Advances in Bridge Management and Inspection

Formerly

Jeremy Shaffer, Ph.D.
Bentley Systems
Goals for Inspection and Management

• Ensure optimal safety and operational capability in the most efficient manner.

  – Inspection is used as the eyes and ears of the program to find and document the current condition including any problems

  – Management utilizes the inspection data along with the organization’s priorities to determine the most efficient way to ensure goals are met (i.e. safety, performance, capacity)
Technology + Bridge Industry

• Technology availability is different from industry adoption

Bridge Industry:
• Safety Focused
  – Utilize only proven approaches
  – Code/rule based
• Government agencies are primary entities
• Skilled Professionals
• Changes are often slow to be implemented
Past ... Present ... Future

• Remember technology 20 years ago

• Technology today

• Imagine technology 20 years from now
AASHTOWare Bridge Management

- Utilized by 44 DOTs plus local and intl. agencies
- BrM/Pontis 5.2 is funded by a voluntary participation from more than 20 state DOTs, under DOT guidance and expertise
- Tools that are easier to use and understand:
  - Planning
  - Deterioration
  - Risk
  - Multi-objective analysis
  - Lifecycle costs
  - Project models
  - Dashboards
  - Corridor planning
Basic Approach of 5.2

• Utilize extensive research and lessons learned over past 20 years
  • Continue to evaluate best approach and layout
  • Interactively working with Task Force
  • TRT Expert Panel of State Representatives
• Multiple Phased implementation
• Integrate full AASHTO and FHWA requirements
Bridge Management 5.2 Stages

• Development on 5.2 is rapidly moving forward with coordinated efforts between the Task Force, TRT, and Contractor
• Phased releases
  • Version 5.1.2/5.1.3 (Mar 2012 / May 2013)
    • New inspection and inventory functionality, integration with mapping
  • Version 5.2.1 (Feb 2014)
    • Core program framework, risk assessments, integrated utility functions, network corridors
  • Version 5.2.2 (Mid-2015)
    • Implementation of new deterioration models and multi-objective analysis
  • Version 5.2.3 (Planned 2016)
    • Integrated project and program planning
    • All administrative features
Bridge Management 5.2 Stages

- Inspection
- Bridge Groups, Risk, Utility Functions
- Deterioration Modeling, Preservation Action, and Projects
- Project/Program Planning and Administration Features

5.1.2  5.1.3  5.2.1  5.2.2  5.2.3
Bridge Management 5.2.1

- Released in Early 2014
- Key Features
- Google Mapping Functions
- Utility Functions
- Needs Prioritization
- Support For 2013 Element Inspection Manual
- Cross-Browser Support
- Key User Requests
Key Parts of Pontis/BrM 5.2

- What do I have?
- What Condition is it in?
Key Parts of Pontis/BrM 5.2

• What Risks Do I have?

Bridge Inventory

Bridge Conditions

Risk
Key Parts of Pontis/BrM 5.2

• What are my identified needs?

- Bridge Inventory
- Bridge Conditions
- Identified Work Candidates
- Risk
Key Parts of Pontis/BrM 5.2

• What are the benefits of the work candidates?
Key Parts of Pontis/BrM 5.2

• How do I compare benefits of very different actions?

- Bridge Inventory
- Bridge Conditions
- Risk
- Identified Work Candidates
- Library of Actions with Benefits/Costs
- Multi-Objective Analysis / Utility Functions
- Condition / Mobility / Risk

Agency Goals
Key Parts of Pontis/BrM 5.2

• What actions should I possibly take?

- Bridge Inventory
- Bridge Conditions
- Risk
- Identified Work Candidates
- Library of Actions with Benefits/Costs
- Condition / Mobility / Risk
- Multi-Objective Analysis / Utility Functions
- Computer Recommended Actions

Agency Goals
Key Parts of Pontis/BrM 5.2

- What are the benefits of preservation actions?

- **Bridge Inventory**
- **Bridge Conditions**
- **Risk**
- **Identified Work Candidates**
- **Library of Actions with Benefits/Costs**
- **Preservation / Life Cycle Cost**
- **Condition / Mobility / Risk**
- **Multi-Objective Analysis / Utility Functions**
- **Computer Recommended Actions**

Agency Goals
Key Parts of Pontis/BrM 5.2

- What is the effect of future time and deterioration?
Key Parts of Pontis/BrM 5.2

- Grouping/comparing needs across bridges into projects and programs

- Bridge Inventory
- Bridge Conditions
- Risk
- Identified Work Candidates
- Library of Actions with Benefits/Costs
- Preservation / Life Cycle Cost
- Condition / Mobility / Risk
- Multi-Objective Analysis / Utility Functions
- Computer Recommended Actions
- Deterioration Models
- Project and Program Planning and Analysis

Agency Goals
Improved Decision Making Tools

Better Tradeoff Analysis

- Mobility
- Life cycle cost
- Condition
- Risk and vulnerability

New functionality:
- Balance multiple objectives
- More control of results
- More transparency
- Risk
- Time-sensitive deterioration
- Indirect Costs

Better fit for agency workflow and business processes
Implementing Utility Functions

• Multi-objective framework that can be used to show the value (utility) of an action for a bridge
• Utility will also be shown for each sub-area
  – Mobility
  – Condition
  – Risk
  – Life Cycle Cost (deterioration models + preservation benefits)
• Work candidates (preservation and others) are evaluated for how they contribute to mobility, lifecycle cost, condition and risk weightings
• Allow for comparison of current and future status and benefits of actions
Multi-Objective Analysis Framework

• The model will score each work candidate identified.
In this example, the bridge has a utility value of 49.92. In this example, the Condition component is weighted the most heavily of all components of a bridge (weighted to be more important than Risk, Mobility, and Life Cycle). In this example, an agency is able to see exactly how every component and subcomponent exactly impacts the overall utility of the asset.
By incorporating utility functions, BrM is able to combine elements of Risk, Lifecycle Cost, Condition, Mobility, and other agency defined criteria to calculate the utility or value of a particular bridge.
Full Transparency for Utility Values

<table>
<thead>
<tr>
<th>Condition Item</th>
<th>Base Value</th>
<th>Scaled Value</th>
<th>Weight</th>
<th>Adjusted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck</td>
<td>4</td>
<td>42</td>
<td>10.00</td>
<td>420.00</td>
</tr>
<tr>
<td>Superstructure</td>
<td>6</td>
<td>81</td>
<td>1.00</td>
<td>81.00</td>
</tr>
<tr>
<td>Substructure</td>
<td>7</td>
<td>91</td>
<td>1.00</td>
<td>91.00</td>
</tr>
<tr>
<td>Culverts</td>
<td>1</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Element ratings</td>
<td>22.74</td>
<td>22.74</td>
<td>1.00</td>
<td>22.74</td>
</tr>
</tbody>
</table>

Utility Value: 45.98

<table>
<thead>
<tr>
<th>Risk Item</th>
<th>Base Value</th>
<th>Scaled Value</th>
<th>Weight</th>
<th>Adjusted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scour</td>
<td>6</td>
<td>58</td>
<td>1.00</td>
<td>58.00</td>
</tr>
<tr>
<td>Accident</td>
<td>20.00</td>
<td>53.81</td>
<td>1.00</td>
<td>53.81</td>
</tr>
</tbody>
</table>

Risk Value: 55.90

<table>
<thead>
<tr>
<th>Mobility Item</th>
<th>Base Value</th>
<th>Scaled Value</th>
<th>Weight</th>
<th>Adjusted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of truck detoured.</td>
<td>10</td>
<td>34.20</td>
<td>1.00</td>
<td>34.20</td>
</tr>
</tbody>
</table>

Mobility Value: 34.2

<table>
<thead>
<tr>
<th>LifeCycle Item</th>
<th>Base Value</th>
<th>Scaled Value</th>
<th>Weight</th>
<th>Adjusted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LifeCycle Value: N/A

No records to display.
Preservation (and other) Actions

- Default Actions supplied by State TRT members
- Actions have a default cost
- Attach actions to benefit groups
Benefit Groups

- Benefit Groups which define what effects an action has

- Benefit Groups can apply to any elements, fields, and/or risks.
Individual Bridge Analysis Pages show benefits of actions

- Provides snapshot of work candidates and a detailed view of effect of each
- View includes all related utility value information and criterion
Recommended Actions

- Calculates the cost/benefit ratio for all possible actions
- Ranks all available actions providing recommendations on what should be applied to a bridge
Visualize Needs with Maps
Bridge Analysis Groups to Assist with Preservation

- Ability to create groups based on any inventory criteria combination
  - i.e. Steel bridges with ADT over 30,000.
- Apply analysis to groups.
Deterioration Modeling

- Implement new deterioration model logic
  - Weibull approach to include time factor
- Easy to construct/new elicitation process
- Utilize AASHTO Elements
  - Protective Systems
  - Defect Flags
- Allow for Multi-path deterioration
Deterioration Modelling

• An agency is able to see the direct impact of performing work on an asset, and how it will impact the bridge currently, as well as years into the future.

• Also able to see the *direct impact of performing work at a later point in time*. This aids an agency in the decision to determine when the *optimized time would be to perform the selected work*. 
Deterioration Modeling and Multi Objective Analysis (example)
Deterioration Modeling and Multi Objective Analysis (example)

<table>
<thead>
<tr>
<th>Work Candidate Existing for the Selected Bridge</th>
<th>Utility</th>
<th>Utility Change</th>
<th>Cost</th>
<th>Benefit / Cost ($)</th>
<th>Cost ($k) / Benefit</th>
<th>Action Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Nothing</td>
<td>49.44</td>
<td></td>
<td></td>
<td>0</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>04 0759-NIMO-041614-27F108E126 - Approach Railing-Repair</td>
<td>50.5</td>
<td>1.06</td>
<td>2000.00</td>
<td>0.53</td>
<td>2</td>
<td>20</td>
</tr>
</tbody>
</table>

**Effects on Each Utility Criterion**

<table>
<thead>
<tr>
<th>Category name</th>
<th>Before WC</th>
<th>After WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Utility</td>
<td>49.44</td>
<td>50.5</td>
</tr>
<tr>
<td>Condition</td>
<td>57.16</td>
<td>59.73</td>
</tr>
<tr>
<td>Deck</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Superstructure</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>Substructure</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>Scour</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Element ratings</td>
<td>33.13</td>
<td>99.91</td>
</tr>
<tr>
<td>(12) Reinforced Concrete Deck</td>
<td>41.39</td>
<td>99.72</td>
</tr>
<tr>
<td>(331) Reinforced Concrete Bridge Railing</td>
<td>47.56</td>
<td>100</td>
</tr>
<tr>
<td>(510) Wearing Surfaces</td>
<td>10.44</td>
<td>100</td>
</tr>
<tr>
<td>Risk</td>
<td>53.81</td>
<td>53.81</td>
</tr>
<tr>
<td>Accident</td>
<td>53.81</td>
<td>53.81</td>
</tr>
<tr>
<td>Mobility</td>
<td>34.2</td>
<td>34.2</td>
</tr>
<tr>
<td>Percent of truck detoured</td>
<td>34.2</td>
<td>34.2</td>
</tr>
</tbody>
</table>

**Effects on Each Element**

- **Element**
  - (12) Re Concrete Deck
    - Str. Unit: 0
    - Env. Condition: Low (2)
    - Effect: (Yellow, Orange, Red)
    - Health Index: (

- **Element: 331**
  - (510) Wearing Surfaces
    - Str. Unit: 0
    - Env. Condition: Low (2)
    - Effect: (Blue, Red)
    - Health Index: (

**Deterioration**

- **Bridge**
  - Action: (Blue, Orange, Red)
  - Default: (Red)
  - Health Index (%)
  - Years:

- **Element: 331**
  - Action: (Blue, Orange, Red)
  - Default: (Red)
  - Health Index (%)
  - Years:
Project Planning Preservation Actions

• Project Planning
  – Ability to create and view projects.
  – Define projects by grouping together work items and bridges.
  – Determine cost and effectiveness of projects and the end result of performing the selected work on the selected bridges.
  – Dashboards to view higher level numbers and effects, while also being able to drill down to specific results and details.
Advanced Inspections and 3D Visualization
InspectTech

- Does inspections better, quicker, and more reliably
- Provides detailed work flows for field-to-office review and approval
- Supports various inspection types and agency-defined fields and forms
- Provides Web or field options
- Integrates inspector tools and reference material into one easy-to-use interactive form
- Licensed by 14 US DOTs and numerous transit, counties, cities
InspectTech Collector Mobile

- Advanced mobility for users of InspectTech
- Sleek, graphical interface
- Custom inspection workflow
- Capture photos, video, audio
- Built-in historical asset information
- Calculations based on NBI
- Automatic report generation
- Cloud service synchronization with home system
After extensive research Mn/DOT selected InspectTech software as the new Structure Information Management System

- Single site for instant entry/retrieval for over 16,000 structures and 500 users (state, local, consultant, and researchers)
- Secure SaaS solution available anytime
- Field module for remote entry
- Integrated maintenance system
- Significant time savings and error reductions during all phases
- Meets all federal regulations and guidelines
- Integrates with Pontis/BrM
The Design Model

- Physical Model
  - Analytical Model
  - CAD File
  - Published iModel / format

- Viewed in Navigator or other program
Information Mobility

Premises servers
(ProjectWise, AssetWise, ...)

Desktop Applications

Cloud

Mobile applications
(Inspections, ...)

Premises servers
(ProjectWise, AssetWise, ...)

Inspections

Information Mobility
Goal: 100 Years Indefinite Operation

• Preservation and detailed data is key
• 3D design/as-built model loaded directly into structure management system for BIM
• Component hierarchy and inventory data
• Data can be viewed and linked on interactive 3D model accessible via the Web
Detailed 3D views

- Collect and report condition data
- Plan maintenance actions with full history
Special Searching Criteria

• Search by entire structure, span or specific component type
• Ability to drill down into the specific parts of the asset tree to the desired level
• Can combine fields and criteria as needed to make simple or complex queries using boolean logic
Typical Approach (Large Bridge)

- Increased potential for typing errors from redundant entry of data
- Time-consuming task of manually retrieving data from multiple hard copies and databases
- Each biennial inspection report is ~2,000 pages
- Nearly impossible to try to manually do complex queries from paper reports
- In case of emergency – needed a better plan to obtain data
- Needed to centralize data to one location for easy access
Hundreds of Pages of this

- There is a notch in top surface of the L3 inside connection plate to transverse diagonal bracing top flange (Photo S4).

L4:
- Moderate corrosion at connection between lower diagonal lateral bracing and bottom chord at panel point 4 and splices between FB and FE brackets to lower chord connection.

L6:
- Three (3) 3" long tack welds on backside bar tend of FE connection to lower cord.

L9:
- Two (2) 3" long tack welds on top of weld between backer bar of lower diagonal lateral bracing and lower chord at L9.

L10:
- Moderate corrosion on splice plate and several splice bolts at L9-L10 at panel point 10.
- Heavy corrosion on few interior bottom plate splice bolts at L9-L10 to L10 chord splice.

L12:
- Four open midspan holes in transverse vertical member flange connects to L12 at flange thickness transition.
- One missing bolt on L11-L12 to L12 chord splice for drainage from truss chord interior mid-depth plate.
- Moderate to heavy rust on all interior bolts and plates at L11-L12 to L12 truss chord splice including the underside of the truss chord interior mid-depth plate.
- Heavy to severe corrosion on several truss chord bottom plate interior splice bolts.

L13:
- Weep hole on outside of truss bottom chord at L13 has heavy corrosion around deep striker with heavy rust stains.
- 8" long vertical weld along backer bar at west side of FB13 to L13 connection plate and L13 inside gusset plate.

L14:
- Pending water and water stains on top surface of L14-L15 chord members. One missing bolt at mid-depth of L14-L15 outside web splice plate to L15 with moderate corrosion along hole perimeter. Hole is actually leaking with rust stains.

- One missing bolt in transverse vertical connection to outside gusset plate. Note that there is no hole in the face plate at this location.

L15:
- Pending water up to ½" on top surface of bottom chord at L15 between inside and outside gusset plates on both sides of vertical.

L16:
- One missing bolt on outside L15-L16 to L16 truss chord splice for drainage from truss chord interior mid-depth plate.

South Truss:
L0:
- Heavy spalling of concrete pad on top surface of bottom chord at L0.
L2:
- Moderate to heavy corrosion on five interior bottom plate splice bolts at L2-L3 to L2 truss chord splice.

L3:
- Vertical backer bar on west side of FB3 connection to L3 inside gusset plate terminates two-thirds up flange beam connection plate and a weld continues from that point to top.

L9:
- One (3 ¼") tack weld between truss bracing member connection plate backer bar and inside gusset plate at L9.

L10:
- Moderate to heavy rust on few interior bottom chord L9-L10 to L10 bottom plate splice bolts.
- Water stains and evidence of pending water on top surface of bottom chord between gusset plates on east side of truss vertical at L10.

L11:
- Weep hole on outside gusset plate has heavy corrosion around penetrator with heavy rust stains (Photo S1).

L12:
- One missing bolt on outside L11-L12 to L12 chord splice for drainage from interior mid-depth plate.
- Moderate to heavy rust on all interior bolts and plates at L11-L12 to L12 truss chord splice including the underside of the truss chord interior mid-depth plate.
Field Selections in Queries
Preservation Support – Usable Data
Details

• 3D Solid Model
• Represent only the details that user cares about
• Utilize color for different layers – condense to single color for search results
• Ability to turn on/off layers
• Information all driven off database and web-interface
Drill down into detail of bridge to add ratings, comments, pictures

User drilling down to bridge, span, superstructure, main span, verticals, north truss and specific parts
DC Metro – 2D Approach
Conclusions

• Software solutions are rapidly developing the analytical engines to quantifying and describe benefits of preservation actions.
• Need data on benefits of each action
  – What is the benefit of bridge washing?
• Goal is to provide easy to use, understandable tools for practitioners.
Questions?

Jeremy Shaffer
jeremy.shaffer@bentley.com