Fundamentals of Asset Management

Step 2. Assess Performance, Failure Modes

A Hands-On Approach
Tom’s bad day...
First of 5 core questions, continued

1. What is the performance of my assets?
   - Why should we assess condition and performance?
   - How do we assess condition and performance?
   - 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 Performance, Failure Modes
- Determine Residual Life
- Determine Life 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
Our objective: to manage sustained performance

- What do we mean by “performance”?
  - Asset functionality
  - Level of service
  - Availability
  - “Maintainability / sustainability”
  - Reliability

- Common “proxies” for performance
  - Condition
  - Age
  - Usage
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
Example: 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

<table>
<thead>
<tr>
<th>Defect</th>
<th>MSCC Code</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal displaced joint</td>
<td>OJL</td>
<td>Large &gt; 1“ pipe thickness</td>
<td>2</td>
</tr>
<tr>
<td>Open joint</td>
<td></td>
<td>if soil visible grade as a hole</td>
<td>165</td>
</tr>
<tr>
<td>Radially displaced joint</td>
<td>JDL</td>
<td>Medium &lt; 1“ pipe thickness</td>
<td>1</td>
</tr>
<tr>
<td>Cracked</td>
<td>CC</td>
<td>Circumferential</td>
<td>10</td>
</tr>
<tr>
<td>Fractured</td>
<td>FC</td>
<td>Circumferential</td>
<td>40</td>
</tr>
<tr>
<td>Broken</td>
<td>B</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Hole</td>
<td>H</td>
<td>Radial extent &lt; ¼</td>
<td>80</td>
</tr>
<tr>
<td>Collapsed</td>
<td>X</td>
<td>Radial extent ¼+</td>
<td>165</td>
</tr>
</tbody>
</table>

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* ("critical assets")
- Consistently applied (across time, across inspectors)
- Cost effective, using smart *data collection techniques*
A staged approach to condition assessment

**CAP 1 - Basic**
All assets

- Desktop Review
  - Photo walkthrough
- Delphi reviews
- Review asset performance
- Interview key staff
- Convene Delphi workshops
- Use age profiles
- Identify CAP 2 assets

**CAP 2 - Intermediate**
"At risk" assets

- Desktop review
  - Combined with Delphi reviews, field inspections
- Use multi-aspect condition scale
- Identify CAP 3 assets (i.e., candidates for economically rationalized advanced inspection)

**CAP 3 - Advanced**
Critical / high cost assets

- Specialist inspections/techniques
- Validate cost effectiveness of specialist inspections and techniques
- Execute and analyze results
- Take action as appropriate

15% - 25% of assets

5% - 10% of assets
# Level 1 assessment score sheet – structural condition

<table>
<thead>
<tr>
<th>Physical Condition Grade – Rating Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Excellent</td>
</tr>
<tr>
<td><strong>3</strong> Good</td>
</tr>
<tr>
<td><strong>5</strong> Moderate</td>
</tr>
<tr>
<td><strong>7</strong> Poor</td>
</tr>
<tr>
<td><strong>9</strong> Very Poor</td>
</tr>
<tr>
<td><strong>10</strong> Failing</td>
</tr>
</tbody>
</table>

Fundamentals of Asset Management
Assessing performance: “performance” has more aspects than just “condition”!

- Condition is only a starting point for assessing asset performance.
- Condition often only indicates the existence of structural defects.
  - Which defects actually drive progressive failure?
  - What is the rate of deterioration?
- At best, condition by itself provides only marginal insight into:
  - Operational performance
  - Capacity
  - Reliability
  - Availability
  - Maintainability

Add operational level measures for these to move from condition score to performance score.
Moving from condition to performance - attributes of performance measurement

- **Physical/Structural Condition** – The current structural state of the asset resulting from an interaction of usage, age, maintenance, design and manufacturing quality, initial construction management, and operating environment.

- **Operational/Process Condition** – The current ability of the asset to meet operational requirements now and in the foreseeable future. Process condition is substantially influenced by required levels of service/asset performance, technical obsolescence, operations and maintenance policies and history, and design effectiveness/process efficiency.

- **Reliability** – the ability of an asset to perform its required function(s) under stated conditions for a specified period of time; reliability is often considered as “how frequently an asset fails”.

- **Availability** – the percentage of time that an asset is capable of functioning relative to the time that the user expects it to function (conversely, unavailability is the percentage of time that an asset is not able to do its job); availability is largely a function of the frequency of breakdowns and their duration.

- **Maintainability** – those characteristics of design and installation which determine the probability that a failed asset can be restored to its normal operable state within a given timeframe using prescribed practices and procedures. Its two main components are serviceability (ease of conducting scheduled inspections and servicing) and reparaibility (ease of restoring service after a failure). This is often measured in terms of “Mean time to repair” or “MTTR”.

4. Assess condition, performance
## Level 2 performance assessment (composite basis) worksheet

<table>
<thead>
<tr>
<th>Asset Identification</th>
<th>Baseline Info</th>
<th>Failure Modes</th>
<th>Performance Elements</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset ID</td>
<td>Asset Name</td>
<td>Build / Install Date</td>
<td>Refurb/Replace Date</td>
<td>Design Life (Yrs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Performance Elements

- **Physical Condition**
- **Operational/Process Performance**
- **Reliability**
- **Availability**
- **Maintainability**

### Composite Asset Performance Score

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Fundamentals of Asset Management
## A composite performance scoring structure

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SCORE</strong></td>
<td>1</td>
</tr>
<tr>
<td>Physical Condition</td>
<td>Substantially exceeds current requirements</td>
</tr>
<tr>
<td>Operational performance</td>
<td>Negligible attention required</td>
</tr>
<tr>
<td>Reliability</td>
<td>As specified by manufacturer</td>
</tr>
<tr>
<td>Availability</td>
<td>Virtually always operational</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Preventive maintenance only; baseline monitoring</td>
</tr>
</tbody>
</table>
What is a “failure mode”?

- A failure mode is a systematic series of sequential and interrelated causal steps that (can) lead to the failure of an asset.
- We recognize two distinct levels of failure modes:
  - Primary (strategic) level failure modes
  - Tactical/operational level failure modes
The transitional nature of failure modes

Rajani, et al., NRCC-48317
Translation of pipe inspection results into condition ratings using the fuzzy synthetic evaluation technique, 2006, p18
How failure modes relate to condition assessment

- At any given point in its life cycle, most assets have many operative failure modes and mechanics at work.

- While assessing condition to determine the state of the asset is very important to managing the asset, *irrelevant assessment is wasteful*.

- By understanding failure modes and identifying those that are most likely to drive a given asset to fail in its operating environment, we can
  - Focus our assessment on those attributes of the asset that provide the most telling “failure signatures” (*what to monitor*).
  - Select and apply those (rapidly improving) technologies that most directly measure the dominant failure modes (*which technology(ies) to use to monitor*).
  - Time the assessment most cost effectively (*when to monitor*)
# Level 3 performance assessment scoring sheet

## Conventional Pumps

**Included:**
- Dry well & line shaft pumps
- Centrifugal pumps
- Vertical multi-stage booster pumps
- Screw pumps

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Distress Mode</th>
<th>Rating 1</th>
<th>Rating 2</th>
<th>Rating 3</th>
<th>Rating 4</th>
<th>Rating 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Shaft, Supports, Bearing Deterioration</td>
<td>Shaft &amp; supports sound - no shaft distortion or deterioration evident.</td>
<td>Minor shaft/ support deterioration evident, no impact on the structural strength or function.</td>
<td>Shaft distortion or bearing/housing wear evident, little impact on structural integrity or function.</td>
<td>Shaft distortion or bearing/housing wear evident and has impacted on asset integrity or function.</td>
<td>Significant shaft distortion or bearing/housing wear evident, high probability of fracture or failure.</td>
</tr>
<tr>
<td>C</td>
<td>Use</td>
<td>Motor Hours Run*</td>
<td>&lt; 10,000</td>
<td>&gt; 10,000</td>
<td>&gt; 50,000</td>
<td>&gt; 100,000</td>
</tr>
<tr>
<td>D</td>
<td>Symptoms</td>
<td>Vibration / oscillation</td>
<td>No unusual vibration / oscillation detectable</td>
<td>Minor vibration / oscillation detected</td>
<td>Moderate vibration / oscillation</td>
<td>Considerable vibration / oscillation (wristwatch shakes)</td>
</tr>
<tr>
<td>E</td>
<td>Temperature</td>
<td>No unusual temperature detected</td>
<td>Minimal heat from casing using hand</td>
<td>Heat detected by hand</td>
<td>Heat detected by hand is uncomfortable</td>
<td>Heat too high to assess by hand</td>
</tr>
</tbody>
</table>

**Notes:***Motor hours run and corresponding condition rating will depend on the type of pump and the application the pump is used for (i.e. thickened sludge conveyance versus influent wastewater).
Emerging sewer inspection tools and technologies

- Laser
- Sonar
- Multi-sensor crawler
- Side view digital camera
Selecting a suitable condition assessment technique

Condition assessment technology is now remarkably robust

Protocols For Assessing Condition And Performance Of Water And Wastewater Assets; WERF Condition Assessment Protocols (CAP) Project (Project 03-CTS-20CO) (484 pages) December 2006

Figure 6-2 Conceptual overview of pathways in the tool selection Expert System.
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

BRE is business risk exposure, CoF is consequence of failure, PoF is probability of failure, MTBF is mean time between failures.
### 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
Tying condition score to asset failure

![Decay curve diagram]

- **Performance vs. Time**
- **Condition**:
  - Excellent
  - Good
  - Fair
  - Poor
- **Minimal performance level**
- **Decay curve**

Fundamentals of Asset Management
Idea 6, root cause-driven (Bayesian)

- "Valued judgment" is used to develop 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*
Default data manager

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
<table>
<thead>
<tr>
<th>Asset Register and Hierarchy</th>
<th>Installed Date</th>
<th>Asset Class</th>
<th>Original Cost</th>
<th>Estimated Effective Life</th>
<th>Condition Rating</th>
<th>Annual Day</th>
<th>Accomp Day</th>
<th>Current Loss</th>
<th>Minimum Condition</th>
<th>Backup Reduction (Redundancy)</th>
<th>Probability of Failure</th>
<th>Consequences of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tom's Spreadsheet</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Assets:**

- **Incoming Server:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Fire:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Data Center:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Network:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Server:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Laptop:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Network:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Server:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Laptop:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Network:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Server:**
  - Installed Date: 2006
  - Condition Rating: 5
- **Laptop:**
  - Installed Date: 2006
  - Condition Rating: 5