration due to age, usage (including operator error), acts of nature</td>
<td>O&amp;M optimization, renewal</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Operations costs exceed that of feasible alternatives</td>
<td>Pay-back period</td>
<td>Replace</td>
</tr>
</tbody>
</table>

NPDES is National Pollutant Discharge Elimination System, CSOs are combined sewer overflows, and OSHA is Occupational Safety and Health Administration.
Condition assessment and the decay curve

Condition assessment assists in recognizing...

- *Nature* and *shape* of the failure or decay (or deterioration) curve
- *Where* on the curve is asset’s current condition
- Asset’s *remaining useful life*, an estimate
Developing a decay curve

- *Longitudinal* study—uses data collected *over the life of a single* asset (or set of assets)
- *Latitudinal* study—uses data collected from *multiple* assets of the same type but of different ages
Tying condition score to asset failure
Idea 6, root cause-driven (Bayesian)

- “Valued judgment” is used to assign failure variables and propositions (sequence of causes of failure)
- “Valued judgment” is used to assign conditional probabilities (likelihood of occurrence)
- “Causal path” networks are developed relating “root cause” to functional failure
- Probabilities are assigned to each of the path elements
What is SCRAPS?

Sewer Cataloging, Retrieval, and Prioritization System (SCRAPS)

Courtesy of WERF and Brown & Caldwell
Example of Bayesian probability

- **Proposition:** Sewer joint failures are common when the sewer is in marshy soil without support.

- Or, equivalently, in Bayesian terms:
  - If probability of marshy soil is *high*
  - And probability of sufficient support is *low*
  - Then *probability of joint failure is high*
SCRAPS Bayesian logic structure

- Need to Inspect
  - Likelihood of Failure
    - Overall Structural Defects
      - Structural Defects
      - Material Degradation
        - Interior Corrosion
        - Erosion
    - Overall Operational Defects
      - Infiltration
      - Operational Defects
        - Exterior Corrosion
  - Consequence of Failure
    - Reconstruction Impacts
    - Socio-Economic Impacts

From WERF’s SCRAPS
Developed by Brown & Caldwell
Default data manager

![Default Pipe Data Manager](image)

1. General and Historical Pipe Information

1a. Required Information
- Year Installed: 1950
- Material: Concrete
- Diameter: 12
- Invert Depth: 10
- Slope: 0.001

1b. Line Structure
- Line Length: 100
- Tubulation Inducing Structure: None
- Number of Laterals: 100 feet
- Laterals Loading: No

1c. Wastewater Volume and Type
- Hydraulic Demand: < 10%
- Sanitary or Combined?: Sanitary
- Parallel System Exists: No

1e. Overflow and Releases
- Has an Overflow or Release Been Observed?: No
- Overflow Type: None

1d. Surcharge
- Surcharge Frequency: 1 time per 5 years
- Surcharge Head: 1.0
- Surcharge Modeled?: No

1f. Calculated Variables
- Cover Depth: 0
- Velocity: 0

1g. Construction History
- Poor Joint Construction: No
- Poor Installation Practices?: No
- Poor Materials?: No

Courtesy of WERF and Brown & Caldwell
View of pipe information from SCRAPS

Courtesy of WERF and Brown & Caldwell
Idea 7, valued judgment/Delphi approach supplements minimal data

“Valued judgment” is used to assign condition scores
- Assemble team of most-knowledgeable personnel
- Poll each member for opinion on condition score and why
- Augment with work order data and failure patterns
- Use photos and process schematics
- Facilitate group consensus through discussion
Important note on condition assessment

- Condition assessment is not an end in itself, but is a means to an end
- The end is to determine remaining useful life
- Good-Fair-Poor-type ratings have little utility unless they lead to an effective estimate of remaining useful life

The remaining useful life of an asset is what we have left to try to manage
Key points from this session

**What condition is it in?**

**Key Points:**
- Condition assessment rating scales must project remaining useful life to be useful for decision-making.
- To be most cost-effective, condition assessment must be guided by the same core concepts that guides all AAM – “failure modes” and the likelihood and consequences of failure.

**Associated Techniques:**
- Condition assessment technology
- Condition rating protocol
### Tom’s spreadsheet

**Fundamentals of Asset Management**

![Tom's Spreadsheet](image-url)

<table>
<thead>
<tr>
<th>Asset Register and Priority</th>
<th>Required LOF</th>
<th>Which Are Most &quot;Critical&quot;?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Date</td>
<td>Current LOF</td>
<td>Probability of Failure</td>
</tr>
<tr>
<td>Asset Class</td>
<td>Minimum LOE</td>
<td>Consequence of Failure</td>
</tr>
<tr>
<td>Original Cost</td>
<td>Condition</td>
<td></td>
</tr>
<tr>
<td>Estimated Effective Life</td>
<td>Rating</td>
<td></td>
</tr>
<tr>
<td>Annual Dep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asset Dep</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sanitation System**

- **Perforator**
  - Installed Date: 2003
  - Condition: Failing
  - Current LOF: 2005
  - Probability of Failure: High
  - Consequence of Failure: Critical

**Electrical System**

- **Miscellaneous**
  - Installed Date: 2001
  - Condition: Failing
  - Current LOF: 2006
  - Probability of Failure: Medium
  - Consequence of Failure: Medium

**Integration Plans**

- **Pumps**
  - Installed Date: 2006
  - Condition: Failing
  - Current LOF: 2007
  - Probability of Failure: High
  - Consequence of Failure: Critical

**Construction System**

- **Sanitary Sewer**
  - Installed Date: 2001
  - Condition: Failing
  - Current LOF: 2005
  - Probability of Failure: High
  - Consequence of Failure: Critical

**EPA Seminar Master File**

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